UNIVERSITY OF SOUTHAMPTON

Faculty of Science

Department of Geography

LATE HOLOCENE PEAT STRATIGRAPHY AND CLIMATIC CHANGE- A MACROFOSSIL INVESTIGATION FROM THE RAISED MIRES OF NORTH WESTERN EUROPE

A thesis submitted for the degree of

DOCTOR OF PHILOSOPHY

by

CHRISTOPHER JOHN HASLAM

1987

Great Bog of Allen swallow down
That heap of muck called Philipstoun
And if thy mor can swallow more
Then take and relish Tullamore

J. Swift (1667-1745)

THE MAIN HUMIFICATION CHANGE (MHC)
JUHRDENER MOOR, GERMANY

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ABSTRACT

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LATE HOLOCENE PEAT STRATIGRAPHY AND CLIMATIC CHANGE- A MACROFOSSIL INVESTIGATION FROM THE RAISED MIRES OF NORTH WESTERN EUROPE

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The present study combines palaeoecological, radiocarbon and chemical analyses of Holocene peat sequences to yield detailed information on the nature and causal mechanisms responsible for the formation of the main humification change (MHC) in north west European raised mires. A suite of 18 sites between western Ireland and north-eastern Poland have been considered. The work has focused directly on the measurement, analysis and interpretation of close-interval macrofossil data. A semi-quantitative technique to assess macrofossil abundance has been developed, facilitating more accurate statements regarding palaeovegetation dynamics.

From the palaeoecological data obtained, a series of semi-quantitative curves for the moisture conditions at each site have been calculated using simple weighted averages ordination. A pronounced increase in surface wetness, associated with an expansion of local wet vegetations, may be recognised in the immediate pre-MHC matrix. Short, sharp dry-wet fluctuations characterise each sequence. In the pre-boundary peats of several western maritime profiles, these oscillations are marked by an unusual Sphagnum sect. Acutifolia (cf. S. capillifolium)-Sphagnum sect. Cuspidata (cf. S. cuspidatum) association. It is suggested that the frequency and severity of these dry-wet shifts excluded other competing Sphagna. DECORANA ordination of macrofossil data has given the opportunity to discriminate between the various mechanisms involved in MHC formation. A shift to more maritime conditions appears important in western maritime areas whilst increased continentality is associated with western continental profiles. The absence of an MHC-type feature in north-eastern Poland confirms that whilst changes in peat formation were being initiated in western maritime and western continental areas, the climatic shift was of insufficient magnitude to trigger unhumified peat formation in more continental regions.

Radiocarbon dates indicate greater diachroneity than was formerly assumed. Based upon these and previously published dates, five periods favouring recurrence-surface formation are identified between 4500-500 B.P. Some correspondence with phase shifts recorded elsewhere in Europe is suggested. Antecedent moisture conditions appear to play an important role in determining the date at which mire stability thresholds were transgressed. Hydrological modelling indicates that variations in surface area, the front of effective efflux, topographic situation and effective precipitation modify the climatic 'sensitivity' of mire systems. Based upon DECORANA sample scores and available radiocarbon dates for the MHC, a proxy climatic curve has been constructed for the period 4500-500 B.P. in north-western Europe.

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SECTION 1 INTRODUCTION

The response of vegetation to climatic change is complex. Vegetation is a dynamical system that is continuously responding to variations in its parameters caused directly or indirectly by the changing climate (Prentice, 1986a). The long time scales involved in palaeoecological studies make the precise recognition of vegetation dynamics problematic. Whether vegetation is in equilibrium with climate is dependent on the response time of the vegetation system considered in relation to the rate of the climatic change to which that system is responding (Wright, 1984; Webb, 1987).

Ritchie (1986) notes that there may be significant differences between species and vegetation types in response times to climatic change. Complicating factors, including soil properties, life-cycle characteristics, anthropogenic influences and hysteresis are identified as response modifiers and have been discussed in relation to palaeo-forest dynamics by Birks (1981) and Ritchie (1986). The ecological niches of Sphagnum mosses are well documented (see for example Clymo and Hayward, 1982; Vitt and Slack, 1984; Andrus, 1986). Although possessing some adaptations for dealing with short-term stress periods, their hydrophytic character ensures that small changes in local hydrological conditions have a direct effect on stand species composition. In ombrotrophic raised mire habitats, variations in large-scale climatic factors (sensu Taylor, 1975) might reasonably be expected to influence mire hydrology (Ingram, 1983). Palaeoecological investigations by Aaby (1976), Van Geel (1978), Barber (1981), Dupont (1986) and more recently Svensson (1987), have illustrated how subtle variations in the macrofossil component may be used to construct detailed surface wetness curves.

Despite the demonstrated close association between Sphagnum and its environment, surprisingly few macrofossil diagrams have been produced from mire sequences. In addition, peat stratigraphic studies, like many pollenanalytical investigations, have largely concentrated on site-specific problems. There is a clear need to move from such small-scale studies towards an intra-regional synthesis based upon discrete time spans. The evolution of "synoptic pollen mapping" (Prentice, 1983) saw an important preliminary step down this pathway. This study was conceived therefore in an attempt to examine the spatial and temporal dynamics of Holocene climatic change in north western Europe, focusing specifically on the Subboreal-Subatlantic deterioration c.2500 B.P.

Using proxy climatic evidence, Lamb et al. (1966) and Lamb (1977, 1982a, 1982b) estimate that at the outset of the Subatlantic mean summer temperatures fell from 16.8'C to 15.1'C, but that winters became milder (4.7'C as against 3.7'C). This is attributed to the strong development of Atlantic westerlies in winter and prevalence of cyclonic northwesterly winds in summer. Rainfall ranged from 97-105% of todays' level. Taylor (1983, p.9) summarizes these environmental changes in the context of the British Isles. Recent isotopic measurements made by Dupont and Brenninkmeijer (1984) and Dupont (1986) indicate that the climate in the Northern Netherlands was:

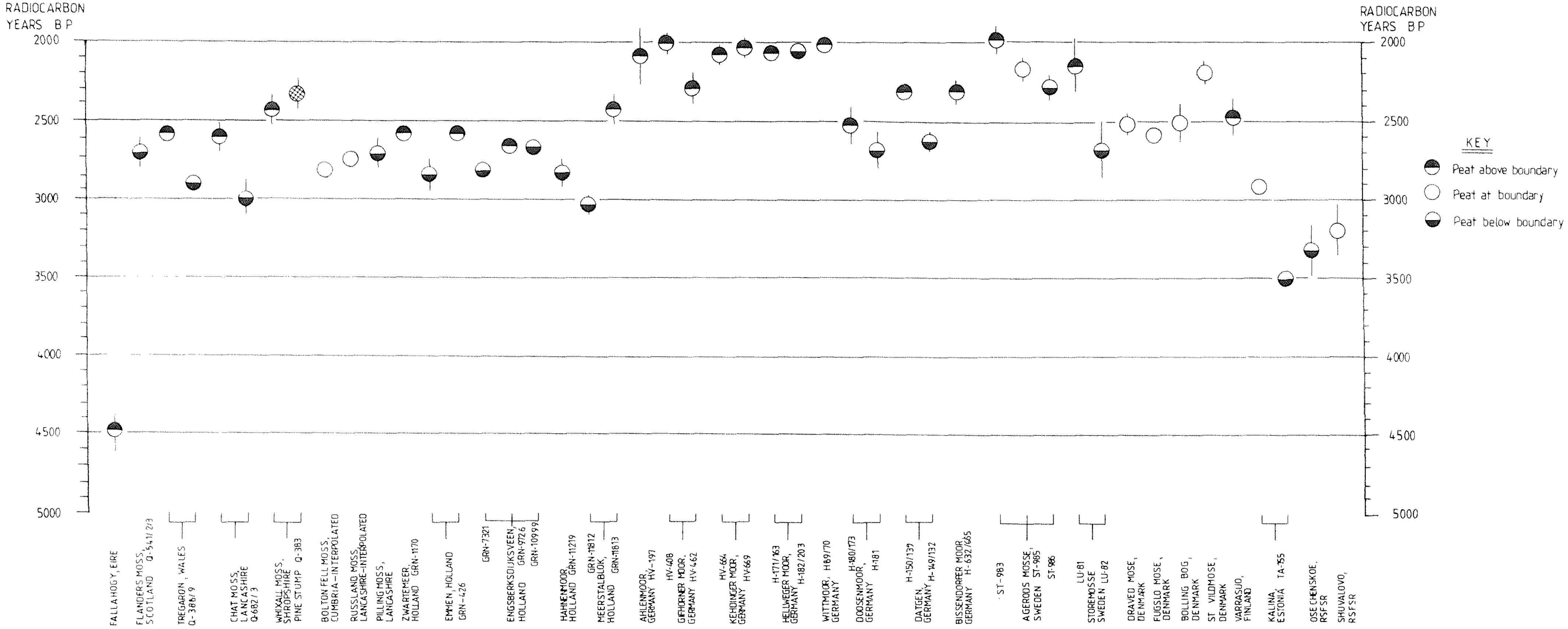
(a) warm (mean annual temperature c.10° C) and dry between 4000-3500 B.P.;
(b) slightly colder (mean annual temperature c.9° C) and becoming wetter around 3000 B.P.;
(c) warmer (mean annual temperature c.11° C) and still wetter between 2800-2500 B.P.;
(d) again colder (mean annual temperature c.9° C) and probably as wet as today after 2000 B.P.

Considerable fluctuation is suggested. The net result of such oscillations would be to increase the precipitation/evaporation ratio, effecting wetter ombrotrophic mire surfaces and changes in the composition, humification and accumulation rate of mire vegetation.

This climatic deterioration is accordingly marked in the stratigraphies of north west European raised mires by a distinct change from a dark, well humified peat to a pale, poorly humified matrix in which plant structures may still be distinguished (Godwin, 1954)(cover plate). Following the work of Weber (1900), this horizon became known by the German term the "Grenzhorizont" or boundary horizon. As Frenzel (1983) notes, however, the prevailing opinion, that Grenzhorizont formation was climate-dependent, led to the mistaken

Figure 1.

RADIOCARBON-DATED AGES OF THE SUBBOREAL–SUBATLANTIC TRANSITION ("THE GRENZHORIZONT") AT DIFFERENT PROFILES IN NORTH-WESTERN EUROPE



interpretation of several stratigraphic sequences. He illustrates how highly humified ombrogenic peats of central Europe have been considered together with humified soligenous or even topogenous fen-carr peats of Russia. Even the use of the term "Grenzhorizont" became corrupted. Soviet peatland ecologists increasingly associated the term with the complete layer of highly humified peat, irrespective of its ecological or plant-sociological situation (Khotinsky, 1971). These difficulties have led Averdieck and Munnich (1957) and Schneekloth (1963) to substitute the term "Grenzhorizont" with a more neutral term, the "Schwarztorf-Weisstorf-Kontact" (the black/white contact) abbreviated to SWK. The term is still in common usage in Germany (K.E. Behre, personal communication) and elsewhere (Tolonen et al., 1985) despite indications suggesting it is not universally applicable (Casparie, 1972). The term "Main Humification Change", abbreviated to MHC, will be used throughout this study to circumvent possible terminological confusion.

Convention places this horizon at 2500 B.P. (Mangerud et al., 1978). Previously published radiocarbon dates indicate greater diachroneity however, the MHC occurring anytime between c.4500 B.P. and c.2000 B.P., and lacking any apparent spatial trend (Burrichter, 1969; Overbeck, 1975; Mitchell, 1981) (figure 1). To what extent such discordance reflects differential climatic change over north-western Europe or is a function of the analytical procedures adopted by earlier workers remains problematic. Commenting upon the problem, Gorham (1982, p.535) notes that "if changes in climate have been chiefly responsible for the initiation of the Grenzhorizont, then it should be possible to demonstrate either synchronous initiation over broad geographic regions, or a sequential pattern in response to a gradual shift in climate across different regions".

This research project will focus attention on the problem of temporal and spatial variation in MHC formation, using detailed macrofossil, radiocarbon and humification measurements obtained from a suite of north-west European lowland raised mire profiles. Throughout the work, every attempt has been made to obtain informed local advice regarding the suitability of potential sites and profile location. Where possible, previously studied sequences have been analysed.

The format of this thesis follows accepted practice. An extensive review of previous research on the MHC problem is followed by a detailed consideration of the methodological techniques adopted throughout the work. Particular attention is paid to the description and critical evaluation of a new semi-quantitative approach used to assess macrofossil abundance. After a section describing the palaeoecological and climatological background of each study site, the results of the macrofossil and humification analyses are dealt with. Section 6 attempts to model these results using a variety of ordination techniques. A detailed consideration is also given to the age-determinations obtained for the MHC by the current study. The final section seeks to combine macrofossil and radiocarbon results into a proxy climatic curve for the period 4500-500 B.P.

The nomenclature of the taxa follows Isoviita (1966), Klinger (1976) and Hill (1978) for Sphagnum and Clapham, Tutin and Moore (1987) for vascular plants.

SECTION 2 PREVIOUS RESEARCH

2.1 THE RECURRENCE SURFACE PROBLEM

In oceanic climates experiencing cool, humid conditions, the development of peatland is largely unrestricted. Moisture surpluses generated by high precipitation and low atmospheric evaporating power allow peat formation on level or even gently sloping surfaces. In the initial stages of development, climate, nutrient supply and topography are important controlling factors. As the peatland develops however, the importance of topography diminishes and any differences in peatland properties largely reflect changes in environmental conditions (Malmer,1983).

Given suitable conditions, these peatlands develop into characteristic structures known as raised mires (German: Hochmoore, Swedish: hogmosse) characterised by an almost horizontal, or at most, just perceptably domed central plateau. The irregular mire surface, covered with a mosaic of open pools and hummocks, is predominantly covered with mosses of the genus *Sphagnum*. Ratcliffe and Walker (1958) have shown that although vascular plant cover is more conspicuous, bog moss may constitute 80-90% of the total ground cover. The sloping margins of the bog (German: Rand) are better drained than the central plateau and support different plant communities, often dominated by species such as *Scirpus caespitosus*, *Molinia caerulea*, *Betula pubescens* and *Pinus sylvestris*. The central plateau of the raised mire differs from soligenous and topogenous peatlands in its hydrology and associated differences in water chemistry, organic matter accumulation and vegetation associations (Sjors, 1948). The absence of a groundwater input means that both nutrient economy and moisture budget of the system is intimately tied to the atmospheric input from precipitation and particulate matter.

In the undrained state, the organic sediments which constitute the raised mire may cover many square kilometres and attain thicknesses of up to 12m depending upon underlying topography. The deposits may be subdivided into a basal tier of peat types formed under the influence of minerotrophic groundwater, and an upper tier of acidic, base-deficient peat, predominantly composed of *Sphagnum* remains (Hammond, 1984).

Recognition that the formation of ombrogenic layers must be sensitively controlled by the environmental conditions prevailing at the time of growth led early peatland investigators to correlate discrete stratigraphic and botanical changes with variations in the postglacial environment. The works of Steenstrup (1842), Geike (1881), Nathorst (1870) and Blytt (1888) form early attempts to classify such variations in the raised mires of Germany, Scandinavia and The Netherlands. Despite meticulous description, little attempt was made to assess the local or regional significance of any variations. Similarly, whilst recognising that the ombrogenic peats of many north-west European raised mires displayed a striking twofold division, with an upper weakly humified, pale brown peat overlying more humified, dark brown peat, no serious attempt was made to investigate the phenomenon. Given the abrupt and distinct nature of the transition this is somewhat surprising. It is not until the beginning of this century that a detailed consideration of the contact-surface between the two peat types was given by the German peat worker, C.A. Weber.

Stratigraphic investigations undertaken by Weber (1900) in the lowland mires of northern Germany indicated that the upper layers of highly humified peat were characterised by a discrete layer of *Pinus* and *Betula* stumps, *Calluna vulgaris* and *Eriophorum vaginatum*. Directly overlying this highly humified matrix was a thin layer of telmatic *Scheuchzeria-Sphagnum cuspidatum* peat. He referred to this as the 'Vorlaufstorf' or precursor peat. Weber (1902, 1908) was careful to note, however, that the Vorlaufstorf was not a ubiquitous phenomenon. He recognised that the growth of unhumified *Sphagnum* peat could occur directly above the humified peat. More recent work in the Somerset Levels (Clapham and Godwin, 1948) has shown that *Sphagnum cuspidatum* did not form a continuous carpet, the implication being that mass flooding did not occur. No mention is made by Weber regarding the vegetal composition of the upper peat.

Weber (1900) called the contact zone between the *Sphagnum* layers the "Grenzhorizont" (the 'boundary horizon') and archaeologically dated its origin between 750 and 1000 B.C. This dating was based upon the discovery of a peat burial (German: Moorleiche) and was later confirmed by Schubert (1933). Interpreting the stratigraphic sequence, Weber (1900) postulated that a period of prolonged warmth and dryness in the Subboreal period had caused drying of mire surfaces accompanied by secondary humification of peat originally formed during the warm, humid conditions of the Atlantic. This interpretation was based upon observations made by Gradmann (1898) concerning the migrational patterns of flora, fauna and prehistoric peoples of southeastern Europe during the Neolithic and Bronze Age periods, the so-called 'Steppenheide-Theorie'. It was believed that the arid climate of this time prevented forest growth on the lighter soils of central Europe, thus providing a corridor of open steppe along which migration to the oceanic west was possible (Godwin, 1975). Recent palynological studies have failed to demonstrate the existence of such a migration.

According to Weber's thesis, Subboreal peat either formed a very thin layer or was completely absent, and the highly humified Sphagnum peat initially had the appearance of present-day post-Grenz peats. Pointing to the absence of any gradient of humification increasing down the profile, as would be expected if secondary humification from above had occurred, Godwin (1946) postulated that a considerable thickness of peat had in fact been formed during the Subboreal. Little or no secondary modification had occurred.

The occurrence of the Grenzhorizont, or MHC, over a broad area led to the assumption that seral vegetation successions could only induce minor variations in peat stratigraphy (Weber, 1911). Climatic deterioration was responsible for the marked change in humification, a change which was synchronous both within individual mire systems and between neighbouring systems. Weber presents little evidence to support the hypothesis of synchronous change, despite having applied palynological techniques as early as 1893 (Overbeck, 1963).

Weber's climatological interpretation of botanical composition and humification changes was followed by a series of works which embodied the concept of climatic control. Of these, the monograph of Granlund

(1932) deserves mention. Granlund analysed 300 sites in southern Sweden and developed earlier work on the relationship between annual precipitation and the degree of convexity of raised mires. Following classification of mires according to annual precipitation, Granlund (1932) plotted long profile length against cupola height. The results indicated that there was a maximum height the cupola could attain. Granlund (1932) termed this the 'limiting height' and postulated that as the peat mass increased in height, so moisture losses via evapotranspiration and surface runoff increasingly counteracted inputs from precipitation and capillary rise from lower levels. The surface layers of the mire thus became drier, peat accumulation rates fell and a 'stillstand' condition was entered characterised by communities of Eriophorum vaginatum and Calluna vulgaris. Stratigraphically, this 'limiting height' was marked by discrete layers of humified peat. A shift in the mire equilibrium caused by increased moisture surpluses and lower temperatures, allowed the subsequent deposition of an unhumified matrix. Wickman (1951) made similar observations.

Whilst the hypothesis was undoubtedly complex, Granlund envisaged a mire system directly controlled by the regional climate and which could display a series of transitions from highly humified to poorly humified peat. The contact-surface first described by Weber (1900) formed one of a series of transitions. Granlund identified several shifts in peat formation, and termed the abrupt boundary between the peat types a "recurrence surface" (Swedish: rekkurensytor; abbreviated RY, German: Rekurrenzflachen). Each surface marked a rejuvenation in mire growth following a period at "limiting height". Swedish mires typically displayed up to four recurrence surfaces, although at Storemosse in southwest Sweden, Granlund (1932) found evidence of five boundaries. He estimated their ages on archaeological grounds as RYI at 750 B.P. (1200 A.D.), RYII at 1550 B.P. (400 A.D.), RYIII at 2550 B.P. (600 B.C.), RYIV at 3150 B.P. (1250 B.C.) and RYV at 4250 B.P. (2300 B.C.). The most pronounced of the recurrence surfaces was RYIII- the 'Grenzhorizont' of Weber (1900).

Subsequent workers identified similar surfaces elsewhere in northwest Europe, although as Tallis (1983) notes, no consistent picture of either assumed dates or number of recurrence surfaces emerged from these studies.

For example, detailed observations made in southern Scania, Sweden, enabled Nilsson (1935) to recognise no fewer than nine recurrence surfaces between 5430 B.P. and the present. This was later revised to seven following work on Agerods Mosse (Nilsson, 1948). Lundqvist (1962) similarly identified seven contact-surfaces at Hogmossen, the five recurrence surfaces of Granlund plus RYVI at 4850 B.P. (2900 B.C.) and RYVII at 5650 B.P. (3700 B.C.). In Ireland, Mitchell (1956) recorded four periods of deterioration between 400 B.P. and 1400 B.P. (3050 B.C. - 550 A.D.); Overbeck et al. (1957) distinguished three major recurrence surfaces (2650 B.P., 2050 B.P. and 1350 B.P.) in Germany, and Godwin and Mitchell (1938) noted two surfaces at Tregaron (2600 B.P. and 800 B.P.).

The synchroneity of these recurrence surfaces was questioned by Jonas (1935) who used horizons obtained by pollen analysis to show that the contact-surface between the Vorlaufstorf and the underlying humified Sphagnum peat could vary even within an individual mire. Although no attempt was made to quantify this variability, Jonas argued that differential flooding of the mire surface was of prime importance. Logically it would be expected that 'fresh' *Sphagnum* peat formed first of all in hollow situations and finally over hummocks of the former mire surface.

In the second half of this century serious attempts were made to address the problem of recurrence surface formation. In particular, the works of V.M. Conway and H. Godwin in the two immediate post-war decades deserve special mention.

In discussing the relationship of bog stratigraphy to climatic change and archaeology, Godwin (1946) asserted that recurrence surfaces were formed not as a result of retardation of the hydroseral stages of mire growth, *sensu* Tansley (1939), rather by 'catastrophic flooding' of the mire surface. Variability between peat layers were due to different climatic conditions and peat-forming communities induced by such changes. Tentative doubts concerning the validity of Granlund's 'limiting height' hypothesis are expressed by Godwin in this early paper, though it is not until 1954 in a paper devoted exclusively to the recurrence surface problem that Godwin developed these ideas more fully.

Commenting upon Granlund's work, Godwin (1954) noted that the 'limiting height' theory would require an incremental increase in atmospheric moisture following the formation of the first recurrence surface noted by Granlund at 6250 B.P.. Finding no evidence to support this view, Godwin (1954) concluded that the likelihood of such a precipitation regime over the last 5000 years seemed "improbable". Dismissing mire height as a causative factor in the formation of recurrence surfaces, he states that, in comparison to the direct effects of precipitation and evaporation, losses via surface drainage played a secondary role in the genesis of phases of surface dryness. Godwin suggested that, should desiccation play an important role in recurrence surface formation, then it might be expected that the better drained, marginal slopes of mire complexes and small raised mires with marked surface curvature to exhibit a series of well-marked growth retardations. Drawing upon stratigraphical observations made by Godwin and Mitchell (1938) and Godwin and Conway (1939) concerning the upper retardation layer at Tregaron Bog, Wales, Godwin showed the reverse to hold true. The retardation layer was more distinct in the central cupola than at the margins.

Developing this thesis one stage further, it is possible to argue that the 'limiting height' hypothesis fails to adequately explain the considerable depth of highly humified pre-MHC peat. Accepting Granlund's hypothesis, a series of distinct recurrence surfaces marking 'limiting height' ought to characterise the entire stratigraphical sequence. Whilst minor structural variations may be discerned in many pre-MHC peats, the matrix remains largely uniform. The possibility of secondary humification of these deposits as argued elsewhere (Weber, 1900, 1926) has been discounted (Godwin, 1946), and alternative mechanisms must be sought. Godwin (1946) expressed the view that complex cyclical climatic changes, which acted independently of either mire height or curvature, influenced mire growth. That peat formation may also occur via a cyclic succession of vegetational communities, as first described by Sernander (1910), was accepted by Godwin, as it had been earlier by both Weber and Granlund. A system controlled by regional climatic parameters, superimposed upon which were autogenic 'regeneration' processes <u>sensu</u> Sernander (1910) and Osvald (1923), was therefore envisaged.

The question of synchroneity in recurrence surface formation, and of the MHC in particular, became subject to detailed investigation. Jonas (1935) had already demonstrated inter-site variability, and, at a broader spatial scale, Nilsson (1948), concluded that, whilst conditions favourable for the formation of 'fresh' *Sphagnum* peats had occurred at broadly contemporaneous periods over much of northwest Germany, Sweden and The Netherlands, the formation of the MHC itself was not a synchronous phenomenon. From studies of a small raised mire, the Bolleveen near Zeijen, The Netherlands, Waterbolk (1950) maintained that the MHC at this site was no older than *circa* 1550 B.P, a date equivalent to Granlund's RY II.

The possibility of differential registration of climatic change had already been postulated by Godwin (1948) with regard to the Somerset Levels. Discussing a layer of *Cladium* peat, an indicator of increased moisture in mesotrophic situations, Godwin (1948) noted that at several localities evidence of climatic deterioration could be found as early as c.3150 B.P. At the majority of sites this shift is not marked stratigraphically until about 2550 B.P. As Godwin stated, the implication was that there was "considerable chance, under varying climatic and varying topographic conditions, that the main flooding horizon or recurrence surfaces may be of somewhat dissimilar ages".

In a parallel but somewhat more speculative discussion, Conway (1948) advanced the possibility of analysing climatic perturbations in terms of rhythmical oscillations of one or more climatological parameters. Developing ideas advanced earlier by Von Post (1946), Conway suggested that each vegetation association displayed particular tolerance limits. If these limits were exceeded, then it would be expected that some form of vegetational response would be elicited. Conway believed that rhythmic climatic fluctuations were the primary factor for such changes. Thus the formation of recurrence surfaces resulted from environmental factors which favoured more rapid and abundant growth of *Sphagnum* species on the mire surface. Conway is deliberately vague regarding the specific climatic factors likely to initiate vegetational change, and instead advances the concept of a theoretical 'moisture-factor'. However, the suggestion is made that the rainfall/evaporation ratio is perhaps the most meaningful variable with regard to the study of ombrotrophic systems. The argument is succinctly presented by Conway:

> " It is postulated that any given stage in the course of the climatic fluctuations over a large area will give a value of the moisture factor which will vary from locality to locality according to the altitude, the general situation, and the topographic characteristics of each locality. Thus the moisture-factor curves for different localities should be roughly parallel in behaviour but not necessarily coincident. Further, unless a given climatic oscillation causes the curve for the moisture factor at a given locality to cross a threshold line, then that climatic oscillation will not be expressed by the vegetation at that locality"
>
> Conway (1948, p. 227)

The implications are clear. Climatic shifts as recorded by recurrence surfaces could vary widely in intensity and consistency of expression over comparatively short distances according to local topographic, altitudinal and locational conditions. These site-specific factors would act to modify climatic fluctuations, such that not all shifts need necessarily invoke a vegetation change. Sites especially sensitive to minor climatic fluctuations would be those situated towards the margins of the regions characterised by that particular vegetation type. Additionally, a time-lag would exist between the initial climatic perturbation and its possible expression in the plant communities of the mire. Conway does not develop the idea further, but the implication must be that the stratigraphical manifestation of climatic change will occur sometime after the theoretical threshold has been crossed.

Critically re-analysing the work of Granlund (1932), Conway casts doubt upon the accuracy of the archaeological datings used to identify his recurrence surfaces, and hypothesises that southern Swedish mires express a minor climatic rhythm with a periodicity of circa 900 years. At still greater temporal resolution, the isolation of 250 year periodicities based upon Betula pollen curves is claimed by Conway (cf. Aaby, 1976; Van Geel, 1978).

The idea of cyclical climatic change was not new. Several years earlier Godwin (1946) had postulated the existence of two main cycles of deterioration associated with the formation of Webers' Grenzhorizont. Initial deterioration circa 3150 B.P. was believed to have caused the MHC found in Irish mires, later termed RS:C by Jessen (1949) and equivalent to RY IV of Granlund. Continued deterioration between 2550 and 2450 was marked by the MHC (RY III) in Britain and western continental Europe. The presence of a third deterioration phase before the cool, humid conditions of the Subatlantic were maintained is mentioned by Godwin (1946) but no attempt was made to estimate its date. The temptation to link this climatic shift with the MHC equated with Granlunds RY IV identified in the Netherlands (Waterbolk, 1950), Germany (Overbeck, 1975; Overbeck et al., 1957) and several of the Somerset Level mires (Clapham and Godwin, 1948) is obvious. More recently, both Mitchell (1956) and Casparie (1972) have identified four distinct wet phases during this period.

Whilst many of the ideas developed by Conway (1948) are undoubtedly speculative, the possibility of differential sensitivity of mire ecosystems to climatic fluctuation provided a mechanism by which observed diachroneity of the MHC could be explained. Questions regarding the exact nature of the climatic variables, or their combination, likely to induce vegetation change still remain problematic. That different factors may become important at different sites remains to be explored fully.

With the advent of radiocarbon dating in the late 1950's, it became increasingly apparent that the formation of recurrence surfaces was not a simple phenomenon. The uncritical acceptance of synchronism in the change between highly and poorly humified peat was questioned by many workers (Overbeck et al., 1957; Averdieck, 1957; Lundqvist, 1962; Schneekloth, 1963, 1968; Nilsson, 1964b; Neustadt, 1967, 1984; Frenzel, 1982). The degree of synchroneity clearly depends on the temporal resolution adopted. As Conway (1948) noted, although broad agreement might be expected, variation between 100 and 1000 years could occur for the same phenomenon. Radiocarbon datings of recurrence surfaces from 42 mires in Scandinavia, Germany, The Netherlands and the British Isles (Nilsson, 1964b) have shown the distribution of dates to be non-random, with clustering at time intervals approaching 1000 years. This leads to speculation that the 'broad agreement' expected by Conway (1948) might equally reflect cyclical climatic fluctuation of 1000 year periodicity.

It is apparent that considerable small-scale variability exists. In the British Isles, radiocarbon dates for peat below the MHC of 2712 +/- 120 B.P. (Flanders Moss, Stirlingshire, Godwin and Willis, 1962 Q-541/2/3), 3070 +/- 150 B.P. (Chat Moss, Lancashire, Birks, 1964 Q-682) and 2954 +/- 70 B.P. (Tregaron, Dyfed, average of two dates, Turner, 1964) have been obtained. Identifying trends towards lighter peat accumulation, and thereby a wetter mire surface, Aaby (1978) recognises a shift in peat formation between 2750 and 2175 B.P. in Danish mires. Initial registration appears to occur on the east coast of Jutland at Fugslo Mose (2600 +/- 60 B.P. K-1356), then at an inland site, Bolling Bog (2510 +/- 107 B.P. K-735) and finally on the north coast at St Vildemose (2260 +/- 85 B.P. K-2729). Given the limited sample size, such inferences must necessarily remain tentative.

In Ireland, Jessen (1949) located a prominent recurrence surface (termed RS:C) in a series of profiles and correlated it with the Grenzhorizont of Weber. Detailed pollen analysis linked with archaeological evidence led Mitchell (1956) to suggest the surface was of greater antiquity, possibly corresponding with a shift towards wetter conditions around 3450 B.P. Radiocarbon datings taken above the boundary at Fallahogy produced a date of 4481 +/- 120 B.P. (Godwin and Willis, 1962 Q-558). The date is equivalent to Granlund's RYV and has prompted the suggestion that Weber's Grenzhorizont is absent in Ireland. It is more likely however, that Jessen's RS:C forms an early expression of the climatic deterioration which commenced in the second millenium B.C. and that subsequent shifts failed to elicit a response in an already 'wet' stratigraphy. Citing the observed parallelism in forest histories, Godwin (1946) was of the view that "it is unlikely that the climatic deterioration actually began earlier in Ireland than further east".

These views are supported by Dickinson (1975) and Barber (1982) who suggest that the effects of the climatic oscillations associated with MHC formation are expressed earlier in more maritime areas of Europe.

However, the extent to which measured variability reflects real differences in the registration of climatic change or results from variations in the sampling and dating procedures adopted by various workers is problematic. In particular, little attention has been paid to what is dated and how it is dated.

Overbeck (1975) states that only the oldest date available for a given recurrence surface should be taken as indicating the date of a climatic shift. The converse may be equally valid, however, namely that the fresh *Sphagnum* peat represents the direct response of the mire to a shift in equilibrium. Since the accumulation rates of highly humified peats may be as low as 62.5y/cm (Barber, 1981), samples taken below recurrence surfaces may overestimate the true age of the deterioration. The problem is particularly acute when large samples are taken. Similarly, when dating "Vorlaufstorf" peats directly overlying the contact surface, few workers have assessed the possible effects of sample contamination caused by reworking of older deposits into the pools at the of time pool formation. The advantages of using post-MHC *Sphagnum* peats where accumulation rates may be as high as 3.3y/cm (Barber, 1982) are obvious.

Careful consideration must also be given to where samples for age determination have been taken. Turner (1981), quoting work on Chat Moss, England (Birks, 1964), notes that the top of the humified *Sphagnum* peat has been dated to 3070 +/- 150 B.P. (Godwin and Switsur, 1966 Q-682) and the unhumified *Sphagnum cuspidatum* pool peat above to 2645 +/- 100 B.P. (Q-683). In reality 9cm of peat, of unknown accumulation rate, separates the samples.

Variability caused by microstratigraphical variation of the mire surface is more difficult to quantify. In assessing the influence of hummock-hollow topography on the formation of post-MHC peats, Godwin (1954, 1960) postulated that whilst precursor peats would form initially in mire hollows, hummock transgression, if it occurred at all, would not take place until some time later. However, any age differences were "unlikely to be significant". Similar conclusions had been drawn by Jonas (1935). More recently, Casparie (1972) has stated that microstratigraphical variations could cause a considerable staggering in the commencement of fresh Sphagnum cuspidatum peat formation. Casparie made no attempt to estimate possible age differences caused by such processes.

These studies highlighted the view held by many workers that besides general climatological factors, local conditions could influence peat formation. In 1954, pollenanalytical investigations by Van Zeist showed that the MHC was not a synchronous phenomenon in the raised mire of south east Drenthe. The formation of "fresh" Sphagnum peat started in the mire centre whilst more marginal areas continued to accumulate humified peat. Van Zeist demonstrated that similar trends could be identified in the diagrams of Schroder (1931), Overbeck and Schmitz (1931) and Florschutz and Wassink (1935). Van Zeist (1954) claims that "since even in a single raised bog the beginning of the growth of the younger Sphagnum peat is not a synchronous phenomenon, one cannot expect much contemporaneity in the position of the Grenzhorizont of the various published diagrams". Work on the Silver Flowe, Scotland (Ratcliffe and Walker, 1958) showed that a phase of drying out of the lower part of the mire partly pre-dated the initiation of pool and hummock complex at the mire centre. Localised water table differences rather than a general diminution in rainfall were cited as a causative mechanism.

Subsequent stratigraphic observations made at a number of Irish mires in the summer of 1959 led Walker and Walker (1961) to hypothesise that "internal" growth factors, such as surface slope, microtopography, depth and nature of peat and the physiological processes of the plants themselves, could act to distort external climatological constraints on growth. They postulated that the principal growth mechanism involved "periodic rejuvenation due to an increase in wetness of the bog surface", followed by progression towards a more stable vegetation component under constant or drying conditions. Oscillations in the relative proportions of Sphagnum and higher plants produced a highly stratified profile, with alternating bands of poorly and highly humified peat. The process was controlled by periodic fluctuations in precipitation or a slowly increasing precipitation, the effects of which were modified by local surface conditions. Walker and Walker (1961) note that "the rejuvenation phases were of the nature of those resulting in recurrence surfaces, although their stratigraphical manifestation is not so distinct".

A series of radiocarbon dates obtained for peat above and below the main recurrence surface at two Swedish mires, Li damossen near Eskilstuna and Hogmossen, Gastrikland, enabled Lundqvist (1962) to quantify the inter-site variability recognised by Van Zeist (1954) and Overbeck et al. (1957). The results indicated that the initiation of fresh Sphagnum peat occurred between 700 +/- 85 B.P. (St-463) and 245 +/- 80 B.P. (St-470) at Lindamossen, and 1135 +/- 80 B.P. (St-673) and 810 +/- 90 B.P. (St-679) at Hogmossen. The earliest formation of unhumified Sphagnum peat appeared to occur in the middle of each mire complex. However, as both Turner (1981) and Barber (1982) have shown, the dates must be treated with caution since dated samples were separated by up to 35cm and taking into consideration dating errors there were no significant differences in the dates. Discounting these possible errors, Lundqvist concluded that "it is the local conditions which are most significant......climate.....is certainly only of secondary importance"

Similar investigations were performed by Schneekloth (1963a, 1963b, 1965, 1967, 1968) and Schneekloth and Wendt (1963) on mire complexes in northwestern Germany. Initial studies on the Weisses Moor near Kirchwalsede (Schneekloth, 1963a) indicated that the MHC was of a similar age in all three profiles analysed. Work on the Hohe Moor near Scheessel (Schneekloth, 1963b) highlighted discordance of several centuries and prompted more detailed investigations at Gifhorn Moor near Hannover (Schneekloth, 1965). Omitting sample Hv462 which represents an extreme value, it is possible to show that the MHC could be dated to anywhere between 1400 +/- 75 B.P. (Hv-21) and 2000 +/- 70 B.P.(Hv-408), a range of c.500 years. At Kehdinger Moor (Schneekloth, 1967) a more uniform position of the MHC was shown. The MHC occurred between 2130 +/- 85 B.P. (Hv-668) and 1845 +/- 70 B.P.(Hv-666), a difference of 285 years. Reviewing the problem, Schneekloth (1968) argued that whilst local edaphic and hydrographic factors were the likely cause of the diachroneity between different mire systems, similar arguments could be invoked to explain the differential regrowth of fresh Sphagnum peat within a single mire. He further postulated that the formation of the poorly humified peat would commence initially in areas of impeded drainage in the mire centre. Studies of several German mires failed to confirm this hypothesis but phytosociological investigations by Olauson (1957) have confirmed that areas of retarded growth may occur on a generally active surface. Subsequent work on Bourtanger Moor in The Netherlands (Casparie, 1969, 1972) has indicated that, in accordance with Schneekloths' hypothesis, highly humified peat continued to form in the marginal areas of this mire for some "considerable time" after the central mire plane was clothed in fresh *Sphagnum cuspidatum* peats. These pool peats developed in response to climatic deterioration c. 2000 B.C. No radiocarbon ages were available, but pollen datings suggested an age difference of 500 years. Casparie (1972) postulated that marginal desiccation and eutrophication created unfavourable conditions for the establishment of unhumified peat. More generally, pointing to the absence of a distinct and continuous recurrence surface in any of the examined profiles, Casparie (1972, p.237) concluded that "they (recurrence surfaces) are undoubtedly the result of local fluctuations in the bog hydrology. Not a single indication has resulted from the investigation to suggest that peat growth reacts directly to changes in the precipitation".

While confirming the importance of climate, these studies highlighted the possibility that recurrence surface formation could reflect the growth dynamics of individual mires and lack any regional significance (Watts, 1985). Considerable disagreement still remains as to the importance of local factors, although recent observations support the view that regional factors are dominant. The work of Dickinson (1975) deserves special mention.

Using pollen-density dating techniques, Dickinson measured the rate of peat growth either side of a marked recurrence surface at Rusland Moss, Cumbria. The technique highlighted the fact that growth rates could increase some time before the climatic shift was marked stratigraphically. The problem was particularly acute in *Eriophorum vaginatum* peats, a species tolerant of a wide range of temperature and moisture regimes (Casparie, 1972) and which may occur in both humified and unhumified peats. In spite of the apparent uniformity, Dickinson demonstrated that the growth rates of *Eriophorum*/*Calluna* peats were considerably lower than *Eriophorum*/*Sphagnum* peats. Such variability failed to be recorded in field observations. The implications were that previous datings based upon stratigraphic observation alone were unsatisfactory in identifying the initial shift of the mire in response to climatic change.

Combining pollen-density measurements with radiocarbon age determinations of peat taken above the main growth-rate increase, Dickinson concluded that the recurrence surface was a synchronous phenomenon across the entire mire. The surface is dated to c.1500 B.P. and is equated with Granlunds RYII. Citing the occurrence of a retardation layer at an adjacent site, Helsington Moss (Smith, 1959), dated to 1514 +/- 100 B.P. (Godwin and Willis, 1960 Q-83) Dickinson argues for a regional climatic change. Whilst unhumified peat was accumulating in the raised mires of the Morecambe Bay region between 1477 and 768 B.P., in coastal Wales there was no apparent climatic deterioration. The absence of Granlunds RYII at Tregaron Bog (Turner, 1970) Dickinson believes may be explained by Conway's (1948) theory of threshold values, and concludes that "although there are definite times when recurrence surfaces tend to be formed, the whole series is not necessarily present in any one raised bog".

More recently, Svensson (1986, 1987) has shown that the initiation of fresh Sphagnum peat above the two main recurrence surfaces at Store Mosse, Sweden are broadly synchronous over the 6000ha mire complex. A series of five radiocarbon dates taken directly above RYIII along an 1800m transect show that peat growth was renewed between 2430 +/- 50 B.P. (Lu-2314) and 2310 +/- 50 B.P. (Lu-2310). The main recurrence surface has been similarly dated, regrowth occurring between 1120 +/- 45 B.P. (Lu-2318) and 970 +/- 100 B.P. (Lu-79). This is equated with RYII. Similar results have been obtained for the Humberhead levels (Smith, 1985) and Cumberland (Wimble, 1986). These findings demonstrate that the regrowth of fresh Sphagnum peat above a recurrence surface is broadly synchronous across the entire mire surface. Whilst Schneekloths' work (1965) highlighted the possibility of intra-site variability, it must be borne in mind that the demonstrated age differences are based upon one decimetre thick samples taken from borings located 300m apart. Despite using pollen-analytical correlations it is possible that different recurrence surfaces have been dated by Schneekloth. On theoretical grounds, Ingram (1982) has shown that even under fluctuating climates, growth at all points on the surface of a raised mire ought to proceed at synchronal rates. The hypothesis provides a mechanism by which the synchronous growth of Sphagnum might be expected, but as Ingram (1982) notes, more information regarding the physical properties of peat is needed before such mathematical modelling may have widespread applicabilty.

From these and earlier studies, it became apparent that allogenic factors played an important role in the growth, abundance and preservation of mire plants. Autogenic processes, although important in the early stages of mire development, were believed to exhibit little or no influence on the stratigraphic profile. Tallis (1983) adopts a conciliatory approach by suggesting that both allogenic and autogenic processes may be involved. It is certainly possible that at the scale of the microsuccession, autogenic factors may influence some plant distributions. Short-cycle regeneration processes as described by Tolonen (1971, 1980), may be the stratigraphical manifestation of such interactions. However, at the macroscale, it seems reasonable to assume that marked stratigraphical transitions present in the long profile represent responses of the mire to shifts in environmental conditions. Similar conclusions have been reached by Aaby (1976, 1978), Moore (1977), Boatman and Tomlinson (1977), Barber (1981, 1982), Schwaar (1984) and Svensson (1986). The monographs of Aaby and Barber deserve brief mention.

Radiocarbon assays on a single 2.5m profile from Draved Mosse, Denmark, supported by analysis of humification, pollen and macrofossils, enable Aaby (1976) to postulate the existence of cyclic climatic variations. Periodicities of circa 260 years were obtained for the last 5,000 years. Using less accurate data, similar periodicities had been obtained by Conway (1948) several decades earlier.

The mire system as a sensitive climatic recorder was supported by Barber (1981) following detailed stratigraphical mapping of 15 sections from Bolton Fell Moss, Cumbria. Using direct and "proxy" temperature and precipitation records, Barber demonstrated a close link between observed variations in peat stratigraphy and climate. "Phase shifts" in plant communities characterised changes in surface wetness. The possibility of differential site sensitivity with respect to fluctuations in climate was hypothesised (Barber, 1982), but as yet no attempts have been made to elucidate the question.

2.2 THE INITIATION OF UNHUMIFIED PEAT ABOVE RECURRENCE SURFACES

Whilst it is generally accepted that increased moisture surplus is the principal cause of renewed peat growth above recurrence surfaces, several alternative hypotheses have been advanced.

The possibilty of triggering caused by atmospheric nutrient addition has been debated at length. Given that the nutrient economy of ombrotrophic mire systems is intimately tied to the atmospheric input from precipitation and particulate matter, it might reasonably be expected that rainfall nutrients will play an important role in the nutrition of raised mires (Miller, 1963; Carlisle et al., 1967). The nutrients usually represent an income to the system, although occasionally may include recycled dust (Wetselaar and Hutton, 1963). The concentration of inorganic elements in precipitation and dry deposition varies according to place and season (Cawse, 1974; Damman, 1983). There are numerous measurements of the concentration of solutes in precipitation. Work by Allen et al. (1968) in northern England showed that periods of very high precipitation were associated with higher concentrations of base elements in rainwater. They postulated that sodium and magnesium were of marine origin and potassium largely of terrestrial origin, at least as far as the British Isles were concerned.

Similar findings were reported for mainland Europe by Tolonen et al. (1976), who showed that sodium concentrations were highest in maritime north Germany and lowest in the Rhone basin of central Germany. Magnesium displayed a similar pattern, although both calcium and potassium showed little spatial variation. Muller (1973) obtained comparable results working in southern Germany. However, the nutrient concentration of precipitation is generally low, and this is reflected in the extreme base deficiency of ombrotrophic peats. Working in southern Germany Waughman

(1980) has shown that the total concentration of inorganic elements is approximately one-tenth that found in fens, or less. Similar findings have been reported by Clymo (1983), who additionally notes that the concentration in the vegetation reflects the total concentration in the peat, with the exception of iron which is more concentrated. It has been hypothesised that essential elements in short supply in precipitation may be actively conserved by the living vegetation (Damman, 1978). It is known for instance, that many mire plants possess ion exchange mechanisms (Tolonen et al., 1976; Clymo and Hayward, 1982; Clymo, 1984) to remove nutrients adsorbed onto the surfaces of peat particles. Nitrogen fixation by root nodules of Myrica gale (Sprent et al., 1978) and blue-green algae associated with Sphagnum (Basilier et al., 1978; Dickinson, 1983) has been demonstrated. A concise review of the nutrient status of peat and peat-forming vegetation is presented by Clymo (1983).

The supply of nutrients undoubtedly increases with increasing rainfall, especially in coastal areas where elements such as sodium, magnesium and chlorine originate principally in sea spray (Gorham, 1958; Boatman, 1961; Sonesson, 1970). Enhanced nutrient concentration of precipitation without a corresponding rise in annual totals seems unlikely except in localised instances. It also remains debatable whether increased rainwater nutrient concentrations, either directly or coupled with increased precipitation, could facilitate a wholesale shift in mire equilibria over much of northwest Europe.

Taylor (1973) has suggested that forest clearance may have accelerated peat development in upland Britain. Subsequent modelling (Taylor and Smith, 1981) has confirmed the presence of a basal pedogenic peat overlain by blanket mire or climatic peat. Taylor (1980, 1983) considers the possible influences deafforestation may have had on the hydrological balance of these areas. However, whilst it has been convincingly demonstrated that prehistoric man could have influenced the local moisture regimes in upland areas, comparatively little work has focused on the magnitude of these processes in lowland areas, and in particular their effects on raised mire systems. Taylor (1983, p.14) notes, for example, that lowland forest regeneration often occurred following clearance by man. In a parallel discussion Frenzel (1976, 1983) suggests that extensive Neolithic, Bronze

Age or Iron Age clearings in the Rhein-Graben region of Germany may have made a significant contribution to the aerosols of the time. Ash deposition could, it is argued, have acted as an aerial fertiliser and stimulated Sphagnum growth in the mountains of the adjacent Schwarzland. Growth rates subsequently declined following migration of prehistoric man away from the western lowlands. Comparable conclusions have been drawn by other workers (see for example, Schwaar, 1977; Keitel, 1978).

Surface enrichment caused by air-borne mineral particles from arable land has been demonstrated by Chapman (1964b). A close correlation was found between the ash content of peat and the occurrence of pollen grains characterising agriculture and bare mineral soils. However, it seems unlikely that marked stratigraphical changes over large areas of Europe could have been initiated by such a practice. In particular, the quantity of nutrients required to elicit vegetational change, the localised nature of prehistoric settlement and the apparent rapid response of mire systems must be considered in more detail. Nevertheless, Conway (1949) has noted that a change in peat type on Ringinglow Bog near Sheffield preceded the appearance of soot layers.

Several authors (Salmi, 1947, 1954; Mattson and Koulter-Andersson, 1954; Paivanen, 1973; Tolonen, 1984) have drawn attention to the linear relationship between the ash content of ombrotrophic peat and peat humification. Tolonen (1984) notes that there are at least four alternative explanations for the enhanced ash content of highly humified peats. Two are pertinent to the present discussion; first, in strongly decomposing environments such as the Subboreal period, the enrichment of of inorganics in the peat matrix is greater. Tolonen (1984) refers to this as "primary ash". Second, the accumulation rates of humified peats are comparatively low (Aaby and Tauber, 1974; Tolonen, 1979), and surface layers are thus exposed to the atmospheric input of incombustible particulates for a longer period. Tolonen calls this "secondary ash". Nutrient enrichment from primary and secondary ash sources may have enabled rapid colonisation and multiplication by Sphagnum on the mire surface. More detailed studies are needed to confirm any possible relationships.

Ivanov (1975) has indirectly offered an explanation of the factors likely to stimulate the regrowth of active Sphagnum. Although much of the discussion focuses upon the distribution and formation of mire microtopes, brief consideration is given to the formation of endotelmic water bodies. Ivanov (1975) argues that periods of increased surface wetness generally lead to expansion of the more transmissive elements, while less transmissive elements expand in drier periods. In stratigraphical terms, hollows and hummocks undergo expansion and contraction according to climatic conditions in a manner as described by Aaby (1976). Increased moisture surpluses associated with climatic deterioration lead to an expansion of pool facies and flooding of the mire surface. Susceptibility to erosion causes rapid pool expansion and coalescence until linkage with rills or endotelmic streams, which are themselves eroding by cutting back their beds, occurs. This ultimately causes lowering of the water table over large areas of the mire. Mire pools, now much shallower, are colonised by semi-aquatic vegetation and peat growth, slowed down as the pools expanded, rapidly accelerates.

Ivanov's (1975) ideas are supported by complex mathematical modelling, and on theoretical grounds at least, this hypothesis appears plausible. However, questions regarding the occurrence of mass overland flow and the buffering capabilities of raised mires are only given superficial consideration. Nevertheless, it is clear that the conditions likely to favour the rapid growth of Sphagnum peat involve a shift in the water balance towards increased wetness.

Casparie (1972) has noted that, on theoretical grounds, a fall in temperature, especially during the moss growing season, would increase moisture surpluses. Increased precipitation need not necessarily be involved. In reality however, it seems probable that a combination of these factors led to raised water tables in the mires of north western Europe. It is uncertain whether nutrient rise from depth accompanied such water table oscillations.

2.3 VEGETATION CHANGES ASSOCIATED WITH MAIN HUMIFICATION CHANGE FORMATION

Raised mires are true marginal habitats, or "Grenzstandorte" as Lotschert (1969) calls them. Bellamy (1959) defined the waters of an ombrotrophic mire as having (Ca^{++}/Mg^{++})<1, few bases and a low pH. Mire plants, although heterogeneous with respect to their origin, have evolved a series of adaptations which enable them to survive in such extreme habitats (Eber, 1982). Favourable life forms have proved to be bryophytes, Sphagnum predominating while species of the suborder Jungermanineae (leafy liverworts) are largely inconspicuous but very abundant; evergreen camaephytes (dwarf shrubs) of the family Ericaceae, and graminoid herbs, including Cyperaceae. Drier raised mire surfaces may also support fruticose members of the lichen genus Cladonia. Remains of the latter are rarely preserved.

It is well known that moist conditions and rising water levels provide favourable growth conditions for Sphagnum (Overbeck and Happach, 1957; Clymo, 1973). Up to 15-23 times their dry weight may be held as water (Vitt et al., 1975). Different species occupy characteristic habitats depending upon their differential ability to absorb and retain water. This ability is governed by two processes; large empty porose hyaline cells of the leaves, stems and branches are able to hold water internally, and external water is held by matric forces resulting from crowding of plants in mats as well as the dense arrangement of leaves and branches. Romanov (1968) reported that the former may attain 27% and the latter 71.6% of the volume in the surface 2.9cm of Sphagnum fuscum hummocks. Sphagnum mosses lack a well developed vascular system, as experiments by Cavers (1911) and Lee and LaRoi (1979) have shown. The main path of water transport takes place outside the plant cell walls between leaves and pendent branches and stems. The mean radius of such spaces varies according to growth habitat of the species. Those found at or below the water level (Sphagnum cuspidatum and S. subsecundum) have larger spaces than those found at higher levels (S. capillifolium and S.fuscum), and are resultingly able to retain less water in the apical tuft (Capitulum) where growth occurs. This is marked on the undulating surface of a raised mire with different species of Sphagna inhabiting different microhabitats, on a scale finer than that observed in many vascular plant distributions (Ratcliffe and Walker, 1958; Alpert and Oechel, 1984). These distributions, and the contributory factors influencing such distribution, form the basis of the reconstructions of past surface conditions on raised mires, in particular wetness (Barber, 1981).

As early as 1900, Weber had noted that the upper layers of the highly humified Sphagnum peat, especially in Germany, were marked by *Pinus* and *Betula* stumps, *Calluna vulgaris* and *Eriophorum* spp., all indicative of conditions of surface dryness. Although pine stumps have been identified at Whixall Moss, Shropshire (Hardy, 1939; Turner, 1964) and at several Irish sites (McNally and Doyle, 1984), subfossil trees are generally rare in British pre-MHC peats (Godwin, 1946, 1960, 1975). Typically fibres and roots of *Eriophorum vaginatum*, *Scirpus caespitosus* and twigs of *Calluna* and *Erica* dominate humified British peats (Godwin and Mitchell, 1939; Godwin, 1946). Godwin (1946) is uncertain as to the specific *Sphagnum* communities associated with the humified peats, pointing to the high degree of humification which makes identification problematic. However, he notes that very decayed Sphagna are abundant. More recently, detailed macrofossil analyses by Casparie (1972), Van Geel (1972, 1978) and Bakker and Smeerdijk (1982) have shown the humified peats to be strongly heterogeneous. Associations of *Erica tetralix*, *Oxycoccus palustris*, *Andromeda polifolia*, *Vaccinium* spp., *Empetrum nigrum*, *Calluna*, *Eriophorum vaginatum*, *Rumex acetosella*, *Rhynchospora alba*, *Polytrichum strictum*, *Leucobryum glaucum*, *Aulacomnium palustre* and *Drepanocladus* have all been identified by Casparie (1972). In particular, Casparie (1972) notes the conspicuous concentrations of *Eriophorum vaginatum* and *Calluna* in the uppermost layers, both believed to be indicators of desiccation/ stagnation of the mire surface (Overbeck, 1952; Godwin, 1946, 1975). Casparie (1972) is more cautious on this point however, and whilst accepting that dry mire surfaces would favour the establishment of these species, notes that local milieu were important.

Jonasson and Chapin (1985) and Shaver et al. (1986) have recently indicated that the thermal and moisture tolernace ranges of *Eriophorum vaginatum* may be considerable, which supports the view that this species prefers areas with a strongly fluctuating water level in comparatively highly humified, not extremely acidic peat (Ratcliffe and Walker, 1958; Casparie, 1972; Boatman, 1983). The longevity of hummock structures dominated by Eriophorum vaginatum has been demonstrated by Walker (1961) and Aaby (1976). Work from Draved Mosse, Denmark, (Aaby, 1976) has shown that a hummock may maintain a quasi-permanent position on the mire surface for more than 2,500 years. Expansion of hummock systems during dry periods was followed by contraction in wetter phases. Similar findings have been reported for Bolton Fell Moss, Cumbria (Barber, 1981) and many Irish mires (Walker and Walker, 1961). The possibility that this species may occur in association with more aquatic species such as Sphagnum cuspidatum, cannot be excluded. Both Osvald (1923) and Barber (1981) have shown that colonisation of pools by Eriophorum vaginatum may occur.

Little information regarding the Sphagna present in the pre-MHC peats is available. Casparie (1972) and Bakker and Smeerdijk (1982) have indicated that Sphagnum capillifolium, a hummock-building moss and indicator of local dry conditions, was present and recent studies on Store Mosse, Sweden (Svensson, 1987) have confirmed this. Conflicting evidence has been presented by Ratcliffe and Walker (1958) and Boatman (1983) who suggest that this species may also be abundant at levels just above the water table. Svensson (1987) has additionally demonstrated that Sphagnum fuscum and Sphagnum tenellum may have been important peat-forming communities.

It has been noted earlier, that a thin layer of telmatic Scheuchzeria-Sphagnum cuspidatum peat often separates the highly and poorly humified layers. Studies on the ecology of Sphagnum cuspidatum (Ratcliffe and Walker, 1958; Boatman and Tomlinson, 1977; Boatman, 1983; Overbeck and Happach, 1957; Clymo and Hayward, 1982) have shown that pool habitats are favoured, although compact forms may grow a short distance above the water level. Similarly, Tallis and Birks (1965) have demonstrated that Scheuchzeria palustris is associated with saturated peats and has no apparent correlation with the ion content of the water. Both Casparie (1972) and Godwin (1975) support this view, although Casparie notes that there are exceptions. Pointing to the localised distribution of Scheuchzeria in strictly synchronous and apparently comparable fresh

Sphagnum cuspidatum peat layers on Bourtanger Moor, The Netherlands, Casparie (1972) postulates that rather acidic, somewhat eutrophicated or mineralised, very moist to wet conditions are necessary for Scheuchzeria establishment. Citing the frequent occurrence of a Pinus-Scheuchzeria association leads Casparie (1972, p.206) to conclude that "factors other than climatic ones also played an important part in the establishment of these plants in the bog- plants which are often regarded as climatic indicators". Scheuchzeria is at present extinct over much of north western Europe.

The poorly humified post-MHC peats are typically more homogeneous. Preservation is often good, enabling accurate species identification. Godwin (1946) noted the dominance of the three Cymbifolian Sphagnum species, S. papillosum, S. magellanicum and S. imbricatum, although darker bands of Eriophorum, Calluna, Scirpus and Oxycoccus were occasionally identified. Working in the Somerset Levels, Clapham and Godwin (1948) isolated Menyanthes remains, a local indicator of wet mesotrophic conditions, along with Oxycoccus, Narthecium, Andromeda and Eriophorum spp.

Van Geel (1978) and Bakker and Smeerdijk (1982), amongst others, have shown that S. imbricatum and S. papillosum dominate the early post-MHC peats. Many workers have discussed the occurrence of Sphagnum imbricatum in subfossil peats. Casparie (1972) indicates that both Sphagnum imbricatum and S. papillosum display a preference for moist surfaces. S. papillosum appears to be closely associated with mire hollows, whilst S. imbricatum occurs in drier situations. Ratcliffe and Walker (1958), Muller (1965) and Boatman (1983) have reached similar conclusions. However, Barber (1981, 1986), Dickinson (1973), Smith (1985) and Wimble (1986) have demonstrated that Sphagnum imbricatum may thrive in wet, but not pool, conditions. Green (1968), investigating the ecological tolerances of this species, has shown that two distinct 'ecads' may exist: a hummock ecad restricted to drier situations in association with S. capillifolium and S. fuscum, and a lawn ecad found just above the water level in association with S. papillosum. This demonstrated phenotypic plasticity with regard to water levels may account for the occurrence of S. imbricatum in contrasting habitats as revealed by palaeoecological analyses. Based on these findings, Green (1968) hypothesises that the plants which formed the majority of 'fresh' Sphagnum peat were probably semi-aquatic ecads.

2.4 THE EFFECTS OF LATER HOLOCENE CLIMATIC DETERIORATION ON PEAT ACCUMULATION RATES

The accumulation of peat is primarily the result of slow vegetative decomposition and not due to high productivity (Damman, 1979). This may be attributed to either anaerobic conditions (Clymo, 1965), extreme nutrient deficiency of the peat, and in particular the bog moss, Sphagnum (Clymo, 1965; Sonesson, 1972; Clymo and Hayward, 1982) or the generally acid environment (Clymo and Hayward, 1982). Since decomposition is believed to be a largely aerobic process, the amount of time it takes plant material to pass through the unsaturated surface layers (termed the 'acrotelm' by Ingram, 1978) is critical. The age of the acrotelm has been estimated in some living mires and lies between 50 and 100 years, on occasion even higher (Jones and Gore, 1978; Oldfield et al., 1979).

Clymo (1984) has proposed that decomposition may continue into the saturated peat layers (termed the 'catotelm' by Ingram, 1978). Earlier workers have assumed catotelmic decay to be negligible or non-existent. Accordingly, age/depth relationships were believed to conform to a linear function and straight-line relationships have been plotted through dated profiles. Examining data from several Finnish mires, Clymo (1984) demonstrated the non-linearity of many age/depth profiles, a phenomena which could not be explained by increasing bulk density, possibly caused by processes of autocompaction as argued elsewhere (Aaby and Tauber, 1974). Subsequent work on Coom Rigg Moss, Northumberland (Clymo, 1984) showed that concentrations of carbon dioxide and methane increased with depth. Clymo (1984) cited this as evidence of catotelmic decay. By implication, catotelmic parameters, and not only those of the acrotelm, determine peat accumulation.

Growth rates are thus determined by the combined effects of net production on the mire surface, the degree of aerobic decomposition, and secondary processes, especially catotelmic decay and autocompaction, operating after incorporation in the anaerobic zone.

Despite the complex nature of peat accumulation, crude growth rates may be calculated by interpolating radiocarbon dated profiles. Systematic studies of north west European mires by Aaby and Tauber (1974) and Tolonen (1979) have shown that growth rates were generally low during the Atlantic and early Subboreal periods but rose towards the end of the Subboreal and peaked in the early Subatlantic. Tolonen (1973, 1979) has reported growth rates for Laaviosuo, south Finland, of 22y/cm between 3100-4420 B.P., 7.8y/cm between 3100-2320 B.P. and 7.5y/cm between 2320-1870 B.P. In the Nigula Bog, Estonia, Ilomets (1982) obtained rates of 24y/cm between 4870-3670 B.P., 14.4y/cm between 3670-2950 B.P., 8y/cm between 2950-2550 B.P. and 3.5y/cm between 2550-2410 B.P.

At Bloak Moss, Scotland, growth rates of up to 3y/cm were attained over the period 3320-3170 B.P. This contrasts with earlier rates in the same mire of 1cm in 28y (Turner, 1981). Similarly, Tregaron Bog, Wales, accrued peat at a rate of 3y/cm prior to 2354 B.P. and thereafter only at 46y/cm (Turner, 1981). A maximum growth rate of 5.7y/cm between 3540-3080 B.P. has been noted for Mongans Bog in Ireland (Parkes, personal communication). Comparable trends have been demonstrated for British hill peats (Durno, 1961; Hicks, 1971).

Detailed work on the accumulation rate of Eurasian raised mires has been undertaken by Neustadt et al. (1965) and Sarv et al. (1982). At Oseechenskoe Bog, RSFSR, peat accumulated slowly between 2885 and 1605 B.P., 1cm taking 41.6y. This contrasts with early Subboreal peats which accumulated at a rate of 50y/cm between 3820 and 2885 B.P. (Neustadt et al., 1965). Sarv et al. (1982) have demonstrated that growth rates were actually higher in the late Subboreal than they were in the early Subatlantic. Values of 7.4y/cm between 3595-3520 B.P. contrast with 62.5y/cm between 3520-2905 B.P.

A series of 33 radiocarbon assays on a single 6m core from Agerods Mosse, Sweden, has enabled Nilsson (1964a) to show that calculated rates can vary considerably according to sampling interval. Whilst average values of 15.6y/cm for Subboreal peats and 12.3y/cm for Subatlantic peats were obtained, Nilsson demonstrated that mid-Subboreal peats had actually accumulated faster (23y/cm) than immediate pre-MHC peats (83.3y/cm). Similarly, early Subatlantic peats had accumulated quicker (6.3y/cm) than the period mean (12.3y/cm). Barber (1982) using material from Turner (1965), has also demonstrated that subtle growth rate variations may be concealed when using large sampling intervals.

Allowing for such errors, the published growth rates nevertheless demonstrate that whilst local factors may have affected the response of individual mires, a general climatic deterioration began, if only marginally, as early as c.3200 B.P. over much of north-western Europe. There is insufficient data to show whether this deterioration occurred earlier in western maritime or eastern continental areas.

Widely differing dates between the uppermost layers of the highly humified peat and the lowermost horizons of the poorly humified peat have been reported by several workers (Lundqvist, 1962; Birks, 1964; Turner, 1964, Neustadt, 1967). Samples from Chat Moss, Lancashire, revealed an age difference 425 years for the MHC (Birks, 1964) whilst Lundqvist (1962) produced evidence for a hiatus of between 310 and 425 radiocarbon years for a recent recurrence surface at Lidamossen and 135 to 350 years at Hogmossen in Sweden. Both series of dates may be questioned however. The dated samples were not contiguous vertically, there being 9cm difference at Chat Moss and up to 35cm separating Lundqvists samples. Given the demonstrated variability of accumulation rates over short distances, it is possible that these differences are significant. Indeed, Barber (1982) has shown that if the extremes of the standard deviations are considered, there is no hiatus at sample site 22 (1145 +/- 60 St-665 and 1280 +/- 80 B.P. St-656) at Hogmossen, and the others are reduced to 120 and 190 years.

At Lidamossen the differences are 145, 140 and 240 years, whilst at Chat Moss the hiatus is only 275 years. These clearly lie within the realms of sampling error.

Turner (1964) working on Tregaron Bog, Wales, also found evidence of a hiatus. The mean of two dates above the MHC was 2646 +/- 70 B.P. (Q-388), and below the contact 2954 +/- 70 B.P. (Q-389), a difference of 308 +/- 110 years. Since this is greater than twice the standard deviation, it is statistically significant. Only 1.8cm separated the samples and Turner (1964) hypothesised that "there was probably a short break, therefore, in peat formation, or even some erosion at that level". A similar argument had been advanced earlier by Godwin (1946, 1954, 1960). Whilst Ivanov (1975) has demonstrated that mire pools are susceptible to erosion, Ingram (1983) suggests that if the surface vegetation remains intact, surface erosion is unlikely. Widespread erosion of blanket mire has been demonstrated by Tallis (1973), but there is little evidence of such phenomena on raised mires. Eggelsman and Schuch (1976) have cited snow melt and heavy rain as the main agents of erosion in the upland raised mires of Germany. Although the possibility of catastrophic flooding of what Turner (1981) refers to as the "dried out bog surfaces" cannot be ruled out, differences in age are perhaps better considered in relation to the relative proportions of the acrotelm and catotelm. Accepting that the climate of the Subboreal was comparatively dry, the increased depth of the acrotelm would permit enhanced biological decomposition and a reduction in the rate of mire growth. In an equilibrium state therefore, a single centimetre could thus represent several centuries of accumulation.

Elsewhere, evidence points to uninterrupted accumulation. Casparie (1972) has shown that the dates directly above and below the MHC in Emmen 11 are inseparable (1815 +/- 60 B.P. GrN-4146 and 1800 +/- 50 B.P. GrN-4148), and similar findings have been made in the Hellweger Moor by Overbeck (1975) (2100 +/-65 B.P. H-171/163 and 2050 +/- 75 B.P. H-182/203) and at Agerods Mosse in Sweden (Nilsson, 1964b) (2270 +/- 85 B.P. St-986 and 2205 +/- 85 B.P. St-985).

Whilst more close sample datings immediately above and below the MHC are required, published evidence supports the view that certain sites are characterised by uninterrupted peat formation and others by a temporary retardation in the accumulation of Sphagnum at the close of the Subboreal.

2.5 INDEPENDENT EVIDENCE FOR CLIMATIC DETERIORATION FROM 1200 TO 400 B.C.

In addition to the evidence supporting climatic change in the first millenium BC obtained from the study of recurrence surfacs, several other sources indicate a widespread deterioration.

Working in the Somerset Levels, Clapham and Godwin (1948) showed that the stratigraphies of several raised mires were characterised by a number of "swamping horizons". These horizons were rich in remains of Cladium mariscus, hypnoid mosses and Myrica gale. Godwin (1948) hypothesised that the layer of Cladium peat was of similar age throughout the region and was caused by mire surface inundation with base-rich calcareous waters from the surrounding Mendip, Wedmore and Polden Hills. In addition, a series of prehistoric trackways were found at the junction of the highly humified Sphagnum-Eriophorum-Calluna ombrotrophic peat and the Cladium flooding horizon.

Godwin and Willis (1959) demonstrated that considerable age differences existed between the trackways and the humified peat. At Meare Heath a shaped wooden stake was dated to 2840 +/- 110 B.P. (Q-52) and the subjacent peat to 3230 +/- 110 B.P. (Q-458). Similarly, the Shapwick Heath trackway was dated to 2470 +/- 100 B.P. (Q-39) and the peat directly below the trackway to 3310 +/- 110 B.P. (Q-44). Godwin and Willis (1959) postulated that the mires were either eroding or at "stillstand", being sufficiently dry to permit foot crossing. Following climatic deterioration, mire surfaces became increasingly wet and in order to maintain communication links wooden trackways were constructed. So severe was the flooding that the trackways were embedded in Cladium-Hypnum peat before being damaged or decayed. The dating of Nidons trackway showed that no such discontinuity existed. The track was dated to 2585 +/- 100 B.P. (Q313), the peat directly beneath to 2642 +/- 120 B.P. (Q-317) and the peat above to 2628 +/- 120 B.P. (Q-318) (Godwin and Willis, 1960). The dates are inseparable and point to continuous accumulation.

Correlating changes in regional forest composition and agriculture (as reflected in pollen diagrams) with stratigraphic changes and the discovery of trackways bearing the marks of Bronze Age axes, Godwin and Willis (1959) tentatively associated the climatic change with Webers' "Grenzhorizont" and Granlunds' RYIII.

Subsequent radiocarbon dates from the Somerset Levels (see for example, Godwin, 1960; Coles and Hibbert, 1968; Coles et al., 1970) indicate that the trackways were constructed between 2840 +/- 110 B.P. (Q-52) and 2410 +/- 110 B.P.(Q-68), with a mean of 2626 b.p. Godwin (1966) provides an average date of 2575 b.p. for the initiation of poorly humified peat.

Late Bronze Age trackways have been discovered elsewhere in Britain. At Fordy, Cambridgeshire, the Little Thetford trackway was dated to 2560 +/- 110 B.P. (Q-310) (Godwin and Willis, 1959), at Kate's Pad, Lancashire, a date of 2760 +/- 120 B.P. has been obtained (Q-68) (Godwin and Willis, 1960) and the Brigg Trackway, Lincolnshire, has been dated to 2552 +/- 120 B.P. (Q-77) (Godwin and Willis, 1960). The latter is believed to correspond to a marine transgression in the Humber-Ancholme valley.

Casparie (1972) identifies four phases of trackway building at the Bourtanger Moor, The Netherlands (4100 +/- 55 B.P.GrN-2986, 3120 +/- 50 B.P. GrN-4149, 2480 +/- 40 B.P. GrN-4622 and 2120 +/- 50 B.P. GrN-4147) and correlates these with phases of increased surface wetness. Trackways have also been found in Germany (Hayen, 1957; Overbeck, 1975) and Ireland

(Mitchell, 1956), although no consistent picture of either dates or climatic significance has emerged.

In addition to the evidence for deterioration from prehistoric trackways, it is also clear that minor fluctuations in relative sea-level occurred. Even though the record is fragmentary, biostratigraphical investigations within lagoonal, tidal flat, perimarine and sand dune zones in the area between the Solway Firth and the Mersey suggest two phases of marine transgression (Tooley, 1974). The contact surfaces between marine and freshwater deposits have been radiocarbon dated enabling Tooley (1974, 1976) to postulate a transgression, called Lytham VII, between c.3700 and 3150 B.P. Following a minor regression, Lytham VIII records a relative sea-level rise between c.3090 and 2270 B.P. A further transgression, Lytham IX, occurred between c.1560 and 1380 B.P., reaching its maximum around 1300 B.P. (Tooley, 1976).

Detailed stratigraphic descriptions of the tidal flat and lagoonal zones have established comparative sea-level curves over much of Britain. Working in Cumbria, Andrews et al. (1973) recorded transgression phases analogous to those obtained by Tooley (1976), and on the north east coast Gaunt and Tooley (1974) have shown a rise at the same time as Lytham VII, VIII and IX, and throughout Humberside and Lincolnshire Smith (1958, 1970) has demonstrated a transgression correlating with Lytham IX. Earlier work in the Fenlands (Godwin, 1940, 1943) and the Somerset Levels (Godwin, 1941) produced evidence for a series of transgressions, but lack of systematic dating makes direct comparison difficult. Nevertheless, Godwins' phases IV, V and VI for Somerset and Fenland are broadly contemporaneous with the Lytham series.

Elsewhere, detailed local descriptions have been produced for The Netherlands (Jelgersma, 1961, 1966; Brand et al., 1965; Hagaman, 1969), the coastal zones of Niedersachsen and Schleswig-Holstein in Germany (Brand et al., 1965), Ireland (Stephens and Synge, 1966; Synge, 1985) and the south (Berglund, 1971) and west Morner (1969) coasts of Sweden. Whilst the demonstrated marine transgression sequences for northwestern Europe are not parallel, correlations certainly exist. Tooley (1976) notes that "the similar chronology of marine events recorded in restricted areas with different tectonic, sedimentary and glacial histories adjacent to the Irish, North and Baltic Seas and the English Channel, reinforces conclusions on the direction of sea-level movements during the Flandrian Stage". Tooley (1976) attributes minor differences to local factors such as sediment consolidation, tectonic subsidence, isostatic recovery and changes in the tidal regime. It must also be remembered that many sequences remain to be accurately dated.

The climatic significance of sea-level rise has been questioned by Turner (1981) who noted that eustatic rise, on theoretical grounds at least, ought to occur only when the climate is globally warmer and ice ablation is enhanced. Citing the possible influence of local factors, Turner (1981) advocates more detailed work on the relationship between climate and sea-level.

There does indeed appear to be a close correlation between the observed transgression maxima and sea-level fluctuations established for north west Europe, and periods of climatic amelioration. Palaeoisotopic analyses undertaken on ice (Dansgaard, 1964, Dansgaard et al., 1982) reveal eleven "warm" periods between 12,300 B.P. and 850 B.P. These warm periods displayed a periodicity of c.290 years. A marked cold phase between 2500 and 2100 B.P. was noted, and shows clear correspondence with the observed period of MHC formation in north west European raised mires.

2.6 SUMMARY

It is generally accepted that the MHC marks a climatic deterioration over north western Europe. Originally believed to correspond to the Subboreal-Subatlantic transition c.500 B.C., the MHC has been shown to vary spatially in both intensity and consistency of expression, and temporally. Whilst local climatological, hydrological and topographic factors may be responsible for small-scale variation on an inter- and intra-site basis, previously published radiocarbon dates suggest significant diachroneity of formation. To what extent such discordance reflects real climatic variability across north-western Europe or results from differences in the sampling and dating criteria applied by previous workers is problematic.

With the aim of obtaining more precise statements regarding the temporal and spatial variation of MHC formation in north western Europe, a series of standardised sampling, analytical and dating procedures were adopted by the current study. These are detailed in the following sections.

SECTION 3. METHODS

3.11 INTRODUCTION

The methods used in the reconstruction of Quaternary environments are many and diverse. Detailed reviews are presented by Tolonen (1966), Birks and Birks (1980), Lowe and Walker (1984) and Schwaar (1984b). Barber (1976 and references therein) deals with methods relevant to the reconstruction of vegetational histories. Only techniques considered relevant to the present study will be detailed below.

3.12 THE ROLE OF MACROFOSSILS IN PALAEOECOLOGICAL RECONSTRUCTION

Middeldorp (1984) proposes that palaeoecological investigations involve two complementary approaches: An analysis of mire ecology using macroscopic remains of plants and locally deposited pollen and spores are used to produce local vegetation histories, whilst studies based upon the study of pollen and spores alone, facilitate statements regarding regional vegetation change. As Middledorp (1984) later notes however, there will be differences in the way these formations react to shifts in the climatic equilibrium. Work on English Pennine blanket peats (Conway, 1954) has shown that forest ecosystems display great stability and react only slowly in response to climatic perturbations. In contrast, lag effects in mires were considered negligible. In spite of this, macrofossil analyses have played a secondary role in the reconstruction of Holocene palaeoclimates. The development of pollen analysis at the turn of the century led to a series of studies where macrofossil results were fitted into a framework provided by pollen analysis (see for example Jessen, 1929, 1949). Advances in pollen microscopy increasingly supported this approach.

Like pollen and spores, many plant macrofossils exist as discrete variables in space and time. Their distribution and abundances are similarly affected by various selective processes which act to provide a distorted picture of the past vegetation.

In considering reproductive structures, account must be taken of both inter- and intra-species variability (Greatrex, 1983). Different species produce varying quantities of leaves, seeds, fruits, stamens and sporangia. The lateral and vertical dispersion of these structures is governed not only by the immediate faunal population but also by their shape, size and weight. Some attempt has been made to model the transport and selection of macrofossils. Work by Ferguson (1985) on the origin of leaf-assemblages deserves special mention. Field and laboratory experiments demonstrated that various selective processes are involved in the transport of abscissed leaves. Habitat, life form, leaf weight and leaf size were all shown to exert a strong control over leaf dissemination. Leaf preservation depends upon contact with a body of water in one form or another. Both external factors and the nature of the individual leaf affect the way in which leaves enter water bodies. Differential bouyancy, leaf shape, configuration of the land surface, its vegetational cover and the amount and distribution of precipitation are all cited as complicating factors by Ferguson.

Variable trophic status, sedimentation rates, water turbulence and faunal populations render direct comparison between aquatic ecosystems difficult. Similar findings have been made elsewhere (Kaushik and Hynes, 1971; Furness and Breen, 1982; Hanlon, 1982).

Work on a series of meres and mosses in England and Wales (Greatrex, 1983) confirmed that the 'seed rain' was far from even. An over abundance of winged Betula fruits was a common phenomenon. Despite this, she reaches the slightly contradictory conclusion that "reconstructions of past plant communities from the consideration of the subfossil assemblages in a single core apply only to the immediate vicinity of the sampling point". Consideration of the data presented in this paper suggests that extra-local input may be important.

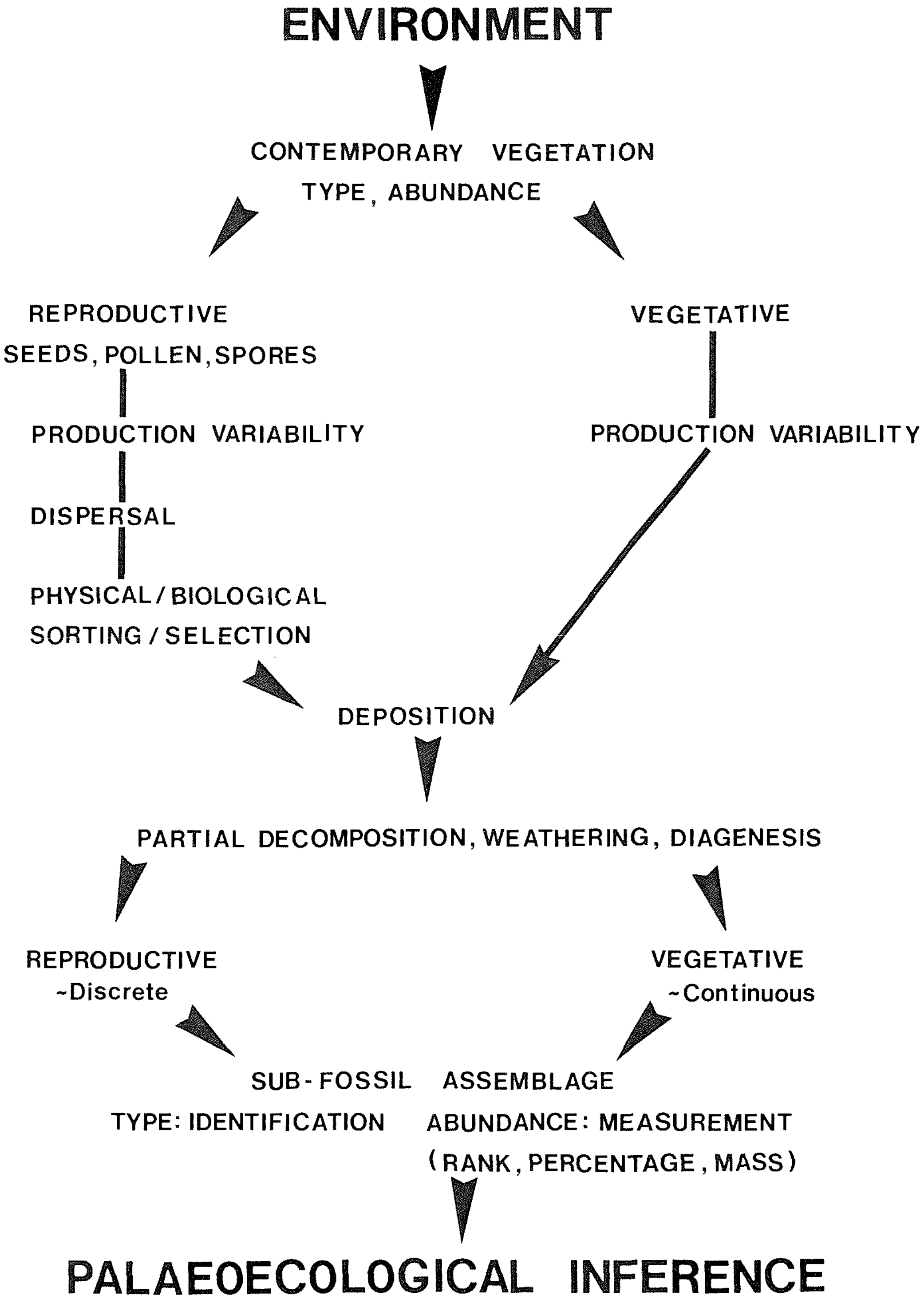


Figure 2. Stages in the reconstruction of palaeoecological communities.

It is clear that the interpretation of many macrofossil assemblages is problematic. In considering the vegetative remains found in acid mires, the situation is more straightforward. Apical growth of Sphagnum mosses combined with low decay rates means that apart from forming an axis in space, the Sphagnum shoot also forms an axis in time. Unlike the discrete nature of pollen, spores and many macrofossil remains, bryophyte assemblages may be considered as continuous variables. Problems of differential dispersal and sedimentation are not applicable (figure 2). Work on Antarctic moss banks dominated by Polytrichum alpestre and Charisodontium aciphyllum (Fenton, 1978, 1980) has shown that lateral and vertical displacement of shoots caused by the loss of structural integrity and increasing weight of material above may be modelled. In most instances such distortion is considered negligible.

Partial decomposition, weathering and diagenesis of deposited sediments are processes which act upon both vegetative and reproductive remains. The differential nature of these alterations acts to distort pattern recognition and must be recognised in all studies of subfossil assemblages. However, the abundance and often excellent preservation of material in mires offers enormous scope for palaeoecological reconstruction.

Contrary to the view that macrofossil assemblages may only be used to reconstruct local palaeoenvironmental histories, studies by Aaby (1976) and Barber (1981) have convincingly demonstrated the role extra-local climatic conditions play in mire growth and peat macrofossil composition. Work by Holzer and Schloss (1981) has confirmed the close correlation that exists between macrofossils of Sphagnum and regional environmental histories as obtained by pollen analysis.

The belief that macrofossil studies may only complement the information available to palaeoecologists from pollen analysis has been increasingly questioned. Recent studies (Walker and Walker, 1961; Tolonen, 1973; Casparie, 1972; Van Geel, 1978; Barber, 1981; Svensson, 1987) have recognised the role such remains can play in the interpretation of past environments, and new semi-quantitative methods of estimating bryophyte abundances (Van Geel, 1978; Janssens, 1983; Dupont, 1986; M.J.

Clarke, personal communication; this study) have facilitated more accurate statements regarding former populations than has hitherto been possible. The use of moss increment dating has illustrated the time resolution that may be achieved in palaeoecological reconstructions.

For these reasons, the palaeoecological reconstructions used in this study are based exclusively upon macrofossil analyses. Wherever possible, published pollen diagrams have been used to supplement this information.

3.3 SAMPLING PROCEDURES

3.31 SITE SELECTION

In order to minimise inter-site variability as many factors as possible were kept constant.

Lowland raised mires were considered appropriate for study, both for their comparative abundance in northwest Europe and ease of access. An upper altitudinal limit of 170m was imposed. Whilst this limitation was not found to be unduly restrictive, it did preclude the study of several low-montane raised mires in the Harz mountains of Western Germany and Polish Carpathians. This was more than compensated for by the the large number of potential sites in Niedersachsen and north eastern Poland respectively.

It was important that study sites were completely ombrotrophic, and thus reacting in response to environmental conditions, at the time of the Subboreal-Subatlantic deterioration. A former minimum size of circa 80ha was chosen. Where the former extent of a mire could not be readily determined, either visually or by examination of historical maps, the site was judged inappropriate for study. None of the sites were vulnerable to the effects of marine incursion (cf. Wimble, 1986).

Although anthropogenic interference was found to be ubiquitous throughout Europe, the MHC was still present in many 'core' areas. Sampling was thus restricted to the former mire plane. Areas proximal to the original sloping marginal rand of the mire, where present, were therefore excluded.

In accordance with the studies of Gross (1933), Walker and Walker (1961), Schneekloth (1965, 1970), Casparie (1972), Overbeck (1975) and Barber (1981), long exposures were considered. Where possible hand-cut peat faces were studied, since as Barber (1981) notes, machine cutting can cause compression and distortion of poorly humified sequences and considerable peat 'smearing' between levels. At Bolton Fell Moss and Totes Moor where no suitable hand-cut faces were available for study, mechanically cut drainage ditches were used.

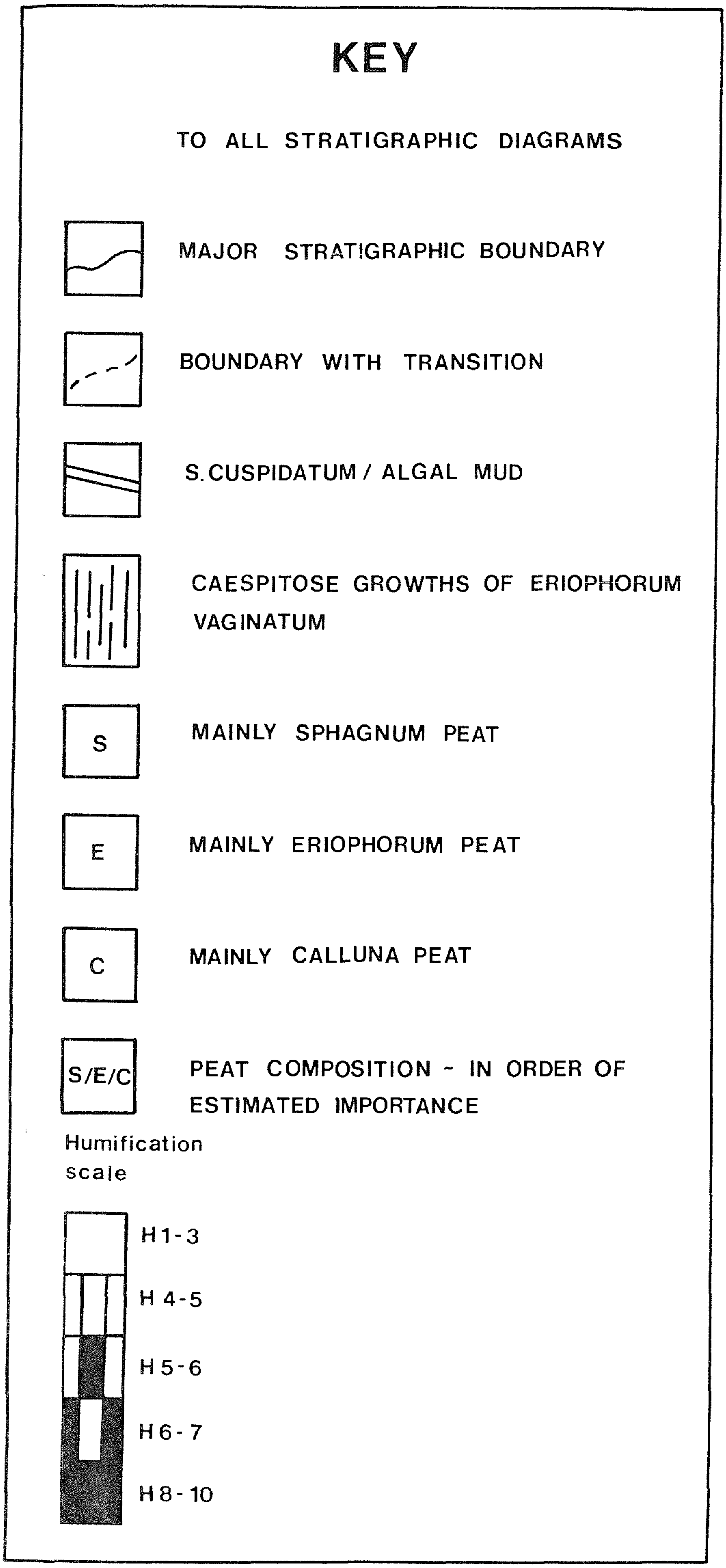
At Flanders Moss, Tregaron, Agerods Mosse, Yggeryds Mosse, Machnacz and Kurianska Bagno suitable peat faces were not available. It was decided to use conventional coring techniques at these sites. A modified Russian-pattern sediment sampler (Barber, 1984) was used to remove a core from the geographical centre of each mire.

Throughout the sampling procedure two explicit assumptions were made. Firstly, that the sample would be representative for the mire as a whole and, secondly, that major variations present in the stratigraphy of each mire represented environmental changes of regional significance. Over recent years much debate has focused upon these matters (Aaby, 1976; Van Geel, 1978; Barber, 1981, 1986; Dupont, 1986). Whilst the situation in autochthonous deposits may be complicated, the view was taken that careful consideration of long profiles would eliminate possible misinterpretation of localised sequences.

Questions regarding the climatic sensitivity of individual mire ecosystems are more problematic. Where no information to the contrary was available, it has been assumed that mires acted in response to regional environmental change.

3.32 STRATIGRAPHICAL RECORDING

Figure 3.


KEY
TO ALL STRATIGRAPHIC DIAGRAMS
MAJOR STRATIGRAPHIC BOUNDARY
BOUNDARY WITH TRANSITION
S.CUSPIDATUM / ALGAL MUD
CAESPITOSE GROWTHS OF ERIOPHORUM VAGINATUM
S
MAINLY SPHAGNUM PEAT
E
MAINLY ERIOPHORUM PEAT
C
MAINLY CALLUNA PEAT
S/E/C
PEAT COMPOSITION ~ IN ORDER OF ESTIMATED IMPORTANCE
Humification scale
H1-3
H 4-5
H 5-6
H 6-7
H 8-10

A representative section was chosen at each site following extensive examination of the available faces. A series of colour slides of the peat face were taken using Kodacolor 64 film. Peat displays strong light absorbancy and is difficult to photograph. Best results were obtained by over-exposing the film by 1 f-stop in good lighting conditions and by 2 f-stops when overcast. Experiments using flash illumination failed to improve picture quality. A vertical pole sub-divided into 10cm divisions was used to scale photographs. At sites where cores were obtained, each individual core section was photographed using a similar procedure.

Stratigraphy was then recorded by pegging a 25cm square quadrat with 5cm string divisions to the peat face. Using an analogous approach, Walker and Walker (1961) demonstrated that an accuracy of +/- 0.50cm may be obtained. Similar findings have been reported by Barber (1981). All stratigraphic boundaries, and their respective depth beneath the contemporary mire surface were recorded in a field notebook and graphed.

Peat composition of each stratigraphical unit was assessed by removing a representative block of peat adjacent to the quadrat using a penknife. When using cores, a necessarily smaller volume had to be removed for analysis. Various peat classification schemes were tested. Those of Walker (1961), Walker and Walker (1961), Chapman (1964a), Magnusson (1964), Casparie (1969), Boatman (1983) and Tolonen et al. (1985) were rejected on the grounds that they did not provide the desired level of accuracy, whilst the Troels-Smith system (1955) was considered unduly complicated for general field use. The notations devised by Barber (1981, p.56) provided an adequate compromise between these extremes. These are presented schematically in figure 3. All methods underestimated Ericaceae abundances. Small fragments of <u>Calluna</u> readily visible under the microscope were rarely noted in the field situation. The low abundances of Ericaceae remains however meant that any discrepancies were usually minor.

The highly degraded state of peats beneath the MHC presented several classificatory problems. Plant structure was rarely discernible even with the use of x10 hand field lenses. No completely satisfactory method was found to circumvent this problem. Estimates made in the field were compared with results obtained from macrofossil analyses and where significant differences were obtained, the stratigraphical notations made in the field were amended accordingly.

Humification of peat deposits was assessed using Von Post's (1924) 10-grade scale. Five classes were designated: H1-3, H4-5, H5-6, H6-7 and H8-10. (figure 3). This approach obviates the need to use intermediate values (H6/7, etc) to describe samples which display slight heterogeneity but clearly belong to the same stratigraphical unit. To avoid confusion with the symbols used to describe vegetal composition, a separate humification stratigraphy was constructed. Following Barber (1981), vegetal decomposition was determined on the same material used to estimate composition.

Precursor peats ('Vorlaufstorf' or pool peat sensu Weber) caused particular problems with regard to humification. These horizons, largely composed of Sphagnum sect. Cuspidata and Scheuchzeria palustris, were often found as discrete pale green bands. Thin interbedding is common. At several sites (see for example Bolton Fell Moss) it is characteristically 'greasy' and gelatinous due to algal remains. Upon squeezing, it readily passes out of the hand: H9 on the Von Post scale. However, plant structure is still discernable (H5-6) and expelled water is rarely turbid (H1-3). No compromise value was appropriate. These levels, therefore, are designated in humification plots using a plain band.

Dissatisfaction with the Von Post system led the author to seek a more quantitative means of assessing the degree of organic decomposition. These studies are detailed in Section 3.5.

3.33 FIELD SAMPLING

As noted previously, suitable peat faces were absent at several sampling localities. At these sites a modified Russian borer (Barber,

1984) was used to remove alternate 30cm long sections, with a 5cm overlap at each end, from adjacent core sites. Maximum distance between access holes was 30cm. The 10cm diameter cores thus obtained provided ample material for subsequent macrofossil analyses, humification determination and radiocarbon dating.

At all remaining sites, monoliths were used. Constructed from 1.50mm thick sheet aluminium, these monoliths measured 50x10x10cm. The use of 200cm long wooden (drilling core) boxes as used by Tolonen et al. (1985) was impractical in isolated field situations, and 30x2.5x3cm iron tins as used by Casparie (1972) did not provide a sufficiently large sample from which macrofossil and radiocarbon analyses could be undertaken. Since a discrete time period was being studied it was thought unnecessary to remove the complete stratigraphical sequence. Sampling focused upon the peat directly associated with the MHC. Accordingly, using a 5cm overlap, two consecutive monoliths were taken.

The carefully labelled tins were pressed into the peat face and the peat surrounding the tins was cut using a breadknife. This procedure severed resistant <u>Eriophorum</u> fibres commonly associated with the highly humified peat directly beneath the MHC and prevented sample disintegration when the monolith was removed. The tins were then knocked into the face using a masonry hammer, photographed and then dug out using a peat shovel.

Contrary to the advice of Barber (1981), it was found unnecessary to line the tins with aluminium foil. Experiments showed that foil disintegration was a common problem. To facilitate subsampling of the recorded face, tins were carefully inverted onto a cleaned glass sheet. No difficulties were encountered in returning the peat to the monolith.

All samples were wrapped in aluminium foil and resealable polythene bags prior to re-labelling. Upon return to the laboratory, stratigraphy and peat composition were re-examined. Few differences from the field situation were recorded, although in some instances 'sweating' had increased peat moisture content. Samples were then placed in a biological storeroom maintained at 2°C. To avoid possible distortion of stratigraphical sequences and provide a readily accessible sample, it was decided not to freeze the peat.

3.4 MACROFOSSIL ANALYSES

As Slack (1984) notes, almost every type of vegetation analysis presents some form of sampling problem and macrofossil analysis is no different. However, providing a consistent approach is adopted then serious biasing of the data is likely to be avoided. An attempt has been made throughout the study to standardise procedures.

The earliest studies of Quaternary floristics were concerned with peat macrofossils only (Watts, 1978). More recently, Walker and Walker (1961), Tolonen (1966, 1971), Casparie (1969, 1972), Van Geel (1972, 1978), Barber (1981), Bakker and Smeerdijk (1982), Dupont and Brenninkmeijer (1984) and Dupont (1986) have demonstrated the detailed palaeoenvironmental information that may be derived from a study of macrofossil assemblages.

In order to obtain a detailed record of floristic changes at the Main Humification Change, contiguous subsamples were taken to circa 15cm each side of the boundary. Sampling interval was subsequently increased to 2cm, 4cm and 8cm respectively, with increasing distance from this horizon. These subsamples were placed in petri dishes and stored in a refrigerator maintained at 4°C until assessment.

3.41 ASSESSMENT OF MACROFOSSIL ABUNDANCE

Birks and Birks (1980) note that fossil bryophyte fragments have not been subjected to detailed identification or quantification in the same way as have other macrofossils or pollen grains. In part this reflects the view that macrofossil analyses may only be used to complement palynological data.

Bryophyte data are conventionally represented as qualitative abundance estimates or by presence/absence (Janssens, 1983). Walker and Walker

(1961) introduced a five-point scale where 1=rare, 2=occasional, 3=frequent, 4=common and 5=abundant. A more elaborate and better defined approach has been suggested by Braun-Blanquet (1951). Subsequent modifications to this scheme have been advanced by Mueller-Dombois and Ellenberg (1974).

The possibility that considerable error may occur using subjective abundance estimates led many palaeoecologists to seek quantitative measures to describe fossil bryophyte assemblages. Early attempts by Green (1965) based upon counts of Sphagnum branch leaves were later shown to be suspect by both the author (Green and Pearson, 1977) and Barber (1981). Similar criticisms have been levelled against the point frequency method introduced by Heikurainen and Huikari (1952) (Barber, 1981). Both approaches have failed to be adopted by other workers.

Contrary to the views of Barber (1981) who, in discussing qualitative abundance estimates, states that "it is difficult to see what other method could be used with this sort of material", recent studies by Van Geel (1972, 1978), Bakker and Smeerdijk (1982), Janssens (1983), Dupont (1986) and Clarke (personal communication) have illustrated the considerable scope identifiable bryophyte remains present for statistical treatment.

Adopting an earlier method introduced by Grosse-Brauckmann and Dierson (1973) both Van Geel (1978) and Bakker and Smeerdijk (1982) have estimated the volume percentages of the assorted elements in the macrofossil sample. Individual components, such as seeds and fruits, were counted, whilst Ericaceae rootlets were classified according to a scale of abundance. Comparable methodologies have been used by Dupont and Brenninkmeijer (1984) and Middeldorp (1984).

A more complex method has been introduced by Janssens (1983). Restricting study to an analysis of bryophyte fragments, Janssens expressed the number of fragments as a concentration in the peat (fragments/100ml). Recognising that different Sphagnum species in a fossil peat assemblage may not be represented by the same proportion of whole plants, branches and leaves, Janssens (1983) applies correction factors in an attempt to allow direct species comparison. Both Clymo

(1965) and Barber (1981) have cited the need for such corrections.

The choice of which abundance measure to use was determined by the time it took to obtain a sample of the population considered statistically representative. Analysis of 641 subsamples from 18 profiles required a method that was both accurate and quick. The pioneering approaches of Van Geel (1972) and Janssens (1983) provide detailed quantitative information but are unavoidably time consuming. The percentage cover approach adopted in this study was developed from earlier work by M.J. Clarke (personal communication).

With the aid of a sharp surgical scalpel and spatula, a 4 cc subsample was removed from the peat monolith/core. Subsample compaction did occur but was minimal. Pre-treatment using boiling water (sensu Tolonen et al., 1985), potassium hydroxide (sensu Bakker and Smeerdijk, 1982; Dupont and Brenninkmeijer, 1984; Middeldorp, 1984) or nitric acid (Godwin, 1956; Wasylikova, 1979) to disaggregate the subsample was considered unnecessary. In addition to rendering remains mucilaginous and unsuitable for use with several mounting media (Barber, 1981), they are time intensive. Washing using plain tap water provided equally satisfactory results.

Initial analyses involved wet sieving the subsamples through a series of five nested soil sieves ranging from 2000 micron to 125 micron mesh size. This also proved unnecessarily rigorous and in subsequent analyses only the 500 micron and 125 micron sizes were used.

Each fraction was washed into a glass dish and systematically scanned using a Nikon stereozoom microscope (SMZ-10) of stepless x6.6-x40 magnification. In highly humified peats it was found that the 125 micron fraction remained too dense for optical examination. Accordingly, the solution was diluted until an acceptable level was attained. Unusual fragments were removed using watchmakers' forceps and placed in glass vials containing a 50:50 ethanol/water mixture. These were subsequently identified.

Following scanning, the 125 micron and 500 micron fractions were combined and placed on a 63 micron sieve. The remains retained on the surface of this sieve were then washed into a glass trough ready for counting using 70ml of distilled water.

In order to facilitate accurate assessment of macrofossil abundance, a quadrat-marked graticule was placed in the eyepiece of the stereozoom microscope. Percentage cover of identifiable Sphagnum (leaves and stems), monocotyledon and Ericaceae remains was calculated along with unidentifiable organic matter (no recognisible vegetative structure). All counts were performed at x20 magnification. Components covering more than half each individual square were designated as having 1% cover. It was found that together with difficulties caused by particle fragmentation, this approach tended to underestimate macrofossil abundance. Although scale differences exist between bryophytes and vascular plant vegetation on contemporary mire surfaces, it was decided at an early stage that in subfossil situations such differences would be reduced. Much above ground biomass in vascular plants is lost before incorporation into the peat matrix. Whilst such sources of error are likely to be small, attempts at quantification proved problematic, and accordingly it was felt inappropriate to apply correction factors. Since a three dimensional situation was being considered, on occasion estimated cover values exceeding 100% were obtained. This was not a problem in data analysis.

It proved impossible to make a general rule as to the number of sample quadrats required at the trough estimation stage. Estimates of the population mean clearly become more accurate as sample size is increased. A compromise had to be reached between the desired level of accuracy and sampling time. Using a variety of ombrogenous peats pilot experiments were performed to calculate optimum sample size. Following computation of the running population means for an increasing sample size, the 95%, 99% and 99.9% confidence limits of these estimates were plotted against sample size. Since no information to the contrary was available, it has been assumed throughout that the population present in the trough approximates to a Gaussian distribution. The point at which confidence limits cease to fluctuate is easily determined (Grieg-Smith, 1957; Kershaw and Looney, 1985) and provides a crude indication of the required sample size.

The relative homogeneity of ombrotrophic peats meant that confidence limit fluctuations fell rapidly, and it was decided that 15 random sample quadrats at each trough estimation provided an accurate assessment of the various macrofossil abundances. The use of random number tables (M.J. Clarke, personal communication) to locate the trough on the microscope stage was not applied. Although biased population estimates may occur from avoidance of the trough edges, towards which macrofossil components occasionally aggregate, disturbance caused by relocation ensured that this was not a serious problem.

The estimates of percentage cover for each individual macrofossil component were read into a specially written microcomputer program which calculates running means, standard deviations and confidence limits of the population. Developed from an earlier program (M.J. Clarke, personal communication) it incorporates two important modifications.

Firstly, account is taken of the possible occurrence of 'empty' squares at the cover estimate stage. Corrections may be applied to obtain absolute cover values for each macrofossil component. The percentage of 'empty space' in each quadrat view is subtracted from the theoretical maximum cover value using the following equation:

$$H(I) = 100 - G(I)$$

Where,
$H(I)$ is the percentage of the quadrat occupied by the various macrofossil components, 100 is the theoretical maximum cover value of the quadrat and $G(I)$ is the quadrat occupied by 'empty' space.

Values of $H(I)$ are then used in the calculation of absolute cover for each component:

$$A(I)=(K(I)/H(I))x100$$

Where,
$A(I)$ is the absolute cover value for each macrofossil component, $K(I)$ is the uncorrected macrofossil cover value and $H(I)$ is the percentage of the

quadrat occupied by the various macrofossil components.

The use of this correction factor provides a more accurate measure of macrofossil abundance and was used throughout the study.

Secondly, calculation of confidence limits makes use of Student's t-distribution. The t-distribution, like the normal distribution, is symmetrical but changes shape according to the number of degrees of freedom. At N>30 the t-distribution approximates the normal distribution (Norcliffe, 1977). Sample standard deviations are initially multiplied by Bessel's correction:

$$\sigma_{n-1} * \sqrt{\left(\frac{n}{n-1}\right)}$$

where,
σ (n-1) is the sample standard deviation and n is the number of samples. This answer is then divided by the square root of n to obtain the standard error. The appropriate value of t at sample size n-1 is multiplied by the standrad error to obtain the 95%, 99% and 99.9% confidence limits. In common with most biological studies, the 95% confidence limits were used on plotted diagrams to enable both an assessment of the significance of the changes in macrofossil abundances as well as the quality of the data.

Having completed this stage of the analysis, the trough was re-examined and between 50-120 Sphagnum branch leaves (depending upon abundance) were randomly removed and placed in vials containing 50:50 ethanol/distilled water awaiting species identification. It is acknowledged that this procedure may lead to possible data bias. Various attempts were made at developing a randomized approach but none proved satisfactory.

3.43 IDENTIFICATION

The use of conventional mounting media such as Berleses' Fluid, Farrants' Medium, Hydramount or Hoyers' solution was considered unsuitable. Although simple to use, these compounds may crystallise out.

Depex was found to be a clearer and more durable mountant. The processes involved in slide preparation are complex and take some time to perfect.

Sphagnum branch leaves were initially stained using Toluidine Blue, a procedure which accentuated cell micro-structure and aided species identification at the microscope stage. The dehydration of leaves, a prerequisite when using Depex, was accomplished in early experiments by washing the contents of the glass vial through a 63 micron mesh sieve and then treating the residues with increasingly more concentrated solutions of ethanol. This was found to be unnecessary. Immediate treatment with 100% ethanol solution achieved the same results and was thus adopted in subsequent analyses.

Using watchmakers' forceps, leaves were transfered to a microscope slide, a drop of Xylol added and then enough Depex to provide a self-sealing mount under a 24x50mm cover slip. Slides were ready for examination within an hour. A Nikon labophot compound microscope with widefield condenser at magnifications x40 to x400 was used to identify the various Sphagna.

The identification of Sphagnum both in field and subfossil situations is complicated by the great variability in morphological characters. Several attempts have been made to produce a definitive key system, with varying degrees of success (see for example Fearnsides, 1938; Proctor, 1955; Duncan, 1962; Crum et al., 1965; Isoviita, 1966; Watson, 1968; Hill, 1973, 1976; Smith, 1978; Jahns, 1980; Lange, 1982; Daniels and Eddy, 1984). Fortunately, the extreme nature of the ombrotrophic habitat excludes many species. Those which remain are readily determinable even from leaf fragments.

A succinct review of the major species found in ombrotrophic peats and aids to their identification is presented by Barber (1981, p.62-66). Although much of this discussion focuses upon work carried out on a single site, Bolton Fell Moss, it has more widespread applicabilty. Consideration of individual species and the various ecological parameters that determine growth will be dealt with in later sections.

Following Van Geel (1972, 1978), Barber (1981), Bakker and Smeerdijk (1982) and Middeldorp (1984), Cymbifolian leaved species of the sub-genus Inophloea were identified to species level. Three Cymbifolian species were encountered: *Sphagnum imbricatum*, *Sphagnum magellanicum* and *Sphagnum papillosum*. The sub-genus Lithophloea presents several identification problems. Determinations were restricted to section level only. The degraded state of many mire surfaces meant that extrapolation from contemporary communities to subfossil assemblages was seldom possible. This in itself is dangerous practice, since there is no guarantee that contemporary species were present in former periods. In instances where species level identification was possible, for example in the case of *Sphagnum cuspidatum*, this is noted in the text where relevant.

It was considered important that identification should not be based solely upon keyed-out information. A macrofossil slide collection incorporating modern and subfossil material was slowly developed and constantly referenced. The complementary nature of these separate approaches ensured accurate species determination.

The identification of macrofossil components other than Sphagna is highly problematic. Whilst leaves and stem fragments of *Calluna vulgaris*, *Erica tetralix*, *Oxycoccus palustris*, *Andromeda polifolia*, *Rhynchospora alba* and *Scheuchzeria palustris* are readily distinguishable, the majority of remains lack specific identifiable characters. The ecological information obtained from counting Ericaceae stem, leaf and seed remains as undertaken by Van Geel (1978) and Bakker and Smeerdijk (1982) was not thought to repay the effort involved. Despite useful surveys of the more common vegetative plant remains by Grosse-Brauckmann (1964, 1972, 1974, 1986), Katz et al. (1977) and Obidowicz (1978), identifications based upon isolated tissue fragments are unreliable. Grosse-Brauckmann (1986) has demonstrated that the histological structure of epidermal layers shows great variability even within single plants. Accurate determinations can only be made using fossil fragments where features of the macromorphology remain intact. The fibrous leaf sheath remains of *Eriophorum vaginatum* and stem bases of *Eriophorum angustifolium* are easily recognisible. Berggren (1969, 1981) was used in the identification of seeds.

Where species level identification has been possible, presence is simply indicated in the macrofossil diagram. No attempt has been made to quantify remains. This is recognised as one of the main drawbacks of this approach. Accurate monocotyledon identification at the trough estimation stage is considered problematic however.

3.5 HUMIFICATION ANALYSES

Peat humification is conventionally recorded using the 10-grade scale of Von Post (1924). Whilst the divisions are carefully graded and may be consistently replicated, subjective variabilities exist. Since consistent characterisation of the peat matrix is a prerequisite to any satisfactory humification scheme, the author sought a more quantitative approach.

No single method of measuring humification is totally satisfactory, mainly due to the heterogeneity and diversity of the organic debris in its physical, chemical and morphological features resulting from variation in biological origin. Physical methods for measuring vegetal decomposition include calculation of bulk density values (Paivanen, 1969; Tolonen and Saarenmaa, 1976; Saarenmaa, 1980; Tolonen et al., 1982), unrubbed and rubbed fibre contents (Sneddon at al., 1971), ash contents (Salmi, 1947; Tolonen, 1984), the laboratory volume weight of the peat (Pyavchenko, 1958) and peat reflectivity (Grandmaison and Laflamme, 1986). In addition, chemical methods using pyrophosphate extracts (Sneddon et al., 1971), Curie point pyrolysis-gas chromatography-mass spectrometry (PYGCMS) (Boon et al., 1986) and colourimetric determinations of sodium hydroxide extracts by different wavelengths (Achard, 1786; Overbeck, 1947; Bahnson, 1968; Aaby and Tauber, 1974; Sapek et al., 1980; Rowell and Turner, 1985) have attempted to clarify the relationship between observed decomposition and humification degree as given by Von Post (1924). Rattio and Huttunen (1976), Rochus and Sipos (1976) and Tolonen (1982) discuss the usefulness of these methods.

Consideration of the available techniques suggested that colourimetric determination of alkaline extracts of the peat was both an accurate and uncomplicated approach.

The organic matter of peats consists of a mixture of plant and animal products in various stages of decomposition together with substances synthesized from breakdown products (Atherton et al., 1967). Humic substances are the main constituents of this organic matter (Rochus and Sipos, 1976). Work by Franciszek and Horst (1976) has shown that the concentration of humic substances is significantly higher in strongly decomposed peats than in weakly decomposed peats. The isolation of these compounds is likely to provide an indication of the decomposition state of peat.

Overbeck (1947) and Bahnson (1968) have demonstrated that aqueous sodium hydroxide may be used to remove the soluble portion of humus. They refer to this extract as 'humic acid', although studies by Kaila (1956) and Haworth (1971) indicate that a considerable proportion of nonhumic substances may additionally be present. More recently, Hayes et al. (1975) and Hayes (1985) have identified hydrophobic lipids and phenolic compounds in such extracts. Nevertheless, it has been shown by several workers (Hayes et al., 1975; Levesque et al., 1980; Hayes, 1985) that light absorption of the alkaline extract is proportional to the amount of humic matter dissolved: high absorbance in strongly humified peats and low absorbance in poorly humified peats. Similar trends have been noted by Tolonen (1982), Boon et al. (1984) and Rowell and Turner (1985).

The method applied has been modified by the author from the approach adopted by Bahnson (1968). Peat subsamples measuring circa 1x2x1cm were removed from levels displaying important macrofossil or humification changes. Time constraints prevented contiguous sampling. Following oven drying at 100°C, the peat was ground in a rotary mill, and 50mg of this sample were placed in a 250ml Kjeldahl flask. Following addition of 50ml of a 0.50% NaOH solution, the flasks were refluxed for an hour. The use of simple condensing equipment prevents gaseous loss of humic substances and is a procedure that has not been adopted by previous workers. After cooling, the contents of the flask are filtered into a 100ml graduated flask and made up to 100ml using distilled water. The flask is thoroughly shaken on a mechanical shaker before measuring absorbance on a Cecil CE303

Grating Spectrophotometer (Series 2). Following Hayes (1985), Mayer (1985) and Thurman (1985) absorbance was measured at 465nm. The zero point of the instrument is determined using distilled water, and each measurement is standardised to a 50mg sample facilitating direct comparison.

Chemical degradation results in fading of solution intensity on standing. Similar observations were made by Bahnson (1968). Experiments showed that this fading was most intense in the first five hours following extraction. Accordingly, absorbance measurements were taken in the sixth hour following extraction.

3.6 ANALYSIS OF ZOOLOGICAL REMAINS

Whilst detailed macrofossil work supported by humification determinations formed the basis of the study, a series of subsidiary analyses were undertaken to assess the effects of climatic change upon mire faunal populations. Studies by Paulson (1952), DeGraaf (1956), Heal (1961, 1962, 1964), Tolonen (1966, 1971, 1979), Van Geel (1978), Van Geel et al. (1980/81) and Tolonen et al. (1985) have demonstrated that the changing abundances of animal remains may be used to indicate former surface moisture regimes.

The abundance of animal remains in peat deposits prevented a detailed study of the various taxa, and as Van Geel (1978) has shown, in many instances identification is problematic. The allocation of 'Type' numbers to indeterminate fossil remains forms a useful means by which such micro- and macrofossils may be classified. Given these limitations, analysis focused upon identifiable remains which would provide information regarding the humidity conditions of the peat-forming environment.

The testate Protozoans are particularly conducive to preservation in peat. Two common testacean Rhizopod species were recorded: Amphitrema flavum and Assulina muscorum. Work in north American raised mires (Tolonen et al., 1985) has shown that these species attain their maximum abundance in wet *Sphagnum*. Moisture contents of 93.2% (range 87.9-95.1%) and 90.5% (range 70.8-95.1%) of *Sphagnum* wet weight were recorded for *Amphitrema flavum* and *Assulina muscorum* respectively. Comparing their results with those obtained by Grospietsch (1953) for European mires, they conclude that these species are good indicators of wet microsites. Similar conclusions have been drawn by Tolonen (1971), Van Geel (1978), Bakker and Smeerdijk (1982) and Van Geel et al. (1983).

Mites are generally well preserved and present few identification problems. Frey (1964) notes that the species commonly found are not the strictly aquatic mites, but the oribatids. Of these, *Hydrozetes* spp. are the most abundant. Studies by Paul and Ruoff (1927, 1929) indicate that *Hydrozetes* spp. occur on submerged *Sphagnum* and other aquatic plants, and may on occasion move freely on open water surfaces. The presence of this species is a reliable indication of extreme dampness.

Finally, mention should be made of Cladoceran remains. The opaque head shields are conspicuous and display useful taxonomic characters. *Chydorus sphaericus*, a chydorid found in locally moist conditions, was the only species recorded.

All observations of zoological remains were made at the trough estimation stage. The isolation methods detailed in Tolonen (1966) were unnecessary. Numbers of Cladoceran and Mite/Protozoan remains per quadrat were counted and identification was based upon line drawings presented by Frey (1964) and Tolonen (1966). The presence of indicator species is noted in the text where relevant.

3.7 RADIOCARBON DATING

The application of radiocarbon dating to samples directly above and below the MHC was seen as an important means by which any temporal variability could be assessed. The comparison of geographically diverse sites on a similar time scale provides the most reasonable basis for inter-site correlation and is an important tool in peat stratigraphic studies.

Lab No.	Site	Depth below present surface (cm)	Radiocarbon Age Years B.P.
SRR-3035	Whixall Moss	11-18	1750 +/- 60
SRR-3036	Whixall Moss	20-26	1930 +/- 50
SRR-3074	Whixall Moss	40-44	2180 +/- 50
SRR-3037	Bolton Fell Moss	42-48	1640 +/- 50
SRR-3038	Bolton Fell Moss	49-55	2980 +/- 50
SRR-3039	Bolton Fell Moss	70-74	3270 +/- 50
SRR-3040	Flanders Moss	164-174	3480 +/- 50
SRR-3041	Flanders Moss	175-185	4050 +/- 60
SRR-3042	Flanders Moss	210-220	4200 +/- 60
SRR-3043	Mongans Bog	57-64	1480 +/- 50
SRR-3044	Mongans Bog	65-71	1650 +/- 50
SRR-3045	Mongans Bog	84-89	1870 +/- 50
SRR-3046	Mongans Bog	90-97	1830 +/- 50
SRR-3047	Tregaron SE	253-258	3410 +/- 60
SRR-3048	Tregaron SE	302-308	3800 +/- 60
SRR-3167	Juhrdener Moor	83-87	1850 +/- 50
SRR-3168	Juhrdener Moor	88-92	1980 +/- 50
SRR-3169	Lichtenmoor	99-103	1230 +/- 50
SRR-3170	Lichtenmoor	104-108	1230 +/- 50
SRR-3171	Totes Moor	94-98	2880 +/- 50
SRR-3172	Totes Moor	99-104	3150 +/- 50
SRR-3173	Gifhorn	43-47	3020 +/- 50
SRR-3174	Gifhorn	48-52	3170 +/- 50
SRR-3175	Machnacz	73-83	1120 +/- 50
SRR-3176	Machnacz	140-150	4040 +/- 50

Table 1 . Summary of radiocarbon age determinations for the Main Humification Change in north west Europe. All dates given in years before present.

In total, 25 samples were dated. Datings were carried out at the N.E.R.C. Radiocarbon Laboratory, East Kilbride, Scotland. Age calculations were based on a half-life time for 14-C of 5568 years and reported as 14-C years before 1950 (14-C years B.P.). These dates are summarized in Table 1. Lowe and Walker (1984), Pearson et al. (1986) and Olsson (1986) detail the techniques involved in Radiocarbon assay.

The samples for the C-14 datings were removed from either the aluminium monoliths or wide diameter Russian cores. Throughout sampling the peat was not touched by hand. Surgical scalpels, cleaned in distilled water, were used to remove blocks of peat immediately below and above the MHC. These blocks were subsequently placed on a clean glass sheet where a 1cm slice of peat was removed from the edges of each sample. The remaining block was securely wrapped in several strengthened plastic bags. Average sample size varied according to the available material. Based on advice from the East Kilbride laboratory, a sample weight of between 140-240g (natural wet state) was obtained. The counting errors on the subsequent radiocarbon dates range from 50-60 years. The results of this radiocarbon dating are presented in Section 6.4.

3.8 EXPLANATION OF MACROFOSSIL DIAGRAMS

A standardised format for all diagrams was necessary to facilitate correlation. As an aid to interpretation, lines linking data points have been drawn in. Actual values for intermediate points do not necessarily conform to these interpolated estimates.

The stratigraphical profile and peat types as recorded in the field, together with Von Post humification determinations and radiocarbon dates where available, are recorded separately to the lefthandside. Abundance estimates of the various macrofossil components, including 95% confidence limits, along with recorded fluctuations in the Sphagnum population form the central portion. The sequence of Sphagna is based upon ecological tolerances from wet to dry and values represent the percentage of each species present in a random sample of between 50-120 branch leaves. The presence of Calluna vulgaris, Erica tetralix, Oxycoccus palustris, Eriophorum vaginatum, Eriophorum angustifolium, Rhynchospora alba and Scheuchzeria palustris is simply denoted by a solid bar.

Estimates of the Cladoceran and Mite/Protozoan populations are presented at the righthandside. Values represent average number per 0.10cc. Confidence limits have been omitted since it was felt their inclusion could lead to confusion. No attempt has been made to plot the individual species present. Where relevant, these are noted in the text.

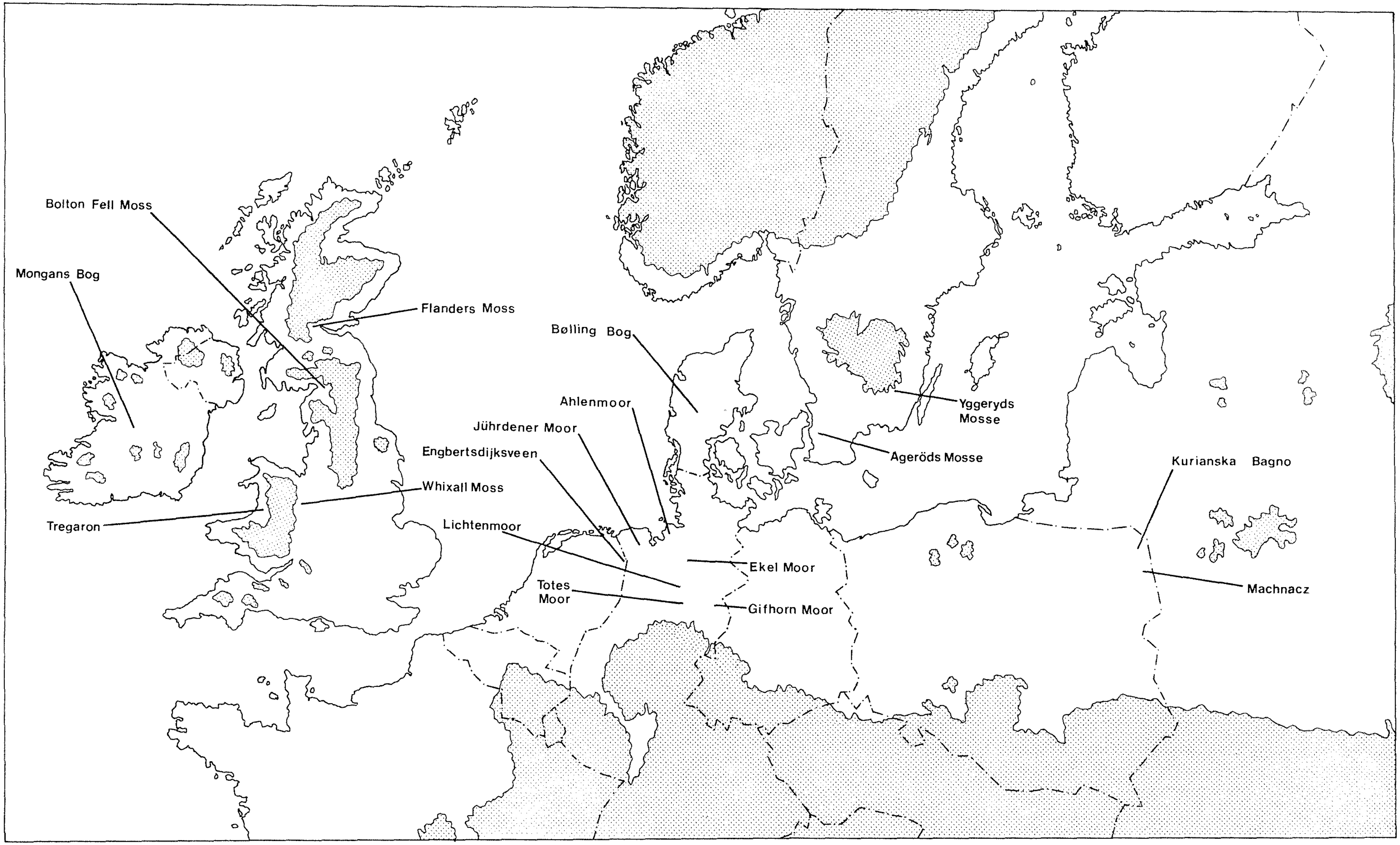


Figure 4. THE STUDY SITES

SECTION 4 THE STUDY SITES : A BACKGROUND

4.1 INTRODUCTION

The following sections provide a brief synthesis of the palaeoecological and climatological backgrounds of each study site. At an early stage of the work it became apparent that accurate palaeoclimatological reconstructions could only be obtained using a detailed sampling strategy. Accordingly, a total of 18 profiles along a 2200km transect from western maritime Ireland to eastern continental Poland were considered (figure 4). Absence of suitable sites and political constraints prevented sampling in eastern England and the German Democratic Republic respectively. Sites where previous palaeoecological investigations had been undertaken were studied wherever possible. This approach yielded valuable additional palaeoenvironmental information than would have been provided by macrofossil analysis alone.

4.2 THE BRITISH ISLES

4.21 MONGANS BOG, Co. OFFALY, IRELAND. (53°18'N, 7°55'W, 48m O.D.)

Peatland covers 16.2% (circa 1.34m ha) of Ireland (Hammond, 1979). Of this 337,940ha (26.0%) is raised mire. Moore (1962, 1968) distinguished two raised mire sub-types based on the relationship between the botanical composition and the increasingly wet climate of western Ireland. The division between the two sub-types is based on the 1,000mm precipitation isohyet. In drier areas a Midland sub-type is characterised by

Andromeda polifolia and Vaccinium oxycoccus, whilst with increasing oceanicity Pleurozia purpurea and Campylopus atrovirens become indicative of a Western sub-type. The present study restricted consideration to the Midland sub-type of Moore (1962) located in the Central Irish Plain.

The Central Plain of Ireland is underlain by Carboniferous limestone. Much of this plain is covered by calcareous drift deposited during the last (Midlandian) glaciation (Mitchell, 1976). This has given rise to a subdued topography with a local relief commonly less than 6.0m in amplitude (Hammond, 1979). Glacial eskers provide some diversity and in places rise 70m above the surrounding land (Mitchell, 1976). In the absence of marked drainage gradients widespread peat formation occurred as a consequence of hydroseral succession from postglacial lakes or paludification of wet hollows. The presence of shell marls and chara chalk muds at the base of many mires reflects the influence of the limestone bedrock.

A series of profiles were examined in County Kildare (Allen, Glashabaun, and Timahoe), County Offaly (Clara and Mongan's Bog) and County Galway (Athenry). Since detailed contemporary and palaeoecological information existed for Mongan's Bog, it was decided to focus initially upon this profile with a view to examinig additional material from Timahoe. Time restrictions prevented this secondary analysis. Preliminary observations indicate that the macrofossil variations recorded in the Mongans profile are repeated at Timahoe. In the absence of radiocarbon age determinations for Timahoe, direct comparison with Mongans Bog proves problematic however.

Mongans Bog, whose name is derived from an Irish word meaning "wet, sedgey place" (Joyce, 1922) is situated in western Co. Offaly 18km south of Athlone and covers an area of 110ha. It is bounded by eskers to the south and north. The eastern sector has been drained by Bord na Mona and awaits exploitation, whilst the southern and western sectors have been cut away for agricultural or fuel purposes. Despite this, Mongans remains one of the last remaining intact Irish raised mires.

Stratigraphic information supplied by Bord na Mona is available for 12 transects across the mire. A more detailed profile extending to 1100cm has been assembled by Bradshaw and Parkes (unpublished data). The sediment between 1100cm and 867cm consists of an admixture of calcareous marl and gravel. The marl grades into a Phragmites-rich fen peat around 867cm, a transition dated to 9230 +/-90 B.P. (GrN-12591)(Parkes and Bradshaw, personal communication). Fen peats dominated by Phragmites australis, Salix spp., Osmunda regalis and Filipendula ulmaria merges into ombrotrophic Sphagnum peat with Calluna and Cyperaceae at 570cm. This transition has been dated to c.5100 B.P.

No macrofossil analyses have been undertaken, although preliminary palynological investigations indicate marked declines in Corylus, Alnus, Ulmus and Quercus at c.2000 B.P. (Parkes, unpublished data). Observations of 15 Irish raised mire profiles led Mitchell (1956) to conclude that there was no consistent pollen feature upon which to base a line of demarcation between the Subboreal and Subatlantic.

Tubriddy (1984) presents detailed information on the contemporary flora and fauna. Comparison with other Offaly mires has shown the Mongans flora to be particularly diverse. The presence of Pleurozium schreberi, Carex panicea and Sphagnum imbricatum indicates an oceanic influence with a pronounced similarity to more western sites (Bellamy and Bellamy, 1966). In contrast, the isolated occurrence of Rhynchospora fusca in the centre of intermittantly dry pools and Sphagnum fuscum on hummocks forms a more continental facies. The predominant influence remains oceanic and this is reflected in the climatic regime.

Meteorological records are available for Birr (53° 05'N, 07° 53'W, 70m O.D.), located 24km to the south of Mongans. The predominance of west to south-westerly winds associated with a high frequency of depressions generates generally mild, wet conditions. Estimates of average annual precipitation vary between 859mm and 897mm (Meteorological Office, 1972; Wernstedt, 1972). Precipitation increases northwards with Athlone receiving 939mm per annum. Distribution remains constant throughout the year, although values in Spring may be marginally lower. Mean annual temperatures rarely exceed 9.5°C, with absolute extremes of 26.4°C and

-11.6°C (Kalb and Noll, 1980). High rainfall combined with mild temperatures generates an environment characterised by high relative humidities, on average around 91% throughout the year, and long effective vegetative season.(*)

Two monoliths were taken from a south facing peat cutting some 125m from the approximate mire centre. Contrary to the observations of Tubriddy (1984, p.19) field analysis revealed that the upper unhumified peats were particularly well preserved.

4.22 FLANDERS MOSS, STIRLINGSHIRE (56°10'N, 4°11'W, 20m O.D.)

Although large tracts of raised mire have developed in the north west and central lowlands of Scotland, most have been exploited for agricultural or fuel purposes (Moore, 1977). An increasing number are currently being afforested and few sites remain undamaged. Several sites were investigated, including Claish Moss, Argyll, Bloak Moss, Ayrshire and Flanders Moss, Stirlingshire.

Flanders Moss in the upper Forth valley displays a distinct MHC which may be traced across the whole of the extensive deposit. The peat immediately below the boundary has been dated to 2712 +/- 120 B.P. (Q-541/2/3) (Godwin and Willis, 1962) and is marked palynologically by a permanent decline in Corylus frequencies (Durno, 1956; Turner, 1965).

Whilst recognised as the most extensive development of raised mire in

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(*)

Effective Vegetative Season : The actual vegetative season minus periods when the mire surface is too dry to permit active growth of hummock Sphagna.

Britain (Durno, 1956; Ratcliffe, 1977) there is a surprising paucity of information regarding the site. Ratcliffe (1977) notes that the complex at one time extended eastwards towards Stirling, but following agricultural reclamation is now confined to an area of 1500ha in the upper Forth valley. The largest single unit, East Flanders Moss, covers an area of 245ha. The Menteith moraine divides the complex into two distinct units. To the west, the group of mires referred to as West Flanders Moss have been afforested, whilst to the East, both Poldar and East Flanders Mosses have been drained awaiting afforestation. The vegetation has been substantially modified and is dominated by <u>Calluna vulgaris</u> and other vascular species. The distribution of <u>Sphagnum</u> is largely discontinuous, field observations indicating that <u>Sphagnum magellanicum</u>, <u>S. papillosum</u> and <u>S. capillifolium</u> are the most abundant. <u>S. imbricatum</u> and <u>S. fuscum</u>, identified by Ratcliffe (1977), were not found in July 1985. The continued presence of <u>Ledum groenlandicum</u>, a rare northern acidophilous mire species, must increasingly be threatened.

Available climatological information for the upper Forth valley is poor (Halstead, 1956). The nearest recording station is located in Stirling approximately 16km to the east. Here average annual precipitation is 963 mm, with October and December the wettest months and the period February to June the driest. This drier phase is several months longer than is generally experienced in the British Isles. Westwards towards the Trossachs rainfall increases, as altitude exerts an increasingly stronger control over the rainfall regime. Accordingly, the mean annual total for a gauge located on the surface of West Flanders Moss (NS 562959, 15m O.D.) is 1369mm (Meteorological Office, 1986). The distribution is also somewhat at variance with Stirling, with wetter periods in early Spring and late Summer. Temperature data is only available for Stirling, the mean daily temperature being 9.0°C with an absolute range of 30.6°C and -13.9°C (Meteorological Office, 1972).

Following examination of the available drainage ditches, it was decided to sample the central plateau of East Flanders Moss using a wide diameter corer (Barber, 1984). A series of overlapping core samples extending to 350cm were taken. The Marine clay which underlies the complex was encountered at 732cm (cf. Durno, 1956).

4.23 TREGARON BOG, DYFED, WALES. (52°15'N, 3°56'W, 62m O.D.)

Tregaron is an extensive raised mire complex occupying a 6km length of the Teifi valley in mid-Wales. The three mires which constitute the complex, the West, South-East and North-East bog, cover an area of some 792ha and form the largest tract of virgin raised mire in the British Isles. The site was given Grade 1 status by Ratcliffe (1977). Subsidiary mires to the south and north may formerly have been present. Their destruction is most likely the result of the extraction of peat for fuel and agricultural reclamation (Nature Conservancy Council, 1984).

Ecological and stratigraphic studies have been undertaken by several workers. Following the preliminary observations of Erdtman (1928), a transect of 32 boreholes taken across the South-East and West bogs by Godwin and Mitchell (1938) revealed shallow Devensian Lateglacial lake sediments underlying the complex. They postulated that a series of recessional moraines deposited in the region of Tregaron village had impeded the flow of the Teifi, causing lake formation. Sediment accumulation formed what is today recognised as a classic sequence from fen peats dominated by <u>Phragmites australis</u> followed successively by <u>Betula</u> woodland with <u>Juncus</u> spp. and <u>Eriophorum</u> spp. and culminating in ombrotrophic <u>Sphagnum</u> peat formation. Hibbert and Switsur (1976) dated the clay-fen peat transition to 10,200 +/- 220 B.P. (Q-930) and the shift to ombrotrophic peat at 6530 +/- 110 B.P. (Q-939). They suggest a mean accumulation rate between 10,000 and 3,000 B.P. of 19.5 y/cm.

Godwin and Mitchell (1938) and later Turner (1964; 1965) noted the conspicuous transition from highly humified to poorly humified peat. Believed to correspond to the pollen zone boundary F2-G, later recognised as the Subboreal-Subatlantic transition (Godwin, 1960), the mean of two dates taken immediately above and below the horizon were 2646 +/- 70 B.P. (Q-388) and 2954 +/- 70 B.P. (Q-389) respectively (Godwin and Willis, 1962).

Turner (1964) attributed the difference of 308 +/- 110 years between the means to a cessation of accumulation or surface erosion.

Whilst the decline in *Corylus* identified elsewhere in Europe (Mitchell, 1956; Van Geel, 1978) may be recognised in the pollen diagrams of Godwin and Mitchell (1938) and Turner (1964), the fall is less marked and of a temporary nature. More diagnostic indicators are the disappearance of *Tilia* and pronounced expansion of *Betula*.

More recently, Hibbert and Switsur (1976) have demonstrated that a marked change from humified *Sphagnum-Eriophorum* peat to less well humified Sphagnum-Eriophorum peat identified in a profile taken from the same area as Turner (1964) could be dated to 4695 +/- 52 B.P. (Q-945). No attempt is made to correlate this feature with that identified by either Godwin and Mitchell (1938) or Turner (1964).

Sphagnum imbricatum, once the dominant peat former, is currently restricted to localised hummocks on Borth Bog, 27km to the north-west. The contemporary surface, described in detail by Godwin and Conway (1939), consists of a mosaic of *Sphagnum papillosum*, *S. pulchrum*, *S. cuspidatum* and *S. tenellum* with *Calluna vulgaris*, *Erica tetralix*, *Empetrum nigrum*, *Eriophorum vaginatum*, *Eriophorum angustifolium*, *Trichophorum caespitosum* and *Rhynchospora alba*. *Narthecium ossifragum* and *Andromeda polifolia* though present, do not form major associations. The spread of *Molinia caerulea* over large areas of the south-east bog is attributed to disturbance resulting from either burning, peat cutting or grazing (Ratcliffe, 1978).

Rainfall data is available for several localities adjacent to the mire complex, and mean annual totals of 1236mm, 1298mm, 1326mm and 1505mm have been recorded at Tregaron, Fullbrook Mill (SN 669625, 178m O.D.), Swydd-ffynon (SN 693654, 168m O.D.), Tregaron, Ty-coed (SN 688619, 213m O.D.) and Strata Florida (SN 755659, 223m O.D.) respectively. The pattern of rainfall is similar at each, with the months November to January the wettest and the spring months the driest.

The sea reaches its lowest temperature in late February/early March so that around the coasts February is normally the coldest month. The lowest mean daily temperatures in these months range from 2°C to 3.5°C and clearly reflect the modifying influence of the ocean. The extreme minimum temperature recorded is -11.1°C (Meteorological Office, 1972, 1984). July is normally the warmest month, and an extreme maximum of 31.1°C has been recorded. Mean daily temperature is 9.6°C. Average annual evaporation is about 430mm at the Welsh Plant Breeding Station (285m O.D.), giving an approximate P/E ratio of 3.1 and high relative humidity with averages around 90% for much of the year. A high incidence of south-westerly winds and frontal depressions leads to a markedly oceanic climate with a long effective vegetative season.

The available peat faces were highly degraded and marginal. Accordingly, a wide diameter Russian core (Barber, 1984) was taken from the approximate centre of the South-East bog in July 1985. This was followed by a second core taken from the centre of the West bog in May 1986. Separate macrofossil analyses were undertaken on each profile. Contrary to the observations of Godwin and Conway (1939), pool complexes were largely absent from the contemporary surface of the West bog.

4.24 BOLTON FELL MOSS, CUMBRIA (55°01'N, 2°47'W, 110m O.D.)

The area defined as the Cumbrian Lowland (Walker, 1966) is mantled by a thick cover of glacial drift, and in coastal areas by marine alluvium. Hollows in the glacial and marine deposits support a variety of mire deposits, including a number of extensive raised mire systems (eg. Wedholme Flow, Glasson Moss, Butterburn Flow). A detailed review of the geology of the area is provided by Walker (1966) and Day et al. (1970).

Contemporary and palaeoecological investigations have been undertaken on Glasson Moss (Ratcliffe and Walker, 1958; Walker, 1966), Coom Rigg Moss (Chapman, 1964a; 1964b; 1965), Scaleby, Oulton, Moorthwaite and Abbot Mosses (Walker, 1966) and more recently, Barber (1981) has tested the cyclic regeneration theory of Osvald (1923) at Bolton Fell Moss using a macro- and pollen-analytical approach.

The demonstrated ability of Bolton Fell Moss to react sensitively to climatic change (Barber, 1981) led the author to focus attention upon this site, a 400ha raised mire located 8km to the north of Brampton and 12km east of Carlisle. Since the site has been amply reviewed by Barber (1981) it is not intended to present a detailed site history. However, since Barber worked on the site during the late 1960's important modifications have occurred. Mechanised peat extraction extends across much of the former mire plane and the uncut south-west quadrant noted by Barber (1981) is now largely degenerate. Water table lowering caused by peripheral drainage has permitted the expansion of *Calluna vulgaris* and establishment of *Pinus sylvestris*. Whilst areas dominated by *Sphagnum* still remain, cover is discontinuous. The intact *Sphagnum*-rich communities contain *S. magellanicum*, *S. capillifolium* and occasional *S. cuspidatum* with *Eriophorum vaginatum*, *Eriophorum angustifolium*, *Erica tetralix*, *Narthecium ossifragum*, *Rhynchospora alba* and *Vaccinium oxycoccus* in varying degrees of abundance. *Sphagnum imbricatum*, once an important peat forming community at the site (Barber, 1981), was not recorded.

Barber (1978, p.183) noted the presence of the MHC at Bolton Fell Moss and correlated it with RY II of Granlund (1932) c. 1600 B.P.

The nearest meteorological station is located at Carlisle. Precipitation data exist for Willow Holme sewage works (NY 388566, 12 m O.D.) and the 24-hour reporting station (NY 384603, 26 m O.D.). Mean annual totals of 825mm and 871mm have been recorded for the period 1941-70 respectively. Although south-westerly winds predominate, the rain-shadow effect of the Lake District is evident. Increased monthly totals between September and January reflect the dominance of south-westerlies and the high incidence of south-easterly winds due to funnelling down the Eden Valley (Meteorological Office, 1985). Mean annual temperature is around 9.5°C. January is the coldest month with mean daily minima about 1.5°C whilst mean daily maxima are highest in July ranging from 18-20°C. Relative humidity averages about 85% over the year, although values in excess of 95% occur for around 15% of the time. This generates a moist environment with long effective vegetative season.

Drainage ditches in the north-eastern and north-western sectors of the site were studied. The division between upper and lower peats was marked, and was in many places characterised by a horizontal layer of vivid green pool muds indicative of widespread surface flooding. Two monoliths were obtained from a representative section in the north-eastern quadrant.

4.25 WHIXALL MOSS, SHROPSHIRE (52°55'N, 2°46'W, 90m O.D.)

The Whixall Moss complex is 23 km due north of Shrewsbury and occupies a shallow Lateglacial basin underlain by till of varying thickness (Pocock and Wray, 1925) and at 1820ha forms the largest expanse of ombrotrophic peatland in Shropshire (Sinker, 1962). The Welsh border dissects the site, separating the southern sector called Whixall Moss in Shropshire, from Fenn's Moss in Clywd. The two mosses are contiguous however, and trial borings undertaken by Hardy (1939) suggest contemporaneous development. To the south of Whixall/Fenn's Moss lie two smaller subsidiary mosses, Cadney Moss and Wem Moss. The latter was given Grade 1 status by Ratcliffe (1977) and is described in detail by Slater (1972). Bellamy et al. (1960) present a background to the meres and mosses of this area.

The development of Whixall Moss was systematically investigated by Hardy (1939). A suite of boreholes across Whixall/Fenn's Moss and Wem Moss display a classic sequence from lake sediments, through eutrophic fen peats rich in _Menyanthes_, _Phragmites_ and _Betula_, grading into ombrotrophic _Sphagnum_ peat. Towards the mire margins, lake sediments are frequently absent, and Sinker (1962) suggests that this may reflect the transgressive nature of these peats. Pocock and Wray (1925) estimated the total peat thickness at between 4.5m and 9.0m. However, Hardy (1939) failed to record more than 3.40m of peat on the untouched central dome of Fenn's Moss. Test borings undertaken by the author in 1985 on the Whixall/Fenn's Moss boundary, some 700m distant from those of Hardy, located glacial sands at 3.27m. This variability most probably reflects the continued shrinkage of the peat following extensive drainage.

Exploitation of peat for fuel and horticultural purposes extends across the entire surface, such that the uncut area noted by Sinker (1962) towards the southern margins is now much degraded. Traces of the former hummock-hollow topography in this region have largely been removed by recurrent burning and continued drainage, allowing mixed communities of *Betula pubescens*, *Calluna vulgaris* and *Molinia caerulea* to become established. *Molinia*, once deliberately seeded in an attempt to consolidate the trackways used to remove cut peat (Sinker, 1962), colonises large tracts of the contemporary surface, and together with *Pteridium aquilinum* has become a considerable problem to the continued extraction of peat. *Sphagnum*, largely absent from these areas, is presently restricted to water-filled abandoned peat cuttings. *Sphagnum* sect. *Cuspidata* (*S. cuspidatum* and *S. recurvum*) and *S. papillosum* occur together with *Eriophorum angustifolium*, *E. vaginatum*, *Rhychospora alba*, *Narthecium ossifragum* and *Erica tetralix*. A detailed flora is presented by Sinker (1962).

A layer of pine stumps is entombed within the lower, highly humified peat. This layer, first described by Hardy (1939) and thereafter referred to as the 'Hardy Pine Stump Layer', is found throughout the Whixall/Fenn's Moss complex and is distinct from an upper and lower *Betula* horizon. The discovery of a bronze looped palstave resting on the roots of an in-situ pine led Chitty (1933) to suggest that the forest dated from the Middle Bronze Age, c.2500 b.p. This view was later supported by Turner (1964), who dated a stump believed to correspond with the Hardy pine stump layer to 2307 +/- 110 B.P. (Q-383).

The nearest meteorological station is based in Shrewsbury (52° 4'N, 2° 45'W). where a mean annual precipitation of 659mm has been recorded (Meteorological Office, 1972). Precipitation data for Whitchurch (Fenn's Bank, 81.3m O.D.) for the period 1916-1950 indicate a mean annual precipitation of 704mm (Meteorological Office, 1958). August to November are commonly the wettest months and the period February to April the driest.

The mean annual temperature over the region is 9.5° C. January is the coldest month in the Midlands with mean minimum temperatures varying from just below 0° C to over 1.5° C. An absolute minimum of -26.1° C has been recorded at Newport, Shropshire in January 1982 (Meteorological Office, 1986). July is the warmest month with mean daily temperatures as high as 21.5°C. An absoulute maximum of 31.7°C has been recorded (Meteorological Office, 1972).

These figures reflect the intermediate position of northern Shropshire, with similarities to the milder oceanic winters experienced in western Britain and warm continental summers of eastern areas.

Two aluminium monoliths were taken from a south easterly facing peat cutting some 900m from the Morris Bridge entrance. Located in the approximate centre of the former mire plane, this site is within 400m of the locality sampled by Turner (1964) (Turner, personal communication).

4.3 THE LOW COUNTRIES OF NORTHERN GERMANY AND THE NETHERLANDS

Though there is little topographic variation over northern Germany and The Netherlands, there is a transition from north western sites dominated by Sphagnum imbricatum to Sphagnum fuscum dominated south eastern mires. This reflects the diminishing modifying effects of the sea bordering western Europe. The contemporary climate is more extreme in the east; there is a greater annual and diurnal range of temperature, and in particular a much more severe winter. In addition, there is rather less precipitation, especially in winter when it takes the form of snow, which lies for several months but does not reach a great depth. The air is on the whole drier, and there is an increasing tendency to long periods of drought, clear skies and settled fine weather.

Annual rainfall decreases from c.760mm on the North Sea coast at Winterswijk (51° 58'N, 6°43'E), Neuenberg (53° 28'N, 8° 00'E) and Bederkesa (53°38'N, 8°52'E) to c.640mm at Nienburg (52° 39'N, 9° 13'E) and Celle (52° 39'N, 10° 06'E) (Hellmann, 1921; Kalb and Noll, 1980). An autumn maximum and April minimum characterises the narrow coastal strip, whilst a pronounced July maximum and January/February minimum is more typical in continental areas (Alt, 1932).

The control of temperature by latitude is slight and the effective control becomes distance from marine influences. This influence is most powerful in January when the North Sea region experiences a relatively mild climate with temperatures just above freezing. During the vegetation period, typically May to September, the pattern is reversed with coastal areas experiencing mean daily temperatures of 14.3-14.5°C and eastern regions 15.1-16.0°C (Deutscher Wetterdienst, 1964; Meyer and Schirmer, 1985). Mean annual temperatures of 8-9°C disguise an absolute range which may vary between 38.0°C and -28.5°C in Hannover (52° 20'N, 9° 43'E) to 34.4 and -23.7°C in Emden (53° 22'N, 7°13'E). Thus, whilst in coastal areas, precipitation exceeds potential evapotranspiration and moisture deficits are uncommon during the growing season, eastern sites experience periods of drought, manifested in a shorter effective vegetative period.

Based upon such climatic gradients, seven profiles representing a continuum from oceanic to continental conditions were sampled in the northern German/Netherland lowlands. Raised mires located in the northern and central Harz mountains were excluded on altitudinal grounds, though the existence of a 'Grenzhorizont'-type feature has been demonstrated at several sites (Beug, 1982).

4.31 THE ENGBERTSDIJKSVEEN, THE NETHERLANDS (52°58'N, 6°39'E, 23m O.D.)

During the mid-Holocene, extensive raised mire complexes developed along the Dutch-German border in the depressions separating Lateglacial coversand ridges (Van Geel et al., 1980/1981). Two of these complexes, the Engbertsdijksveen 10km north of Almelo and the Meerstalblok (52° 41'N, 7° 02'E) 9km south east of Emmen were sampled in April 1986 under the guidance of Van Geel and Van Der Hammen of the University of Amsterdam.

Early palynological studies on the Engbertsdijksveen were published by Florschutz and Wassink (1935) and Florschutz (1957). More recently exhaustive palaeobotanic and isotopic analyses have been undertaken by Van Geel (1976, 1978); Casparie et al. (1981); Dallmeijer (1981); Goris and Knoll (1981); Brenninkmeijer et al. (1982); Middeldorp (1982); Brenninkmeijer (1983); Dupont and Brenninkmeijer (1984); Wijmstra et al. (1984) and Dupont (1986). An entire profile of the Engbertsdijksveen has been analysesd for micro- and macro-fossils with a resolution of 1cm by Van Geel (1978). These studies have demonstrated that peat formation was initiated following paludification of cover sands at 6225 +/- 45 B.P. (GrN-7305). Mesotrophic peats rich in *Juncus effusus*, *Carex rostrata*, *Scheuchzeria palustris* and *Salix* spp. were succeeded by ombrotrophic *Sphagnum* peats about 3500 y B.P. Although a major recurrence surface, equated with the MHC, has been noted by several workers (Van Geel, 1978; Casparie et al., 1981; Dupont and Brenninkmeijer, 1984) radiocarbon dates show that since 3945 +/- 35 B.P. (GrN-6816) the mire has displayed a remarkably uniform accumulation rate of circa 12.5 y/cm. In addition, the transition from highly humified to poorly humified peat is marked by a series of discrete *Sphagnum cuspidatum*-rich bands. These have been correlated with cyclic fluctuations in the pollen curve of *Corylus avellana* by Van Geel (1978), the minima of which indicate colder and wetter Spring conditions. Similar observations were made in the section Wietmarscher Moor III (Van Geel, 1972). Fluctuations in the order of 150-200 historical years have been postulated.

Post-MHC peats are characterised by a permanent decline in *Corylus* frequencies and a transition from *Sphagnum* section *Acutifolia* (*S. capillifolium*) to *Sphagnum* section *Cymbifolia* (*S. papillosum* succeeded by *S. imbricatum*) peats. Recent isotopic measurements by Breninkmeijer et al. (1982) and Dupont and Brenninkmeijer (1984) have confirmed that a decline in the deuterium and O-18 curve coincides with the appearance of the hygrophilous *Sphagnum papillosum*. This period of increased surface wetness has been dated to 2815 +/- 55 B.P. (GrN-7321) by Van Geel (1978) and 2650 +/- 55 B.P. (GrN-10999) by Dupont and Brenninkmeijer (1984).

The longevity of the *Sphagnum papillosum* phase varies across the mire.

Observations by Van Geel (1978) indicate that S. papillosum formed the habitat dominant for approximately 100 years before being replaced by S. imbricatum, whilst Dupont and Brenninkmeijer (1984) identify a similar phase lasting some 700 years. A similar sequence of Sphagna has been recorded for the Meerstalblok by Dupont (1986). From the analysis of hummock and hollow sequences, Dupont has convincingly demonstrated that the growth of Sphagnum imbricatum started almost 1000 years later in hollow situations than it did on hummocks. Thus, variations between diagrams most probably reflects the sampling location with regard to hummock and hollow facies, bearing in mind the observed preference of Sphagnum imbricatum for 'drier' situations (Schumaker, 1958; Green, 1968; Daniels and Eddy, 1984).

With help from Dr Van Geel, a large pit was excavated on the burnt surface of the Engbertsdijksveen and two monoliths spanning the MHC were obtained. This profile was located some 200m west of Engbertsdijksveen I (Van Geel, 1978) and 800m north of Engbertsdijksveen VII (Dupont and Brenninkmeijer, 1984). Additional material was collected from the profile sampled by Dupont (1986) in the Meerstalblok. Time restrictions prevented analysis of this second section.

4.32 GERMANY

4.32.1 JUHRDENER MOOR (53°20'N, 8°00'E, 16.5m O.D.)

Lying 30km to the south west of Wilhelmshaven, the site covers 1120ha, of which 1090ha is designated raised mire and 70ha transition mire (Schneekloth and Tuxen, 1975). Palynological studies (Pfaffenburg, 1942) have shown that peat was initiated c.7000 years B.P. A transitional peat matrix underlain by estuarine silts and clays and composed of Sphagnum spp. with Pinus sylvestris and Betula pubescens, is succeeded by a discrete layer of Sphagnum cuspidatum-Scheuchzeria palustris peat. Above this lies 1.6m of highly humified and 0.8m of poorly humified peat. No macrofossil investigations have been undertaken, although Schneekloth and Tuxen (1975) note that the upper peats are composed of a Sphagnum sect. Cymbifolia-Sphagnum sect. Acutifolia admixture.

The area has been extensively cut and deep ploughed for agriculture, but where the surface of the former mire plane remains intact, it is dominated by Ericaceae (Calluna vulgaris and Erica tetralix), Molinia caerulea, Betula pubescens, Pinus sylvestris and Myrica gale.

With the help of Prof. Dr. K.-E. Behre at the Niedersachsisches Landesinstitut fur Marschen- und Wurtenforschung, Wilhelmshaven, two monoliths were obtained from a south facing peat cutting located in the former mire centre.

4.32.2 AHLENMOOR (53°42'N, 8°46'E, 0m O.D.)

Based upon work by Baden and Grosse-Brauckmann (1958), Baden et al. (1962) and Schneider (1962), Muller (1965) produced a vegetation map accompanied by preliminary stratigraphic details for the site. Subsequent studies supported by radiocarbon datings (Korber-Grohne, 1967; Schneekloth, 1968, 1970; Behre, 1976) have provided more detailed palaeoecological information. Situated in the confines between Holocene marsh land and the moraines of the penultimate ice age (Riss-glacial), podsolization of the underlying Pleistocene sands facilitated peat initiation c.7000 years B.P. Pollenanalytical datings (Schneekloth, 1970; Meyer and Schneekloth, 1973) indicate that highly humified peats were formed during late Atlantic and early Subboreal times. These deposits attain a maximum thickness of 3m, although over much of the mire rarely exceed 1-2m (Schneekloth, 1981).

The boundary between highly humified and poorly humified peats has been dated by several workers. These studies have shown that the chronological position of the MHC may vary considerably according to sampling locality.

Radiocarbon dates obtained by Schneekloth (1968) suggest that the MHC may have formed at any time between 2140 +/- 190 B.P. (Hv-197) and 2500 +/- 100 B.P. (Hv-2034). Conflicting results have been presented by Korber-Grohne (1967) who, based on two overlapping sequences 100m apart, dated the highly humified peat below the MHC to 2910 +/- 70 B.P. (GrN-2285). Material from the lower layers of the unhumified peat, but not directly above the boundary, was dated to 2125 +/- 50 B.P. (GrN-2286) a date inseparable with those of Schneekloth (1968). Schneekloth (1968, 1970) attributes such variability to internal differences in the hydrographical, morphological and bioecological conditions of the mire. Both studies were based on borehole data however, and the possibility of stratigraphic confusion cannot be discounted. These arguments have been developed more fully in Section 2.1

Poorly humified peat, identified as Sphagnum imbricatum by Schneekloth (1981), extends to a depth of 1-2m. Although up to 1750ha of the total area of 3960ha are currently being exploited for commercial purposes, areas of semi-natural vegetation still remain. Typical associations have been discussed by Ekkehart (1976).

Two monoliths were obtained from a drainage ditch in an area currently awaiting cutting. This profile is located 1000m north east of the Ahlenmoor V section studied by Behre (1976).

4.32.3 EKEL MOOR (53°16'N, 9°16'E, 36m O.D.)

Covering an area of 1220ha, Ekel Moor lies 7km to the west of Tostedt. Little palaeoecological information is available for the site. In a provisional pollen diagram, Overbeck (1942) demonstrated that the mire had developed over podsolized coversands during the late Atlantic. More recent investigations (Overbeck, 1975; Schneekloth and Tuxen, 1978) have shown that a basal Betula-Pinus peat is succeeded by a highly humified matrix which varies in depth between 1.3-2.0m according to the underlying topography.

Based on unpublished radiocarbon dates for the transition to ombrotrophic peat (4670 +/- 60 B.P., Hv-13261) and the boundary with the upper poorly humified peat (2210 +/- 65 B.P., Hv-13259), the pre-MHC peats have been shown to have accumulated at a rate of 22.4y/cm (J. Schwaar, personal communication). Schneekloth and Tuxen (1978) state that the post-MHC peats, which rarely exceed 1.0m in thickness, are entirely composed of *Sphagnum* of the section *Cymbifolia*.

An attempt was made to sample the profile examined by the International Peat Society in 1985 and for which unpublished radiocarbon dates existed. This was prevented by the presence of sub-surface ice. Accordingly, a south facing profile 200m to the south west of the IPS section was sampled using monoliths. This section is located in the approximate mire centre, and in an area currently being exploited for milled peat.

4.32.4 LICHTENMOOR (52°42'N, 9°23'E, 22m O.D.)

Stratigraphic details for this site, which lies 8km to the north east of Nienburg and covers an area of 3800ha, have been presented by Schneekloth and Schneider (1970). Developed directly over podsolized sand hollows and flats, the mire attains a maximum peat thickness of 4.3m. The poorly humified peat, which may extend to a depth of 3.0m, is principally composed of Sphagna of the section *Acutifolia*. There is no published palaeoecological or chronostratigraphic information for the site.

Large tracts of the former mire plane have been exploited for commercial purposes, generally to a sub-MHC level. The absence of suitable central sites necessitated the cutting of a profile into the wall of a drainage ditch 600m from the mire centre. Following field examination, this was sampled using a series of overlapping monoliths.

4.32.5 TOTES MOOR (52°34'N, 10°39'E, 42m O.D.)

Totes Moor is the largest unit in an extensive mire complex 2.8km to the west of Neustadt. Underlain by podsolized sands, except in the eastern quadrant where transgression over sandy-limnic sediments deposited by the Steinhuder Meer has occurred, the Moor presently covers 2700ha. Working on a 2.8m profile, Schneekloth (1968) has pollen-analytically dated peat inception to 3500 years b.p. The lower fen peats vary in thickness between 0.8m in southern areas to over 2.0m in the north. Ombrotrophic deposits display similar depth variability.

The lower highly humified peats are characterised by a discrete layer of pine stumps situated 0.5m below the MHC. These were first described by Birk (1914) and more recently by Tacke and Keppeler (1941). In an extensive review of the distribution and mode of preservation of pine layers in German mires, Hayen (1960) postulates that the Totes Moor pines were killed following a rapid rise in the mire water table. The subsequent identification of a _Scheuchzeria palustris_-_Sphagnum cuspidatum_ layer directly above the MHC by Overbeck (1975) supports this theory. There are no radiocarbon dates for either the pines or this horizon.

Where present, the upper post-MHC peats attain a maximum thickness of 2.5m. Birk (1914) and Schneekloth and Schneider (1970) identify these upper peats as being composed of Sphagna belonging to the section _Acutifolia_. The present surface is largely degenerate, and areas left following commercial extraction have become colonised by _Betula pubescens_ and _Molinia caerulea_.

Following examination of a series of drainage ditches, a representative section was sampled using monoliths. This profile was located 1800m to the north east of Steinhuder Meer.

4.32.6 GIFHORN MOOR (52°32'N, 10°36'E, 57m O.D.)

Gifhorn Moor has an area of circa 5000ha and belongs to the continental raised mire area of Central Europe, having a 'fresh' *Sphagnum* peat which is predominantly composed of *Sphagnum fuscum*. A series of stratigraphic (Potonie, 1908; Weber, 1930) and pollen-analytical (Selle, 1936; Overbeck, 1952; Overbeck and Schneider, 1940; Kubitzki, 1961) studies have been undertaken. Overbeck (1950), Overbeck et al. (1957) and Schneekloth (1965) have focused specifically on the formation of the MHC.

Developed over podsolized sands during the Boreal, fen peats are succeeded by felted layers of *Scheuchzeria palustris* which in turn grade into a highly humified matrix. These pre-MHC peats vary in thickness between 1.5-2.0m and in the south of the Weisses Moor are characterised by a less humified band 50-90cm thick. This lower boundary was first described by Potonie (1908) and is accordingly referred to as the "Potonie Kontackt". Overbeck et al. (1957) date the peat below the boundary to 4040 +/- 150 B.P. (H-119/103). Preliminary macrofossil investigations (Overbeck, 1950) show that the lower peats are composed of *Sphagnum* sect. *Acutifolia*, most probably *S. fuscum*. Small amounts of *Sphagnum magellanicum* may also be identified. A thin layer of greasy pool muds rich in *Sphagnum cuspidatum* and *Scheuchzeria palustris* mark the transition between highly and poorly humified peat. The post-MHC peats are almost entirely composed of *Sphagnum cuspidatum*. The appearance of hydrophilous rhizopods such as *Amphitrema flavum*, *Assulina muscorum*, *Hyalosphenia papilio* and *Arcella* spp. indicate conditions of extreme wetness at this time (Grospietsch, 1952).

Dating of the MHC has been undertaken by several workers and a variety of ages has been obtained. From a borehole located in the centre of the mire (Profile V) Overbeck et al. (1957) dated the peat below the MHC to 2100 +/- 100 B.P. (Hv-71/85) and the immediate post-MHC peats to 2050 +/- 110 B.P. (Hv-72/88). Subsequent material removed from below the MHC in a core 300m to the northwest was dated to 2131 +/- 157 B.P. (CWU-19)(Overbeck, 1975). Similarly, Schneekloth (1965), working on an 8000m north-south transect of the mire showed that unhumified peat inception had occurred between 2345 +/- 110 B.P. (Hv-462) and 1400 +/- 75 B.P. (Hv-21). Overbeck (1975) notes that whilst the marginal nature of many of the cores obtained by Schneekloth (1965) may have influenced the date of the MHC, more detailed studies are needed to demonstrate the possible influence of sample location on recurrence surface formation.

Much of the mire has been cut for horticultural peat and little, if any, of the former surface is preserved in its virgin state. Several long profiles created by these activities were examined in detail, and a series of overlapping monoliths were obtained from a representative section 300m to the west of Profile V of Overbeck et al. (1957).

4.4 SCANDINAVIA

4.41 BOLLING BOG, DENMARK (56°11'N, 9°22'E, 68m O.D.)

Peatland covers approximately 3% of the land area of Denmark (Aaby, 1986). Since the pioneer studies of Dau (1829) geobotanical studies have furnished detailed information on Danish regional vegetational history (see for example the reviews presented by Andersen, 1967, 1978; Iversen, 1967). Most workers have concentrated upon pollen-analytical approaches, and few direct macro-analyses have been published. Those of Aaby and Tauber (1974) and Aaby (1976, 1978) deserve mention.

Based on 59 calibrated radiocarbon dates, rates of peat formation have been assessed by Aaby and Tauber (1974). In addition, colourimetric analysis of humification degrees, pollen and rhizopod analyses and quantitative abundance estimates of Sphagnum leaves were undertaken. These intensive investigations revealed a series of shifts to wetter surface conditions between 4500 B.P. and 500 B.P. The most pronounced of these shifts has been dated to 1490 +/- 70 B.P. (K-2140) and is marked by a change from Sphagnum cuspidatum dominated peats to peats composed of Sphagnum imbricatum with infrequent Sphagnum papillosum. A corresponding increase in the rate of peat formation from circa 30y/cm to circa 14y/cm was noted.

Extending this work, Aaby (1976, 1978) examined fifteen open sections from six Danish mires and identified a number of periodic palaeoclimatic shifts with a time interval of approximately 250-270 years between the mean values of groups of dates. Several dates do not accord with this rhythm, especially around 3400 B.P. and 4000 B.P., and further studies are needed to check the significance of the apparent periodicity.

At one of the sites investigated by Aaby (1978), Bolling Bog near Silkeborg in central Jutland, shifts to wetter conditions have been recognised at 2405 +/- 107 B.P. (K-735/736), 1500 +/- 108 B.P. (K-734/735) and 970 +/- 105 B.P. (K-1147/1148). Since dated sections were available, study was focused upon this site.

The mire consists of a series of mire complexes in a glacigenic landscape dominated by coversand ridges. The former Bolling Lake where Iversen (1947) identified the Bolling Layer, separates the two largest mire complexes: the Engesvang complex to the north west and the Moselund complex to the south. The site was surveyed in 1942 by Thogersen to assess the available peat resources. The Engesvang complex was found to cover some 170ha and attain a maximum peat thickness of 3.0m, whilst the Moselund complex covered approximately 194ha and extended to 6.0m. More detailed stratigraphic and pollen-analytical information was collected by Iversen in 1947, and although never published, was kindly made available by the Danish Geological Survey. It thus proved possible to locate and sample the profile studied by Iversen on the Engesvang complex.

Interdigitating layers of sand and Gyttja with Phragmites australis characterise the base of the mire. These are succeeded by fen-peats and Sphagnum peat. No date is available for the transition to ombrotrophic conditions. Towards the upper boundary of the lower highly humified Sphagnum peats, Iversen identified a layer of charcoal and postulated that surface conditions were particularly dry at this period. The peat immediately below and above this this transition has been dated to 2430

+/- 110 B.P. (K-735) and 2380 +/- 100 B.P. (K-736) respectively. The unhumified peats are conspicuously intercalated with bands of moderately humified material indicating a tendency towards drier surface conditions at this site. A second recurrence surface has been dated to 1570 +/- 100 B.P. (K-734) and 1430 +/- 100 B.P. (K-733) respectively.

The undisturbed mire surface lacks a distinct hummock-hollow structure, and has a uniform vegetation dominated by Calluna vulgaris, Eriophorum vaginatum and Erica tetralix. The encroachment of Betula pubescens is likely to continue as periphoral drainage continues.

The pollen diagram, derived from the central part of the mire (Iversen, unpublished data) commences during the early Subboreal following the Ulmus decline. Similarities with diagrams produced elsewhere in Denmark (Andersen, 1978; Andersen et al., 1983) and Sweden (Nilsson, 1964b) are apparent. In particular, the appearance and rapid expansion of both Fagus and Carpinus characterise the transition from humified to unhumified peats and form the basis of the division between the Subboreal and Subatlantic.

Located between oceanic influences to the west and continental influences to the east, the Danish climate is characteristically transitional. These differences, although slight, are the chief features of regional variations in climate and are much more significant than differences between the northern and southern parts of the country. Annual rainfall totals of 752mm and 783mm have been recorded for the two nearest meteorological stations at Vesteruig (56°46'N, 08°19'E, 19m O.D.) and Studsgard (56°05'N, 08°55'E, 54m O.D.) respectively (Kalb and Noll, 1980); this is comparable with the amount received in the English Midlands. Precipitation during the latter half of the year is appreciably greater than during the earlier half. This is due to summer thunderstorms and to the fact that although cyclonic activity from the west is greater in winter, the cyclones have easier access to the country in summer. The minimum precipitation occurs in February, and levels remain low until July when they rise towards the August maximum.

Oceanic influences have a profound effect on the temperature regime. During winter months the temperature of the Baltic Sea is lower than that of the North Sea, due to cold continental winds. In summer the differences are less marked and the effect of latitude becomes more apparent. Thus temperatures are higher inland and in the east than in western coastal areas. Lying in a transitional zone between these two influences, Bolling experiences warm summers but cool winters. Absolute maxima and minima of 33.6°C and -22.9°C have been recorded at Vestervig, with a mean annual value of 7.8°C (Kalb and Noll, 1980). Relative humidities are accordingly lower, with mean annual values of 88%.

As noted earlier, it proved possible to locate the section studied by Iversen in 1947. A representative profile towards the centre of the former mire plane was cleared and microstratigraphy examined. Two monoliths spanning the MHC were taken

4.42 AGERODS MOSSE (55° 55'N, 13° 25'E, 55m O.D.) AND YGGERYDS MOSSE (56° 46'N, 15° 27'E, 170m O.D.), SWEDEN

A continuous mountain barrier extending from north to south Sweden, which reduces maritime influences in the east of the peninsula, produces a marked contrast in temperature between coastal areas and the high plateaux, and causes a further contrast between precipitation received on the western slopes and that in the east where a distinct rainshadow effect is experienced. Thus, whilst mean annual precipitation is 593mm in Lund (55° 42'N, 13° 12'E, 73 m O.D.), a total of only 471mm is received in Kalmar (56° 39'N, 16° 23'E, 12 m O.D.) 230km to the east. The distribution remains similar however, with the months June to August the wettest and the spring months the driest (Tioblom, 1876; Andersson, 1970). Mean annual temperatures of 7.9°C in Lund and 7.3°C in Kalmar disguise the absolute range; extreme maxima and minima of 34.0°C and -28.0°C recorded in Lund compare with values of 31.5°C and -31.0°C in Kalmar. The effective vegetative season is correspondingly shorter in eastern areas, and mire surfaces may remain snow covered until early May.

These climatic differences are reflected in the surface vegetation of

Swedish mires. Whilst those in the west display affinities with more western maritime areas, being characterised by an open mire plane dominated by Sphagnum imbricatum and S. papillosum, eastern sites possess more continental facies. In particular, the presence of Pinus sylvestris, Sphagnum capillifolium and S. fuscum on the mire plane with abundant Ledum palustre in marinal lagg areas reflects drier site conditions. Erica tetralix is absent from eastern sites. Such reasons prompted the study of two sites, Agerods Mosse in central Scania and Yggeryds Mosse in eastern Smaland.

Agerods Mosse covers 1500ha and forms the northern unit of a mire complex developed in the Ringsjon lake basin. The stratigraphy has been discussed in detail by Nilsson (1935, 1964a). Following paludification of glacial sands during the Atlantic, gyttja deposits are succeeded by wood peats composed of Betula pubesens and Pinus sylvestris. A short phase of Eriophorum vaginatum dominance is followed by a transition to full ombrotrophic conditions during the late Atlantic. The Sphagnum peat displays a complex series of humification changes and a number of recurrence surfaces have been identified. Using pollen-analytical and radiocarbon methods, Nilsson (1964a, 1964b) postulates seven phases of recurrence surface formation at 4650 b.p., 3700 b.p., 2750 b.p., 2250 b.p., 1300 b.p., 950 b.p. and 550 b.p. Nilsson (1964a) notes the similarity with mires outside Scania and suggests that the majority of levels represent recurrence surfaces of regional significance. The MHC, prominent in the P100 profile dated by Nilsson (1964b), is marked by a shift from Sphagnum cuspidatum peat with Eriophorum vaginatum and Trichophorum caespitosum to one dominated by Sphagnum imbricatum with infrequent Calluna vulgaris. Immediate pre-MHC peats have been dated to 2270 +/- 85 B.P. (St-986), post-MHC peats to 1995 +/- 80 B.P. (St-983) and the boundary itself to 2205 +/- 85 B.P. (St-985). The difference of 210 +/- 115 years between the post-MHC and boundary peats Nilsson (1964b) tentatively attributes to temporary surface erosion.

Pollen-analytically, the Subboreal/Subatlantic transition coincides with a rise in the Picea curve and decline in Alnus and Corylus curves. Fagus and Carpinus increase at the zone boundary and continue with almost continuous curves throughout the Subatlantic. Carpinus reaches its highest values in early Subatlantic time whilst the frequency of *Fagus* rises in more recent history. Similar observations have been made elsewhere in southern Sweden (Fries, 1951; Magnusson, 1964).

Yggeryds Mosse is one of the fourteen principal sites investigated by Granlund in 1932. The untouched raised mire, covering an area of 52ha, rests directly upon podsolized Pleistocene sands and is bounded on its western margin by an esker. The surface vegetation is composed of scattered *Pinus sylvestris* with a ground flora of *Sphagnum capillifolium*, *S. fuscum*, *S. cuspidatum*, *S. balticum*, *Calluna vulgaris* and *Empetrum nigrum*. The lagg is dominated by a mixed *Ledum palustre*-*Pinus sylvestris* association.

The recorded cross-sectional stratigraphy was at variance with that observed by Granlund (1932). Notably, the basal fen peats were thicker and a band of poorly humified *Sphagnum* peat separating the fen peats from the lower highly humified *Sphagnum* peats was identified. An elementary pollen diagram (Granlund, 1932) indicates that the MHC is marked by the expansion of *Picea* and establishment of *Fagus*. There are no published radiocarbon dates for the site.

Open peat sections were absent at both Agerods and Yggeryds Mosse. Accordingly, samples were obtained using a modified Russian-type wide diameter corer supplied by the University of Lund. At Agerods, three cores were taken within 25m of the area sampled by Nilsson in 1951 and 1960, whilst at Yggeryds two cores were removed from the approximate mire centre, adjacent to Profile 6 of Granlund (1932).

4.5 MACHNACZ (53°19'N, 23°15'E, 140m O.D.) AND KURIANSKA BAGNO (53°50'N, 23°20'E, 141m O.D.), POLAND.

The distribution of Polish peatlands, which cover approximately 1,300,000 ha (4.2%) (Zurek, 1976), is related to the area topography developed during the last glaciation. Small peatland complexes have formed in the morainic uplands of the Baltic coastal and Lake districts, and in montane basins in the Malopolska, Carpathian and Sudety Uplands. However, impeded drainage conditions have led to extensive wetland formation in the Central Polish Plain. With the support of Professor H. Okruszko and Dr S. Zurek at IMUZ, Falenty, near Warsaw, one such peatland complex in the Biebrza ice-marginal valley, north eastern Poland, was examined.

The natural fens and raised mires preserved in the Biebrza valley belong to the largest mire complex in Europe. In total, 78.8% of the 195,000 ha are covered by peat deposits (Liwski et al., 1984). Only the elevations formed by morainic islands, dunes or higher fragments of outwash plains form non-peatland areas. Raised mire *Sphagnum*-moss covers some 523ha or 0.6% of the total area.

Occurring in local watershed zones, raised mires are typically composed of a tussock-bog peat that is characterised by its high content of *Sphagnum magellanicum* (Kulczynski, 1949). An admixture of *Sphagnum recurvum* and *Eriophorum vaginatum* with scattered *Sphagnum fuscum*, *Oxycoccus palustris*, *Andromeda polifolia* and *Ledum palustre* may also be identified. *Pinus sylvestris* covers the entire mire plane.

Limited stratigraphic and macrofossil information is available for these virgin mires. No radiocarbon determinations relating to the inception of ombrotrophic peat in this area or their growth rate are currently available. Studies by Bremowna and Sobolewska (1934) suggest that growth may have commenced during the late Atlantic following paludification of small interdunic depressions. More recent investigations (Marek, 1965; Oswit, 1973; Zurek, 1975) support this idea.

Two sites were sampled using a Russian-type corer: Machnacz 23km north east of Bialystok and Kurianska Bagno located 16km west of Augustow. Both mires are located in interdunic depressions and cover approximately 100ha. No palaeoecological information is available for Kurianska Bagno. However, preliminary macrofossil studies have been undertaken on Machnacz by Grabika (personal communication). Following paludification, fen peats dominated by *Carex limosa*, *Drepanocladus fluitans* and *Calliergon giganteum* are succeeded by a highly humified matrix containing *Eriophorum vaginatum* and *Pinus sylvestris*. *Sphagnum recurvum* and *Sphagnum magellanicum* occur in small amounts throughout the profile. Von Post humification values range from 65-70% in a uniform stratigraphy with no apparent MHC-type feature. The catotelm-acrotelm boundary is marked by a shift toward less humified *Sphagnum magellanicum* dominated peats. Caesium-137 dating of the acrotelm (Oldfield, personal communication) reveals an accumulation rate of 7.4y/cm. A comprehensive review of the contemporary vegetation for each study site is presented by Czerwinski (1986) and Sokolowski (1969, 1985).

Available macroclimatic information for the Biebrza ice-marginal valley is poor. Brief reviews have been presented by Pioro (1971) and Kossowska-Cezak (1984). A distinct differentiation is noted in the totals of annual precipitation: the lowest values are recorded in the northern and southern sectors of the valley (low throughout the year, 470-500 mm), whilst the highest occur at the western margin of the Bialostocka Plateau (over 600 mm). The nearest meteorological stations to Machnacz and Kurianska Bagno, Augustow and Krypno, both receive a mean annual precipitation of 531 mm (Kossowska-Cezak, 1984). Temperature and relative humidity patterns are influenced by the westerly air flow. During the winter months there is a temperature drop from south-west towards north-east, in agreement with a general temperature pattern in north-eastern Poland. Thermic conditions in the valley remain similar to the neighbouring plateaux, with mean February minima reaching -5.4°C. A differentiation between these two areas is not noted until summer when mean July maxima may vary by as much as 1° C. Values of 23.6°C are typical for valley situations. Mean annual totals of 6.5°C reflect the short vegetative season (circa 202 days) and high number of days with a snow cover (86-98 days). Air humidities are lowest in June (about 70%) and highest in November and December (about 90%). Studies by Lenart and Przybylska (1973) and Kossowska-Cezak (1984) have shown that marginally increased humidities are associated with the peatland complexes throughout the year.

Table 2. Environmental gradients associated with an west-east transect across north western Europe. Adapted from Damman (1979) and Meteorological Office (1972).

	WEST (maritime)		EAST (continental)
Summer Temperatures	Lower	→	Higher
Precipitation	Higher	←	Lower
Relative Humidity	Higher	←	Lower
Potential Evapotranspiration	Lower	→	Higher
Moisture Deficit In Vegetative Season	Rare	→	Common
Winter Snow Cover	Largely erratic	→	Quasi-permanent
Annual Irradiation	Low	→	High
Effective Vegetative Season*	Long	←	Short

←

Higher moisture surplus
More active *Sphagnum* growth

---

* The actual vegetative season minus periods when the bog surface is too dry to permit active growth of hummock *Sphagna*.

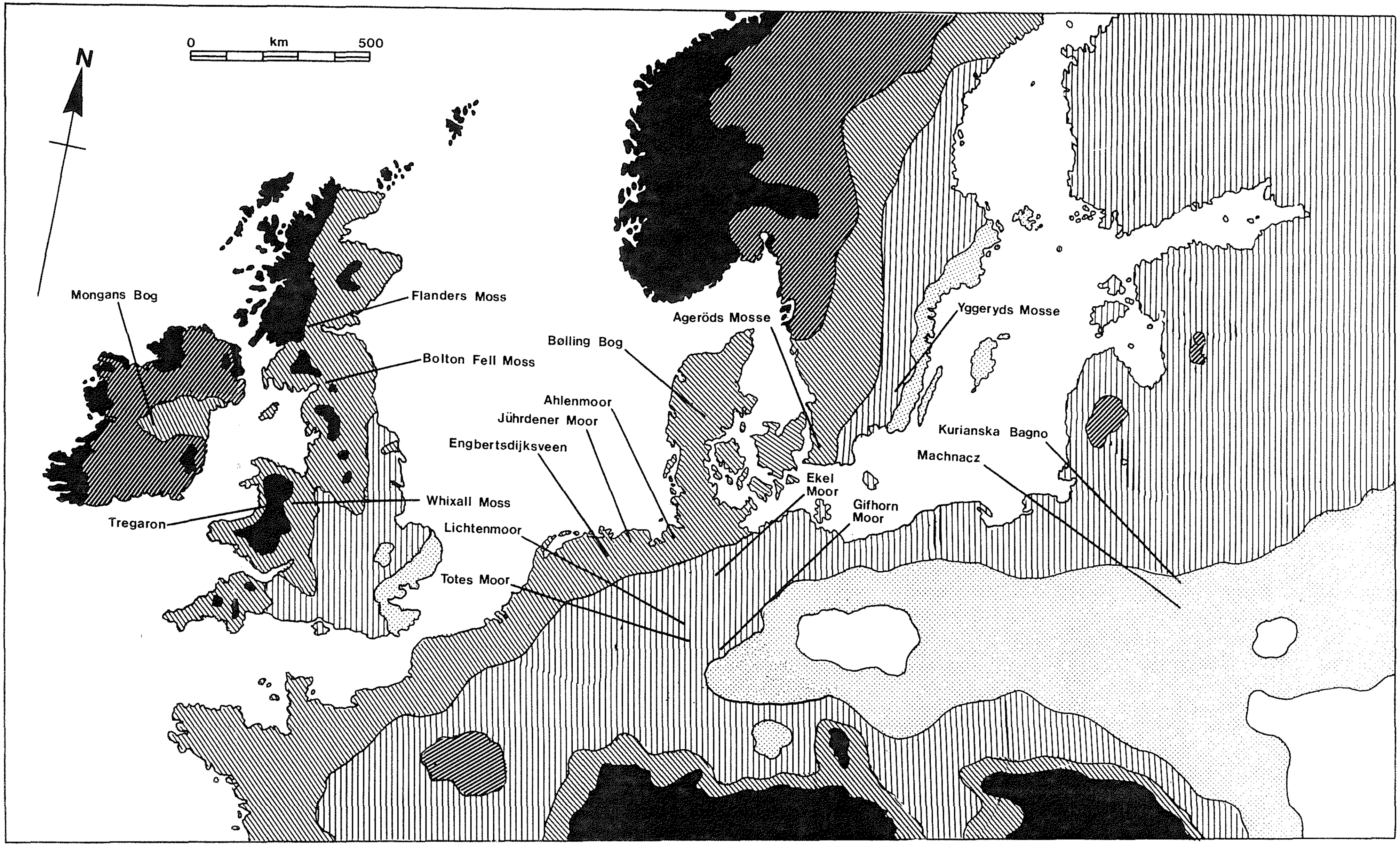


FIGURE 5. THE ANNUAL AVERAGE POTENTIAL WATER DEFICIT (SOIL MOISTURE DEFICIT IN mm) IN NORTH WESTERN EUROPE. ADAPTED FROM GREEN, 1964; BAUMGARTNER & REICHEL, 1975; GURNELL, 1981.

4.6 SUMMARY:

The sites sampled in the present study were chosen to reflect a variety of contemporary climatic regimes, from western maritime to eastern continental conditions. Table 2 summarizes these variations. A map of annual average potential water deficit for the study area is presented in figure 5. The transition from western coastal sites where annual water deficits are low to eastern sites experiencing high potential deficits is apparent. The relevance of this parameter to MHC formation is discussed more fully in Sections 6.4 and 7.2. Every attempt was made to minimise intra-site differences in altitude, size and sampling location with regard to the geographical centre of each mire.

With the exception of Polish sites where complete stratigraphic sequences were obtained, the expression of the MHC was distinct and samples spanning the boundary were taken for macrofossil and radiocarbon analysis using monoliths or a modified Russian borer (Barber, 1984). The following Section details the results of these analyses.

SECTION 5

MACROFOSSIL RESULTS: DESCRIPTION AND INTERPRETATION

5.1 INTRODUCTION

The results outlined in the following sections were obtained using the quantitative abundance technique described earlier. In total, 641 macrofossil analyses were undertaken.

To facilitate the presentation, discussion and future comparison of the results, the diagrams from each study site are considered separately. Diagram zonation, either visually or mathematically, has been used by many workers to aid interpretation. Though this technique undoubtedly has many advantages when considering long sections, it was felt that the restricted time spans considered by the present study negated such an approach.

Whilst many of the recorded macrofossils have been produced in ecologically distinct vegetation types and/or habitats, care must be taken when attempting to interpret the diagrams, especially when identification to species level is not possible (e.g. *Sphagnum* sect. *Cuspidata* and *Sphagnum* sect. *Acutifolia*), since these taxa often have representatives preferring different ecological habitats.

Although numbers of preserved zoofossils per 0.1cc have been calculated, identification and counting to species level was not undertaken (see also Section 3.6). Where pertinent, reference to diagnostic indicator species is made in the text. Guides to the identification and ecological preferences of the macro- and zoofossils mentioned in the following descriptions are presented by Grosse-Brauckmann (1972, 1974), Barber (1976), Van Geel (1978), Van Geel et al. (1981), Bakker and Smeerdijk (1982), Van Geel et al. (1983) and Tolonen et al. (1985).

5.2 THE BRITISH ISLES

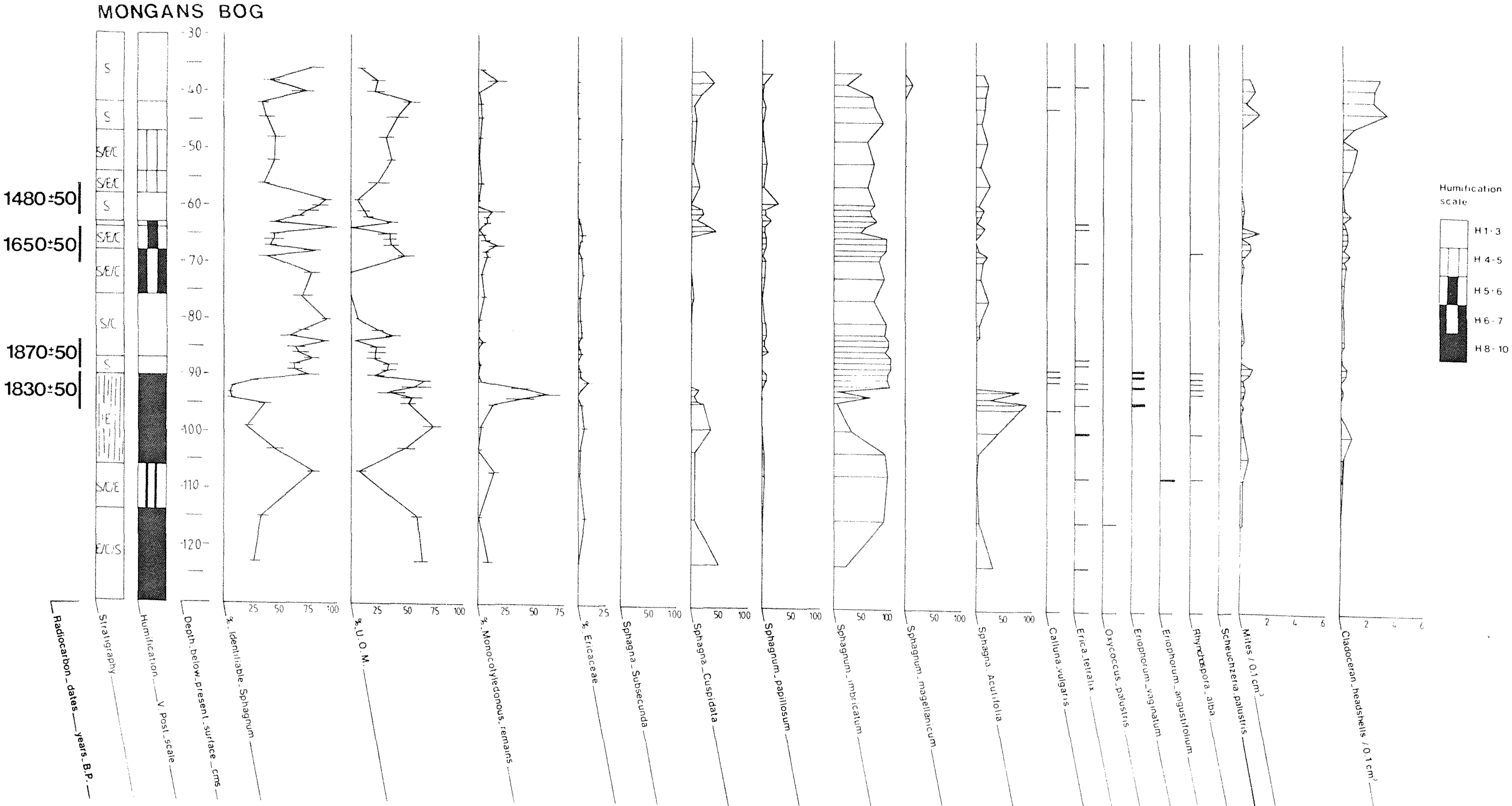


Figure 6.

C.J. HASLAM
JANUARY 1986

5.2.1 MONGANS BOG, Co. OFFALY

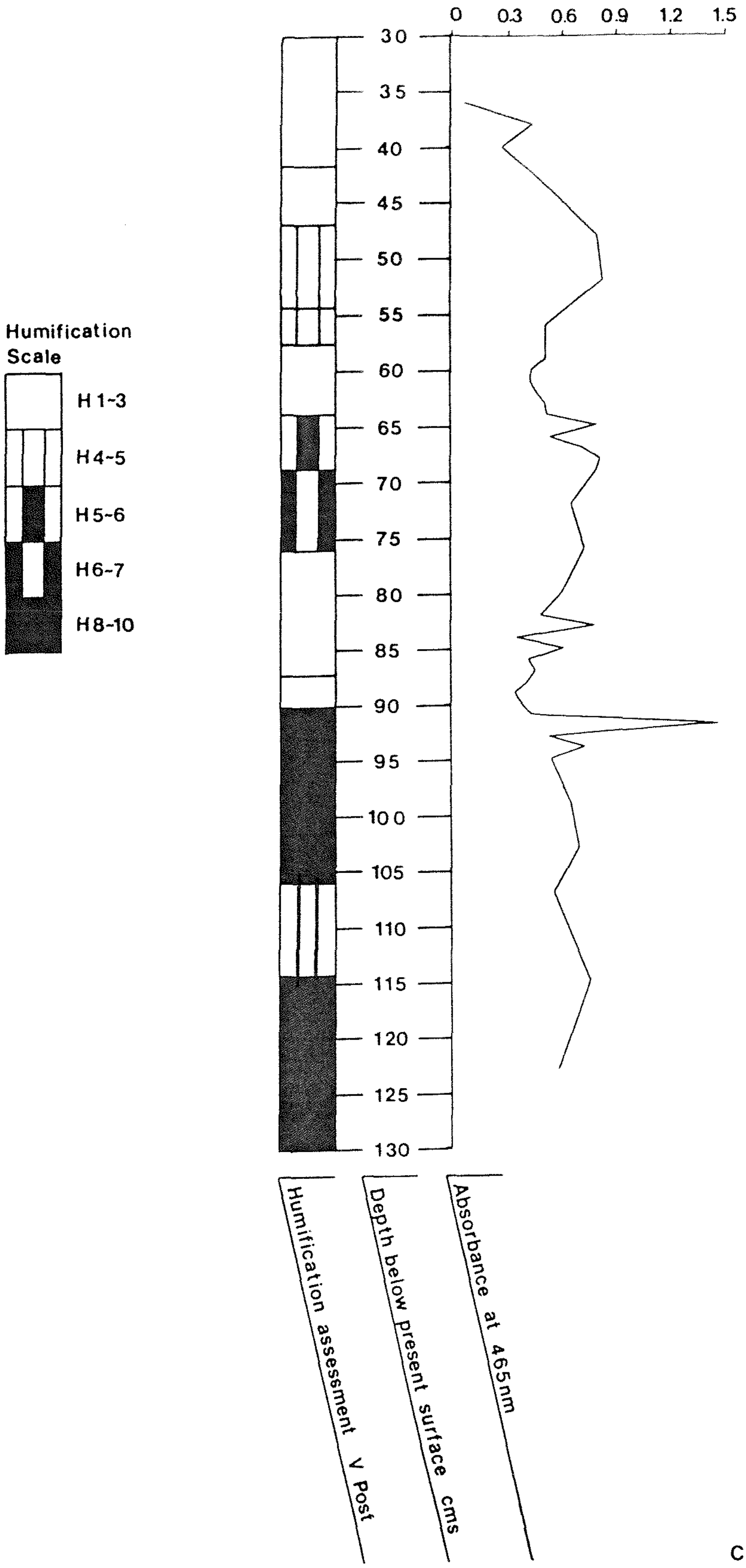
The Mongans section displays a complex series of humification changes (figure 6). Three recurrence surfaces were noted in the field at 114cm, 90cm and 63cm, the most distinct of which was that at 90cm. This was accordingly designated as the MHC. Macrofossil analyses, and in particular the curves for % identifiable *Sphagnum* and % U.O.M., confirm the presence of a major stratigraphic boundary at this depth.

The pre-MHC peats are characterised by reduced values of % identifiable *Sphagnum* and correspondingly high values of % U.O.M. The recurrence surface at 114cm and the band of unhumified peat between 114cm and 106cm is clearly picked out by a temporary rise in identifiable *Sphagnum* and the occurrence of more hygrophilous species such as *Rhynchospora alba*, *Eriophorum angustifolium*, *Erica tetralix* and *Oxycoccus palustris*. *Sphagnum imbricatum* dominates the moss flora along with traces of *Sphagnum cuspidatum* and *Sphagnum papillosum*. Although occasional leaves of *Sphagnum* sect. *Acutifolia*, most probably *S. capillifolium*, were identified, the indication is that these peats were formed in a lawn environment. This phase is short-lived and a gradation towards a more humified matrix composed of caespitose *Eriophorum vaginatum* ensues.

The occurrence of *Eriophorum vaginatum* in the immediate pre-MHC peats of British mires has been commented on by several workers (Godwin and Mitchell, 1939; Godwin, 1946) and is taken to represent a phase of surface dryness. The evidence from Mongans is ambiguous however. Whilst an expansion of the Ericaceae component (*Calluna vulgaris*) occurs together with high values of % U.O.M., the moss flora contains both wet and dry surface facies, being composed of an admixture of *Sphagnum cuspidatum*, *S. tenellum*, *S. imbricatum* and *Sphagnum* sect. *Acutifolia* (cf. *S. capillifolium*). The possibility that *S. imbricatum* may display a wide tolerance with regard to water levels, or exist in both semi-aquatic and hummock 'ecads' may explain the presence of this species. The identification of *S. imbricatum* throughout the profile, which contains both wet and dry phases, supports this view. Similar conclusions have been reached elsewhere following experimental (Tallis, 1961; Green, 1968) and palaeoecological (Van Geel, 1978; Barber, 1981;

Figure 7.

MONGANS BOG



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Smith, 1985; Wimble, 1986) investigations. The presence of Sphagnum tenellum and S. cuspidatum, both associated with wet habitats, remains problematic.

The transition to unhumified peat at the MHC is distinct. Falls in % U.O.M., % Monocotyledonous remains and % Ericaceae are associated with a sharp and permanent rise in % identifiable Sphagnum. Following a phase of Sphagnum sect. Cuspidata-Sphagnum sect. Acutifolia dominance, Sphagnum imbricatum expands. A marked rise followed by subsequent, but temporary, decline of S. imbricatum in the immediate pre-MHC peats is particularly striking, and may provide evidence of an oscillatory climatic deterioration. The establishment of Sphagnum imbricatum as the habitat dominant is associated with the extinction of both Sphagnum sect. Cuspidata and Sphagnum sect. Acutifolia, and the re-appearance of S. papillosum. Though S. papillosum never attains dominance, its presence together with S. imbricatum, Rhynchospora alba and Erica tetralix is indicative of a wet lawn environment. The occurrence of Amphitrema flavum, Assulina muscorum and Hyalosphenia papilio in the immediate post-MHC peats support this view (Grospietsch, 1952; Van Geel, 1978). Both zoological populations peak at this level.

The existence of a stratum of more humified peat within the fresh matrix was noted in both the field and laboratory. Extending between 64cm and 76cm, the upper boundary was marked by a thin layer of Sphagnum cuspidatum pool muds. A similar feature has been noted elsewhere in Ireland (Mitchell, 1956). Macrofossil analyses reveal a complicated picture with fluctuating % identifiable Sphagnum and % U.O.M. Variations in the Sphagnum population are more consistent however, showing the establishment of a low hummock situation with Sphagnum sect. Acutifolia (cf. S. capillifolium), S. imbricatum, S. papillosum and infrequent Erica tetralix. The onset of wetter conditions is marked by a fall in both S. imbricatum and Sphagnum sect. Acutifolia and the appearance of S. cuspidatum. Zoological remains show a second peak during this phase. Partial pool infil is accomplished by successive populations of S. papillosum, Sphagnum sect. Acutifolia and S. imbricatum.

Chemical analyses of humification (figure 7) support the findings of both

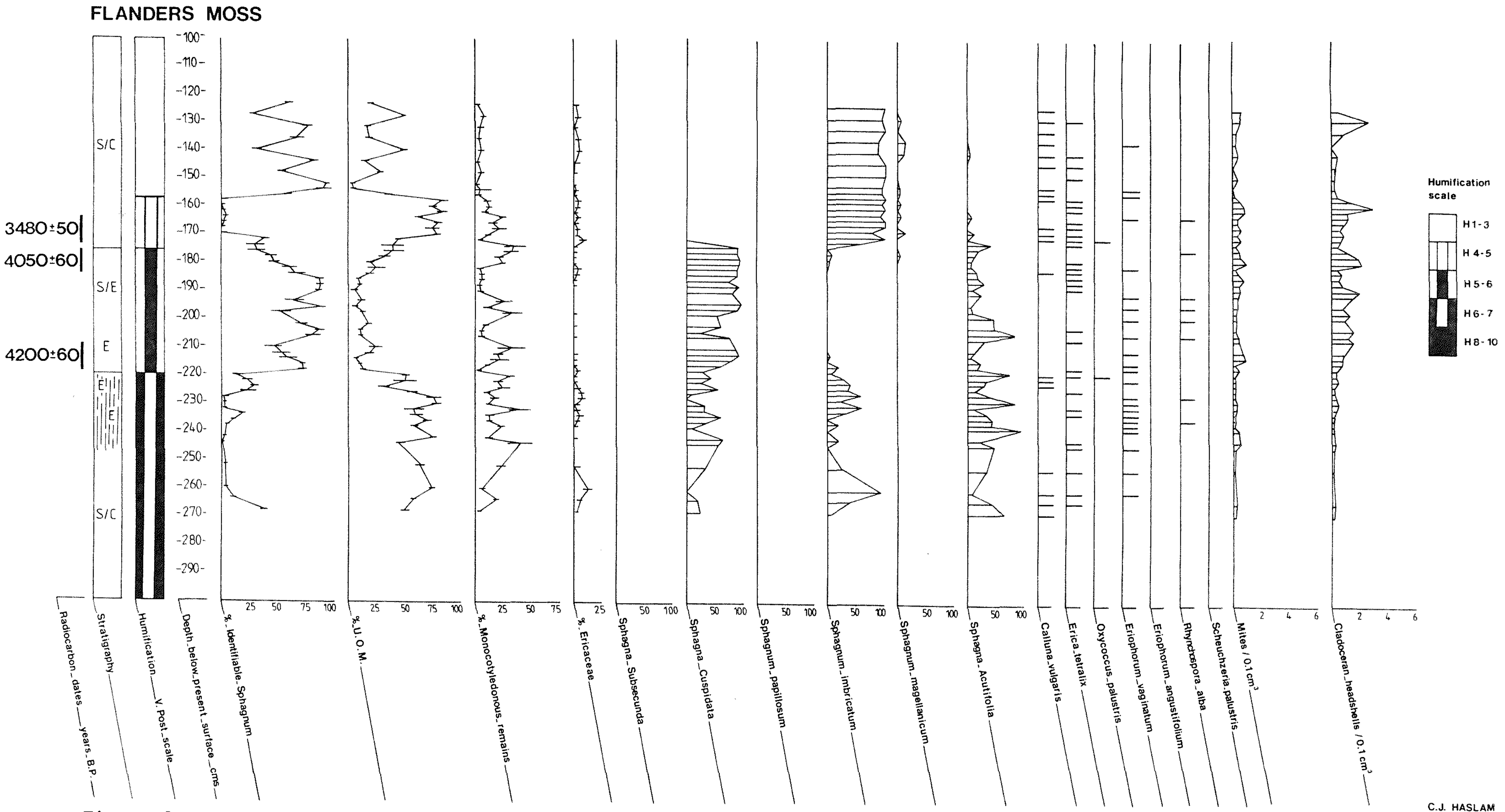

Figure 8.

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the stratigraphic and macrofossil investigations. High absorbances, indicative of a decomposed matrix, characterise the pre-MHC peats and culminate in a pronounced peak in the immediate pre-MHC peats at 93cm. This corresponds with maxima in the % U.O.M. and % Monocotyledonous remains (Eriophorum vaginatum) curves. Transition to poorly humified peats is associated with reduced absorbance. The fluctuating nature of the curve during this period highlights the possibility, touched upon earlier, of an oscillatory shift in peat formation. The upper recurrence surface is similarly marked by reduced absorbances in the post-boundary peats.

Immediate pre- and post-MHC peats have been radiocarbon dated to 1830 +/- 50 B.P. (SRR-3046) and 1870 +/- 50 B.P. (SRR-3045) respectively, whilst the peats below and above the second boundary are dated to 1650 +/- 50 B.P. (SRR-3044) and 1480 +/- 50 B.P. (SRR-3043) respectively. These dates show close correspondence with the phases of recurrence surface formation identified by Mitchell (1956) at 3400 B.P., 2050 B.P. and 1450 B.P. Whether the third Mongans recurrence surface noted at 114cm is related to the earliest of these phases is uncertain. More recently, Pilcher and Larmour (1982) have identified a prominent recurrence surface in a montane raised mire in Co. Tyrone which may also be dated to c.1800 B.P.

5.2.2 FLANDERS MOSS, STIRLINGSHIRE

The Flanders Moss stratigraphy (figure 8) displays a simple two-fold division between a lower humified and upper non-humified matrix, the MHC occurring at 177cm. Macrofossil analyses reveal a more complex situation however, in particular, the identification of Sphagnum sect. Cuspidata in in the lower pre-MHC 'dry' peats.

The lower humified matrix between 270cm and 220cm is characterised by low % identifiable Sphagnum and high values of % U.O.M. and % Monocotyledonous remains, mainly Eriophorum vaginatum. Sphagnum sect. Cuspidata, S. imbricatum and Sphagnum sect. Acutifolia dominate the sparse moss flora in what was probably a dry lawn environment. Slightly drier conditions at 232cm are indicated by an expansion of both S. imbricatum and Sphagnum sect.

Acutifolia, and the occurrence of caespitose *Eriophorum vaginatum* growths. This low hummock situation is short lived however, and by 220cm the development of wetter conditions is marked by a rise in % identifiable *Sphagnum*, expansion of *Sphagnum* sect. *Cuspidata* (cf. *S. cuspidatum*) and falls in *S. imbricatum*, *Sphagnum* sect. *Acutifolia* and *Eriophorum vaginatum*. Stratigraphically, a transition to marginally less humified peat occurs.

Although a slightly drier phase, marked by an expansion of *Sphagnum* sect. *Acutifolia*, occurs at 218cm, continued deterioration leads to the extinction of *Sphagnum imbricatum* and establishment of *Sphagnum* sect. *Cuspidata* (cf. *S. cuspidatum*) as the habitat dominant. This level has been dated to 4200 +/- 60 B.P. (SRR-3042). The persistence of *Sphagnum* sect. *Acutifolia* suggests that whilst conditions were certainly wet, full pool conditions were not attained. A wet lawn environment with *Eriophorum vaginatum*, *Rhynchospora alba* and isolated *Sphagnum capillifolium* seems more probable. A drier phase at 200cm is indicated by the expansion of *Sphagnum* sect. *Acutifolia*.

The shift to unhumified peat formation occurs at 177cm. Macrofossil analyses show that following a temporary expansion at 178cm, *Sphagnum imbricatum* replaces *Sphagnum* sect. *Cuspidata* (cf. *S. cuspidatum*) as the habitat dominant at 176cm. Zoofossils, which increase in abundance between 217 and 177cm, peak in the immediate pre-MHC peats. *Arcella rotundata*, accompanied by *Amphitrema flavum* and *Hyalosphenia papilio*, dominate the rhizopod assemblage. The abundance of *Assulina seminulum*, characteristic of floating, submerged or very wet *Sphagnum* swards (Tolonen et al., 1985), indicates particularly wet surface conditions.

The transition from *Sphagnum* sect. *Cuspidata* to *Sphagnum imbricatum* is particularly striking. Whilst the reasons for this shift remain unclear, it seems possible that the onset of slightly drier conditions at 177cm followed by a prolonged dry phase between 170 and 158cm may have acted as the necessary trigger mechanism. Falls in the curve for identifiable *Sphagnum*, a rise in % U.O.M. and a temporary expansion of the less hydrophilous *Sphagnum* sect. *Acutifolia* (cf. *S. capillifolium*) support this interpretation. Values of % identifiable *Sphagnum* remain unusually low in

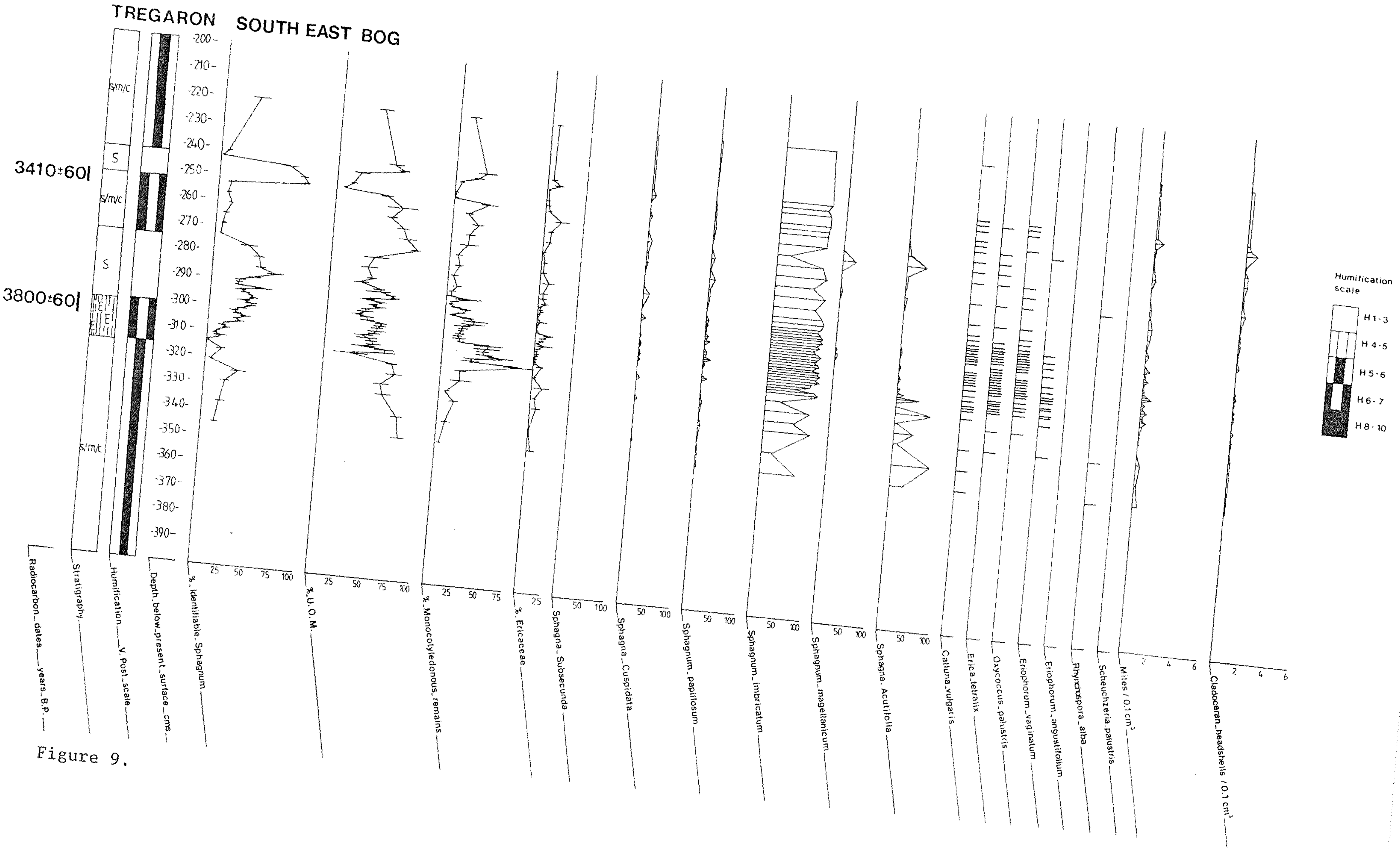

Figure 9.

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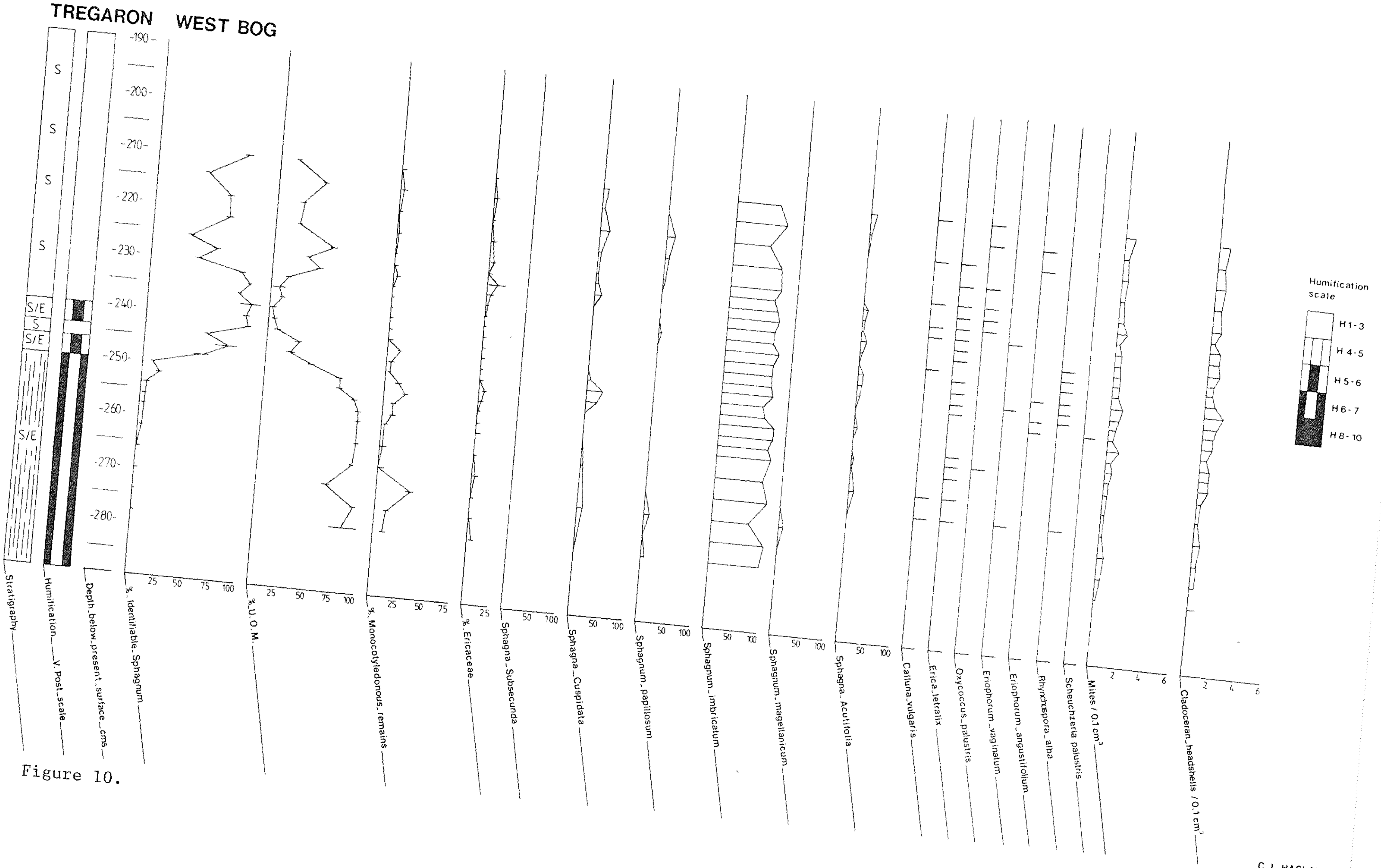
TREGARON WEST BOG
S
S
S
S
S/E
S
S/E
S/E
-190-
-200-
-210-
-220-
-230-
-240-
-250-
-260-
-270-
-280-
25 50 75 100
25 50 75 100
25 50 75
25
50 100
50 100
50 100
50 100
50 100
50 100
2 4 6
2 4 6
Stratigraphy
Humification V. Post. scale
Depth below present surface cms
% Identifiable Sphagnum
% U.O.M.
% Monocotyledonous remains
% Ericaceae
Sphagna Subsecunda
Sphagna Cuspidata
Sphagnum papillosum
Sphagnum imbricatum
Sphagnum magellanicum
Sphagna Acutifolia
Calluna vulgaris
Erica tetralix
Oxycoccus palustris
Eriophorum vaginatum
Eriophorum angustifolium
Rhynchospora alba
Scheuchzeria palustris
Mites / 0.1 cm^3
Cladoceran headshells / 0.1 cm^3
Humification scale
H 1-3
H 4-5
H 5-6
H 6-7
H 8-10
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Figure 10.

these immediate post-MHC peats. A complex shift in peat formation involving a series of oscillations between wet and dry conditions is indicated by the fluctuating curves for all macrofossil components both sides of the MHC. Sphagnum imbricatum dominates the post-MHC peats. Together with Sphagnum magellanicum, Erica tetralix, Eriophorum vaginatum and Assulina muscorum, a 'dry' lawn/low hummock situation is suggested.

Immediate pre- and post-MHC peats have been dated to 4050 +/- 60 B.P. (SRR-3041) and 3480 +/- 50 B.P. (SRR-3040) respectively, suggesting a growth hiatus of 570 +/- 55 years. Working on the southern boundary of South Flanders Moss, Turner (1965) dated the humified Sphagnum peat, 0-2cm below the MHC, to 2712 +/- 120 B.P. (Q-541/2/3)(Godwin and Willis, 1962). The considerable age difference for the same stratigraphic feature is problematic. However, the marginal nature of Turners' (1964) site and the resultant possibility that local edaphic and hydrological factors may have influenced 'fresh' Sphagnum peat initiation needs to be explored more fully. Schneekloth (1968) and Casparie (1972) have developed similar arguments. Their work is reviewed more fully in Section 2.1. The peat accumulation rate between 215 and 180cm was particularly active therefore, at 4.3y/cm.

5.2.3 TREGARON SOUTH EAST AND WEST BOGS, DYFED

The uninterrupted dominance of Sphagnum imbricatum characterises both the Tregaron South East and West bog profiles (figures 9 and 10). This is significant since it points to relatively small local hydrological changes associated with the formation of the MHC.

No MHC-type feature, as recorded in section 13 by Godwin and Mitchell (1938) and subsequently by Turner (1964), could be identified in the field stratigraphy of the South East bog. The most striking appearance of 'fresh' Sphagnum peat occurred at 300cm and this was accordingly designated as the MHC. Godwin and Mitchell (1938) recorded unhumified peat to a depth of 285cm in the South East bog and 240cm in the West bog.

Turner (1964) noted the MHC at 170cm below the present surface.

Although fragments of Rhynchospora alba were isolated by the macrofossil analyses, low values of % identifiable Sphagnum, high values of % U.O.M. and abundant leaf, seed and stem remains of Calluna vulgaris indicate particularly dry conditions in the pre-MHC peats. A Sphagnum imbricatum-Sphagnum sect. Acutifolia (cf. S. capillifolium) association dominates the moss flora and supports evidence suggesting a hummock situation. The rhizopod fauna is dominated by a Trigonpyxis arcula-Hyalosphenia subflava association, typical of lichenous communities in dry raised mires according to Tolonen et al. (1985).

Deterioration towards wetter conditions is first noted at 317cm where a gradual rise in % identifiable Sphagnum and the extinction of Sphagnum sect. Acutifolia occurs. The development of low hummock conditions, with a Sphagnum imbricatum-Sphagnum papillosum-Erica tetralix-Oxycoccus palustris association, in which Calluna vulgaris and Eriophorum vaginatum, immigrating from the surrounding hummock centres, were important constituents, is suggested. Interestingly, the mite and cladoceran populations do not record any trend towards increased wetness over this period.

The formation of 'fresh' Sphagnum imbricatum peat at 300cm coincides with the appearance of S. tenellum and S. papillosum, both indicators of wet conditions. Pool formation did not occur however. The peats directly below this boundary have been dated to 3800 +/- 60 B.P. (SRR-3048). This date is at variance with those obtained by both Turner (1964) (2954 +/- 70 B.P. Q-389) and Hibbert and Switsur (1977) (4695 +/- 55 B.P. Q-945) who worked on open sections towards the eastern margin of the South East bog.

This wetter phase is of short duration, and by 276cm a return to drier local conditions is indicated by a fall in % identifiable Sphagnum and rises in the curves of % U.O.M. and % Monocotyledonous remains (mainly Eriophorum vaginatum). The re-establishment of Sphagnum sect. Acutifolia (cf. S. capillifolium) at 261cm and the abundance of small diameter Calluna vulgaris twigs points to a particularly active hummock environment.

Between 252cm and 242cm a sharp rise in % identifiable Sphagnum and associated falls in % U.O.M. and % Monocotyledonous remains, marks the wettest phase in the section. Though the moss flora remains little altered, a Sphagnum imbricatum-S. tenellum mixture, the isolation of a hygrophilous rhizopod assemblage with Amphitrema flavum and Hyalosphenia papilio indicates a moist low hummock environment. Peat above this second recurrence surface has been dated to 3410 +/- 60 B.P. (SRR-3047). An average peat accumulation rate of 7.8y/cm between the MHC and the upper recurrence surface may therefore be calculated. A return to more humified hummock conditions occurs at 242cm.

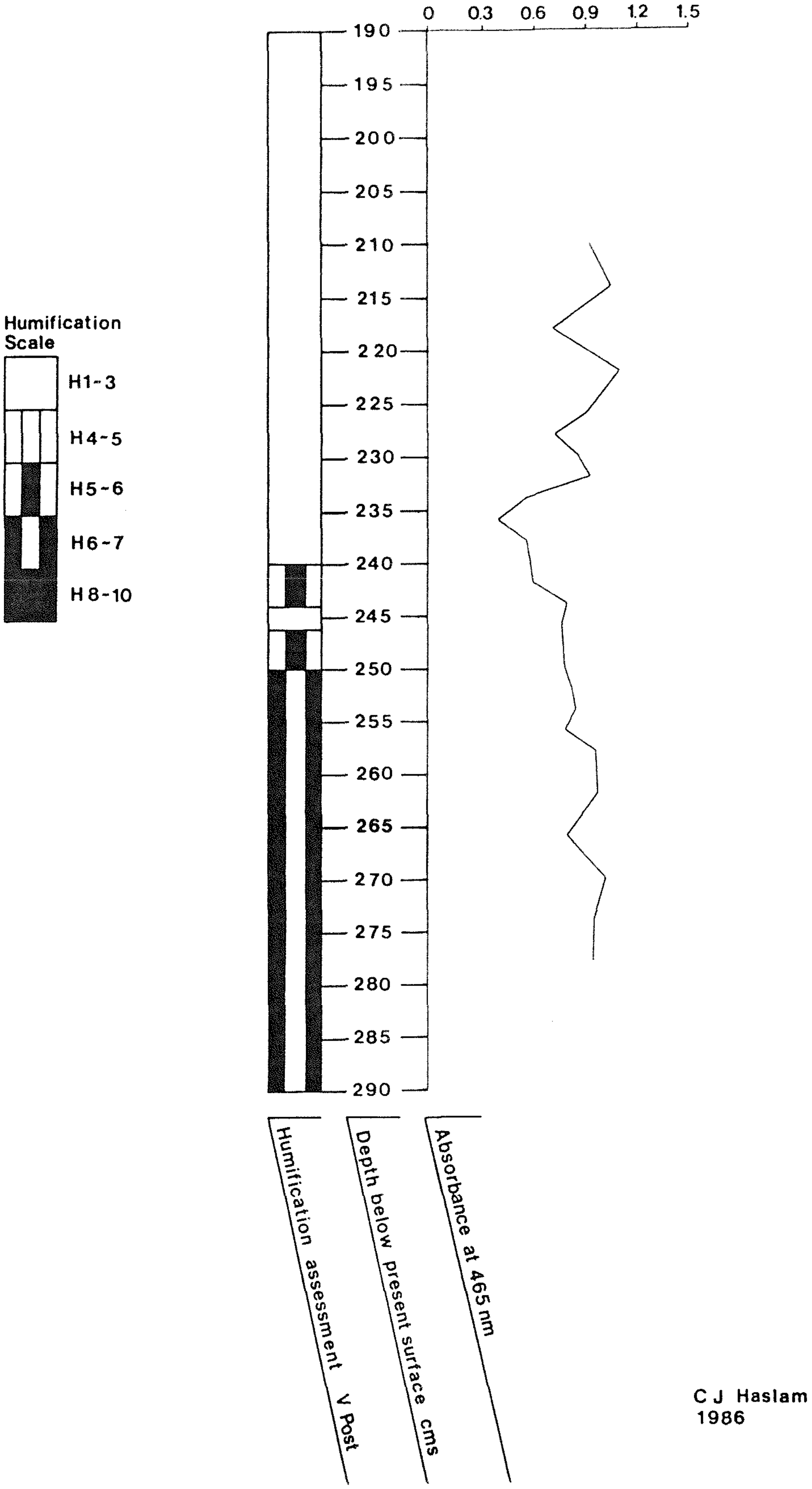
The macrofossil results for the South East bog record a 'dry' stratigraphy in which oscillations in local hydrological conditions appear small. The species and humification profiles suggest that the sample core was most likely taken through the margins of a quasi-permanent hummock dominated by Sphagnum imbricatum. Fluctuations in the macrofossil components reflect the expansion and contraction of this hummock in response to regional climatic change. This interpretation is supported by the stratigraphic studies of Aaby (1976) and Barber (1981). Accordingly, a second undated core was obtained from the centre of the West bog adjacent to section 28 of Godwin and Mitchell (1938).

The stratigraphy of this profile is similar to that recorded by Godwin and Mitchell (1938), with the exception of a band of unhumified Cymbifolian peat noted in the upper layers of the pre-MHC matrix (figure 10). There are no radiocarbon dates available for this section.

The pre-MHC peats are composed of a highly degraded matrix with low values of % identifiable Sphagnum. Sphagnum imbricatum dominates the moss flora together with Erica tetralix and infrequent Oxycoccus palustris. The invasion of Sphagnum papillosum, S. magellanicum, Sphagnum sect. Cuspidata (cf. S. cuspidatum), Eriophorum vaginatum and Rhynchospora alba into this low hummock assemblage at 270cm indicates a temporary transition to wet lawn conditions. The onset of wetter conditions is not seen until 254cm when

Figure 11.

TREGARON WEST BOG



% identifiable Sphagnum rises for the first time. This rise coincides with a S. cuspidatum expansion. Although full pool conditions were not attained, a very wet lawn community characterised by Scheuchzeria palustris with Eriophorum angustifolium and Rhynchospora alba became established. The hygrophilous rhizopods, mainly represented by Amphitrema flavum and Hyalosphenia papilio, also show increased frequencies at this level.

Continued deterioration triggered a shift in peat formation and the deposition of unhumified Sphagnum peats between 247cm and 244cm. Marginally drier conditions, shown by a rise in % U.O.M. and temporary expansion of Sphagnum sect. Acutifolia, mark a return to a more humified matrix from 244cm to 240cm. Renewed deterioration resulted in a permanent shift to unhumified peat deposition at 240cm. Post-MHC peats are characterised by wet-dry shifts, though these are not marked stratigraphically. 'Dry' low hummock conditions at 230cm and 226cm are marked by an expansion of Sphagnum sect. Acutifolia and Oxycoccus palustris, whilst a Sphagnum cuspidatum-S. papillosum-S. imbricatum-Eriophorum angustifolium assemblage denotes a transition to wetter lawn conditions at 218cm.

Humification analyses for the West bog clearly demonstrate the oscillatory shift in peat formation (figure 11). Wetter phases at 267cm and 257cm in the pre-MHC peats and drier periods in the post-MHC matrix at 232cm, 222cm and 214cm may be identified. An increase in wetness followed by a return to drier conditions characterises the immediate pre- and post-MHC peats. Macrofossil analyses have demonstrated a transition from low hummock to wet lawn and back again during this period. The dominance of Sphagnum imbricatum through both wet and dry phase shifts supports the view expressed by Green (1968) that this species displays a wide tolerance with regard to water levels. Humification values remain low throughout the profile and reflect the mild, oceanic nature of this site.

5.2.4 BOLTON FELL MOSS, CUMBRIA

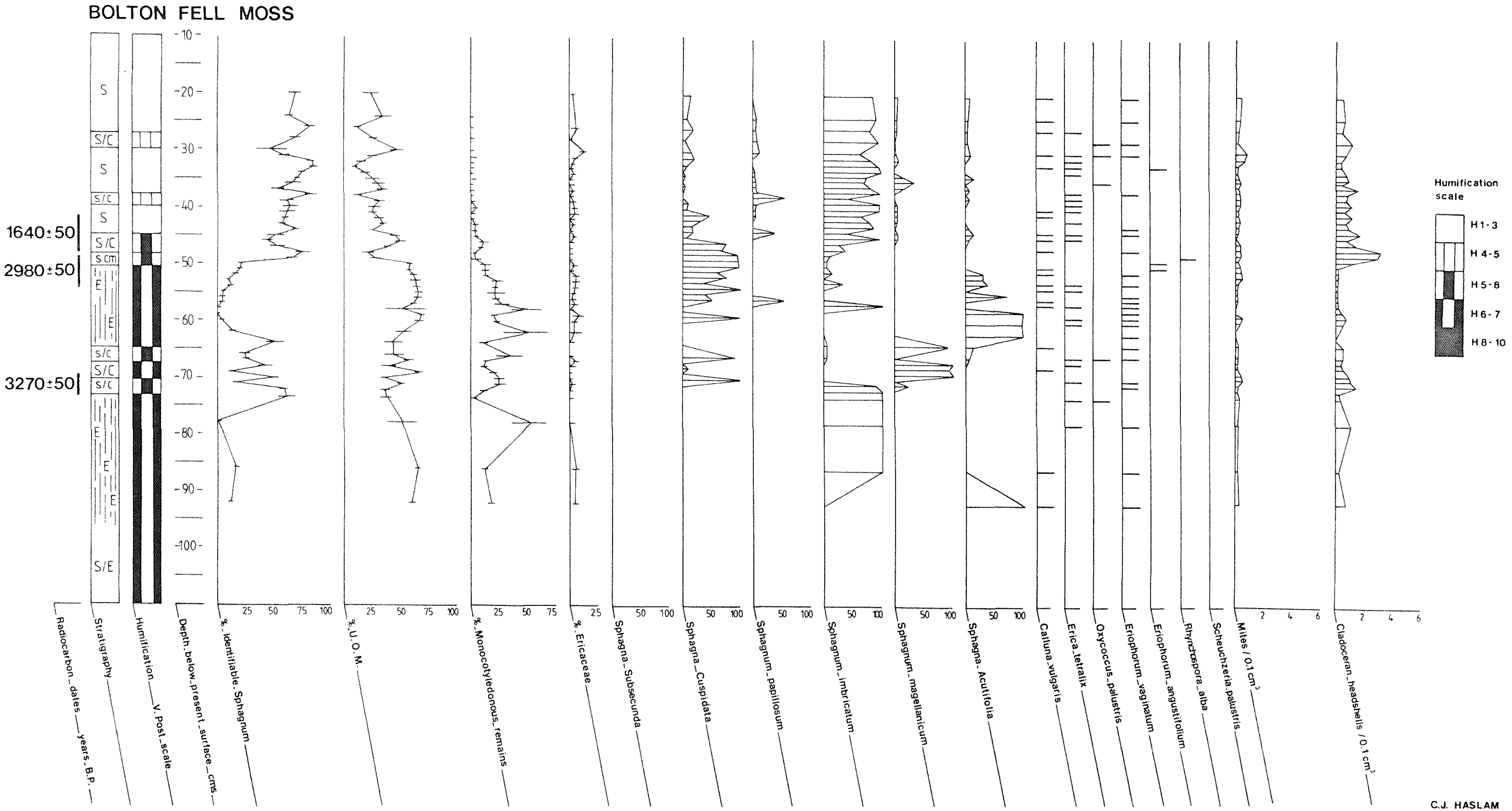


Figure 12.

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A distinct 2cm thick band of greasy Sphagnum cuspidatum/algal pool muds from 48-50cms separates the lower highly humified Eriophorum vaginatum peats from the upper Cymbifolian Sphagnum peats. The transition to an unhumified matrix is not direct however, both pre- and post-MHC peats displaying a series of more and less humified bands. This banding points to the oscillatory nature of the shift in peat formation (figure 12).

The pre-MHC peats are particularly highly humified, though wetter phases at 65cm-68cm and 71cm-73cm may be recognised. Stem fragments, leaves and seeds of Calluna vulgaris are frequent in the lower profile. Together with Eriophorum vaginatum and Sphagnum sect. Acutifolia, it appears that these peats were formed in a dry hummock situation. Sphagnum imbricatum replaces Sphagnum sect. Acutifolia as the dominant moss at 86cm, though the reasons for this shift remain unclear. Marginally wetter conditions, as indicated by the rise in % identifible Sphagnum and the presence of Amphitrema flavum, may have precipitated the shift.

A deterioration towards wetter surface conditions occurs at 75cm and is marked by a rise in % identifiable Sphagnum and the appearance of the more hydrophilous Ericaceae, Erica tetralix and Oxycoccus palustris. Shallow pool formation between 73-65cm leads to the extinction of Sphagnum imbricatum and the establishment of a Sphagnum cuspidatum-Sphagnum magellanicum association. This transition has been dated to 3270 +/- 50 B.P. (SRR-3039). A slightly drier phase between 71cm-68cm is associated with a Sphagnum magellanicum expansion and the occurrence of Trigonpyxis arcula, an indicator of periodic drying (Grospietsch, 1958; Tolonen et al., 1985).

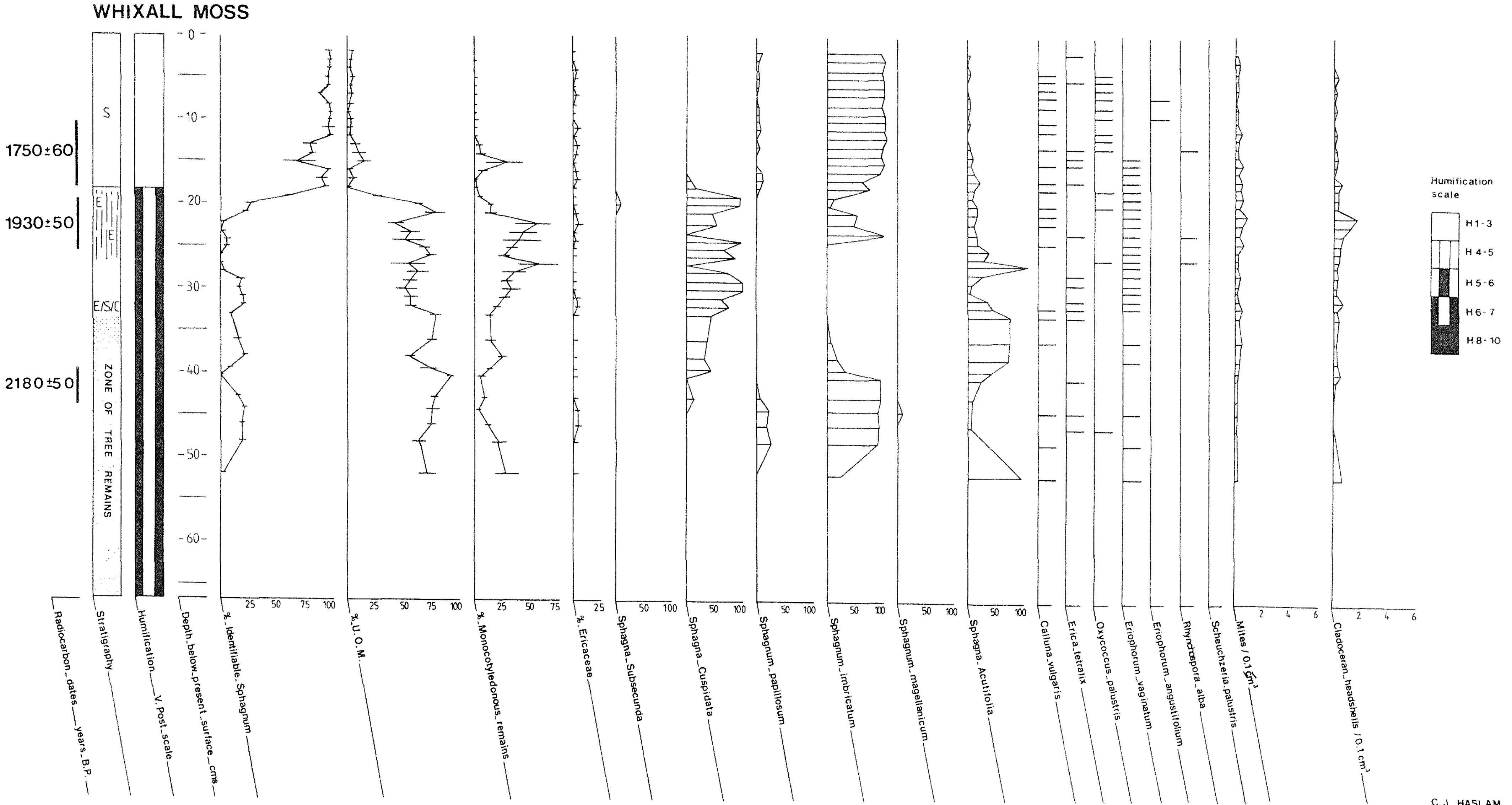
Drier surface conditions at 65cm, shown by a rise in % U.O.M. and an associated decline in % identifiable Sphagnum, allow the re-establishment of Sphagnum sect. Acutifolia (cf. S. capillifolium) and the formation of a low hummock colonised by Erica tetralix and Eriophorum vaginatum. Whilst conditions were certainly dry during this phase, evidence suggesting an oscillatory climatic deterioration may be identified. In particular, the establishment of a Sphagnum sect. Cuspidata (cf. S. cuspidatum)-S. papillosum-S. imbricatum-Sphagnum sect. Acutifolia association indicate the formation of an unstable wet lawn-low hummock situation. Drier phases appear to be associated with a *Sphagnum imbricatum*-*Sphagnum* sect. *Acutifolia* association, and wetter periods by a *S. papillosum*-*S. imbricatum*-*Sphagnum* sect. *Cuspidata* association. The presence of *S. imbricatum* in both wet and dry phases suggests a wide tolerance range with regard to water levels (cf. Green, 1968).

Continued deterioration leads to pool formation at 51cm and the establishment of *Sphagnum cuspidatum* as the habitat dominant. *Eriophorum angustifolium* and *Rhynchospora alba* replace *Eriophorum vaginatum* in this particularly wet environment. The cladoceran population also displays a marked peak at this level.

A shift towards marginally drier conditions at 48cm, indicated by a rise in % U.O.M. and fall in % identifiable *Sphagnum*, appears to have favoured the establishment of *Sphagnum imbricatum* and initiation of unhumified peat formation. Progressive pool infill by *Sphagnum imbricatum* and *S. papillosum* results in the development of a low hummock colonised by *Sphagnum imbricatum*, *S. papillosum*, *S. tenellum*, *Sphagnum* sect. *Acutifolia*, *Erica tetralix* and *Oxycoccus palustris*. Drier phases at 38-40cm and 28-30cm are marked by an increase in % U.O.M. and the proportion of *Calluna vulgaris* remains.

Immediate pre- and post-MHC peats have been dated to 2980 +/- 50 B.P. (SRR-3038) and 1640 +/- 50 B.P. (SRR-3037) respectively. A hiatus of 1340 years is suggested. The age determination SRR-3037 is considered erroneous however. Although Godwin (1960) and Turner (1964) conclude that surface erosion and reworking of older sediments in pool environments may distort age determinations directly below recurrence surfaces, it seems more likely that younger material, introduced from above by downwashing, peat cutting machinery and/or rootlet penetration, may have contaminated sample SRR-3037. If the immediate pre-MHC date is correct, then the accumulation rate in the humified matrix between 72cm and 52cm was 14.5 y/cm, a rate higher than the average values for post-MHC peats calculated by Walker (1961, 1970) and Barber (1981).

5.2.5 WHIXALL MOSS SHROPSHIRE


WHIXALL MOSS
1750±60
1930±50
2180±50
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E
E
E/S/C
ZONE OF TREE REMAINS
0
10
20
30
40
50
60
Radiocarbon dates years B.P.
Stratigraphy
Humification V. Post scale
Depth below present surface cms
% Identifiable Sphagnum
% U.O.M.
% Monocotyledonous remains
% Ericaceae
Sphagna Subsecunda
Sphagna Cuspidata
Sphagnum papillosum
Sphagnum imbricatum
Sphagnum magellanicum
Sphagna Acutifolia
Calluna vulgaris
Erica tetralix
Oxycoccus palustris
Eriophorum vaginatum
Eriophorum angustifolium
Rhynchospora alba
Scheuchzeria palustris
Mites / 0.1 cm³
Cladoceran headshells / 0.1 cm³
25
50
75
100
2
4
6
Humification scale
H 1-3
H 4-5
H 5-6
H 6-7
H 8-10
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Figure 13.

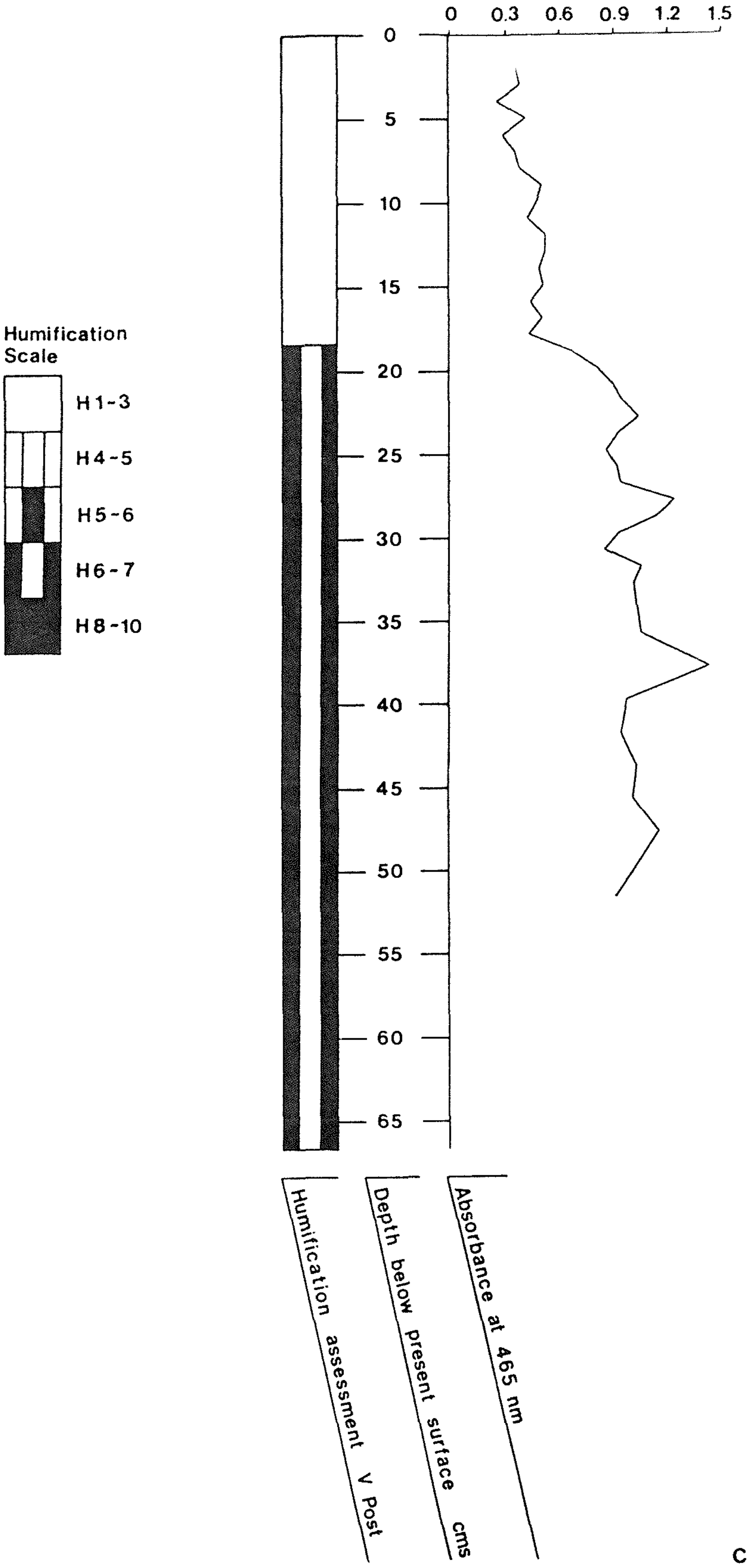
The macrofossil results for Whixall Moss (figure 13) accord with those obtained for Bolton Fell Moss and Flanders Moss. In particular, the alternation between *Sphagnum* sect. *Cuspidata* and *Sphagnum* sect. *Acutifolia* in the immediate pre-MHC peats is striking. An uncomplicated stratigraphy indicates a direct shift from a humified to unhumified matrix. Distinct wet and dry phases may be identified within both pre- and post-MHC peats however.

Highly humified lower pre-MHC peats are composed of a *Sphagnum* sect. *Acutifolia*-*Calluna vulgaris*-*Eriophorum vaginatum* association, characteristic of a hummock situation. This interpretation is supported by the occurrence of a 'dry' rhizopod species, *Trigonpyxis arcula*. The onset of wetter surface conditions between 50cm and 42cm facilitates the expansion of *Sphagnum imbricatum* and successive establishment of *Sphagnum papillosum*, *Sphagnum magellanicum* and *Sphagnum* sect. *Cuspidata* (cf. *S. cuspidatum*) into a wet lawn environment. A return to drier conditions at 40cm is marked by a rise in % U.O.M. and associated fall of % identifiable *Sphagnum*. *Sphagnum* preservation is particularly poor at this level. This shift marks the re-establishment of *Sphagnum* sect. *Acutifolia* (cf. *S. capillifolium*) as the dominant peat former and extinction of *Sphagnum imbricatum*. The peat at this level has been dated to 2180 +/- 50 B.P. (SRR-3074). The presence of *Calluna vulgaris* and *Eriophorum vaginatum* indicate a hummock environment. However, the isolation of leaf fragments belonging to *Sphagnum cuspidatum* questions this interpretation. This may have been a low hummock/lawn situation dominated by a *Sphagnum* sect. *Acutifolia*-*Sphagnum cuspidatum* association, in which short, sharp wet and dry shifts occurred.

Wet phases with *Sphagnum cuspidatum* at 30cm and 25cm and a drier phase with *Sphagnum* sect. *Acutifolia* at 27cm characterise the immediate pre-MHC peats. A temporary *Sphagnum imbricatum* expansion, similar to that identified at both Bolton Fell Moss and Flanders Moss, is associated with a drier phase at 23cm. Renewed deterioration led to pool formation between 20cm and 18cm. *Sphagnum cuspidatum*, *Sphagnum subsecundum*, *Rhynchospora alba* and *Eriophorum vaginatum* characterise this phase. Hygrophilous

Figure 14.

WHIXALL MOSS



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rhizopods, mainly represented by Amphitrema flavum and Hyalosphenia papilio, also show increased frequencies at this level. The ability of Eriophorum vaginatum to tolerate a wide range of water table fluctuations has been demonstrated by several workers (Casparie, 1972; Van Geel, 1978; Barber, 1981; Jonasson and Chapin, 1985). Results obtained from Whixall Moss corroborate this view.

Pool infill commences at 18cm and marks the shift to unhumified peat formation. The peats directly below and above this boundary have been dated to 1930 +/- 50 B.P. (SRR-3036) and 1750 +/- 60 B.P. (SRR-3035) respectively. Almost uninterrupted accumulation is suggested. Dates indistinguishable from those of the present study have been presented for Fenns Moss by Godwin and Willis (1960), who dated the immediate pre- and post-MHC peats to 1842 +/- 110 B.P. (Q-435) and 1670 +/- 110 B.P. (Q-434) respectively.

A wet lawn environment dominated by Sphagnum imbricatum, with Sphagnum papillosum, Erica tetralix, Oxycoccus palustris and the ubiquitous Sphagnum sect. Acutifolia, prevails throughout the post-MHC matrix. Drier phases at 15cm and 8cm are marked by an expansion of % U.O.M. and Sphagnum sect. Acutifolia and associated falls in % identifiable Sphagnum.

The shift to unhumified peat formation is clearly shown in the humification profile for Whixall Moss (figure 14). Particularly low absorbance values were recorded for the post-MHC peats. A gradual deterioration towards wetter conditions is indicated in the pre-MHC matrix, with marked 'wet' phases between 46cm and 40cm, at 32cm and between 27cm and 25cm. This interpretation is supported by the macrofossil results. 'Dry' phases, though less clear, may be identified in the post-MHC peats between 15cm and 12cm, at 7cm and 5cm. None of these shifts are marked stratigraphically.

In addition to the macrofossil and humification investigations, a short study was made of the 'Hardy pine stump layer' at Whixall Moss (Hardy, 1939; Turner, 1964). Subfossil pine layers have been identified in many north west European raised mires (Casparie, 1972; Overbeck, 1975; Mitchell, 1976; McNally and Doyle, 1984). The widespread occurrence of these tree remains has been cited as evidence for large-scale climatic change, indicating relatively dry conditions during the Boreal and Subboreal periods (Birks, 1975). If large-scale climatic amelioration promoted the spread of pinewoods onto western European mires, then subfossil trees might be expected to be broadly synchronous. Radiocarbon dates place these pine trees in broad temporal bands however (Vogel et al., 1969; Casparie, 1972; Overbeck, 1975) suggesting that a combination of local and regional factors were involved in pinewood encroachment.

Though Turner (1964) dated a stump believed to correspond to the Hardy pine stump layer to 2307 +/- 110 B.P. (Q-383), a date overlapping at one standard deviation with SRR-3074 (2180 +/- 50 B.P.), little is known of the duration, population structure or dynamics of the Whixall Moss palaeowoodland. In an attempt to obtain an insight into these factors, dendrochronological techniques were applied.

The application of dendrochronology, the science of tree ring analysis, is based on the fact that distinct annual radial increments ('growth rings') are formed by many woody perennial species in extra-tropical environments (Kramer and Kozlowski, 1979; Hughes et al., 1982). Some measurable feature of these rings is influenced by environmental conditions prior to, or during, ring formation. The most widely used ring feature in dendrochronological analysis is total radial width of the annual increment (Fritts, 1971, 1976; LaMarche et al., 1982). Other features of tree-rings which have been used include cell wall thickness and wood density (Schweingruber, 1982), vessel area (Eckstein and Frisse, 1982), radial width of earlywood and latewood (Eckstein and Schmidt, 1974; Vysotskaya et al., 1985), and ratios of stable isotopes of carbon, oxygen and hydrogen (Wilson and Grinsted, 1977; Wigley et al., 1978; Long, 1982). Comparison of ring width patterns was chosen for its comparative simplicity. Cogent reviews of dendrochronological techniques as applied to mire environments are presented by Stockton et al. (1985) and Munaut (1986).

Sections of subfossil pine, cut with a hand saw, were carefully dried,

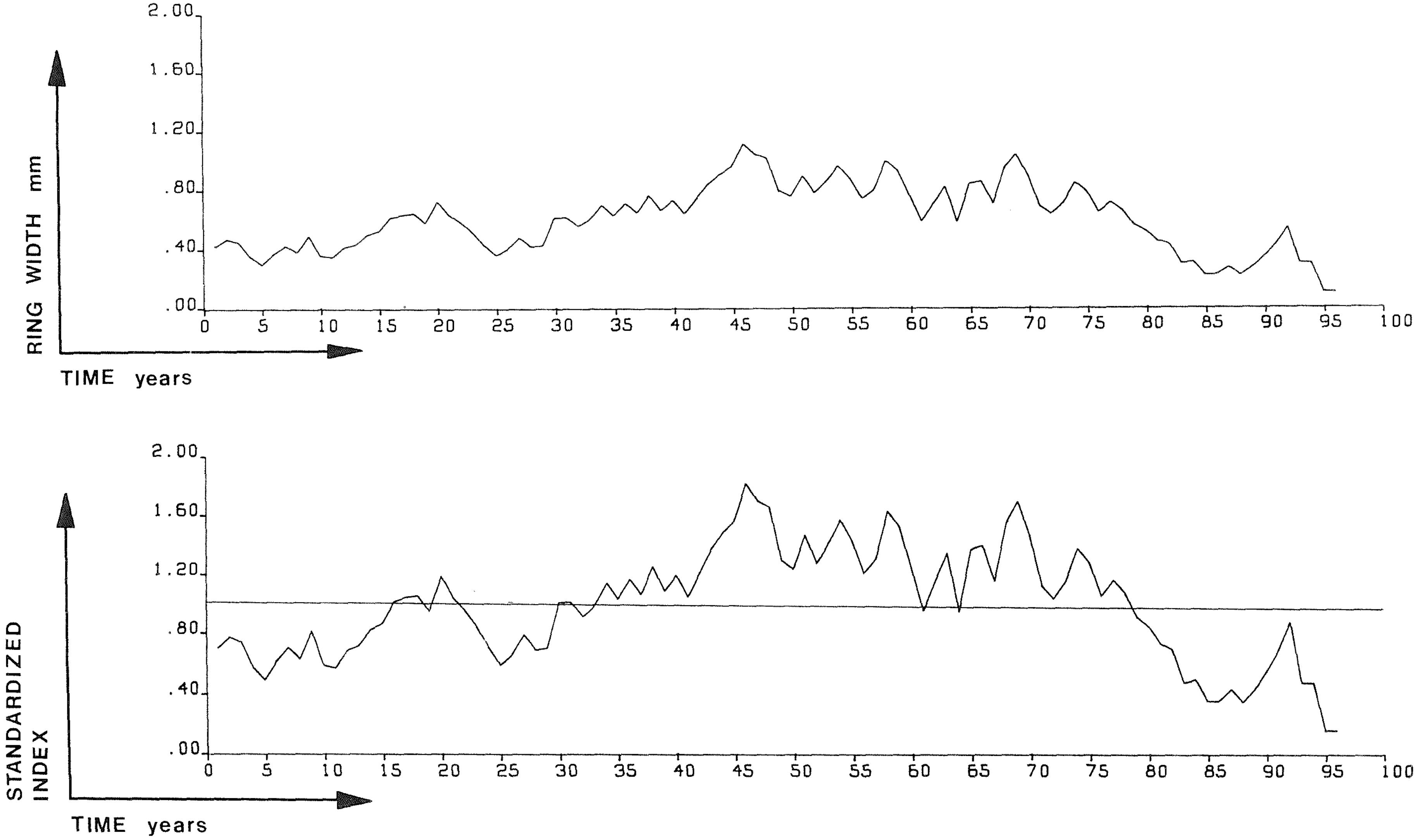

FIGURE 15. MEAN RING WIDTH AND STANDARDIZED INDEX CHRONOLOGY FROM SCOTS PINE (*Pinus sylvestris*) STUMPS IN WHIXALL MOSS, SHROPSHIRE, ENGLAND.

sanded and coated with clear nail varnish to enhance ring definition. With the aid of a graticule, annual ring widths were measured in units of 0.01mm along three radii of most sections using a Nikon stereozoom microscope (SMZ-10) of stepless x6.6-x40 magnification. Where sections had been damaged, measurement was restricted to one or two radii. The resulting radial series of ring widths were compared to allow the identification of missing or 'false' rings (Kozlowski, 1971; Fritts, 1976). A mean ring series for each tree was based on a mean of the radial series. These series are presented in Appendix 1. In total, 14 trees were analysed.

In order to remove non-climatic signals due to increasing stem diameter or tree disturbance, ring width series are standardised by fitting an exponential curve. This has the effect of scaling the variance so that it is more homogeneous than is normally seen in ring width series. It also scales the mean of each series to c.1.0 and reduces first order autocorrelation due to trend (Fritts, 1976, p.226). This new time series is referred to as the Standardized ring width chronology. Standardized chronologies for the Whixall Moss pines are presented in Appendix 1. The master chronology (figure 15) was obtained by visual crossmatching of plotted ring width curves.

The master chronology from Whixall Moss covers 96 years and shows that the average age of the trees sampled is only 64 years. Growth was very irregular, particularly between the years 30-78. This probably reflects annual changes in the local mire water-table, since this must be the major environmental factor affecting ring production in such a marginal environment. Mean annual radial increments of 0.610mm are particularly low and compare with vales of 4.00mm/year for contemporary pines on mineral soils (McNally, 1983) and 1.90mm/year for subfossil pines in Ireland (McNally and Doyle, 1984) and over 1.00mm/year at Bourtanger Moor, The Netherlands (Casparie, 1972). The reduced productivity of trees growing on peaty substrates has been attributed to the nutrient deficiency of such soils (McVean, 1963) allied to decreased nutrient assimilation by roots under conditions of reduced aeration (Brown et al., 1966). Nearly all the stumps have multi-level root structures; the lowest level are almost horizontal whilst those of the higher levels point diagonally upwards. A vertical tap-root is rare. This is believed to reflect the growth response to waterlogging. Similar observations were made at Bourtanger Moor, The Netherlands by Casparie (1972), who dated the pine stump layer at this site to 4360 +/- 55 B.P. (GrN-1087) and 4440 +/- 70 B.P. (GrN-2986). A sharp rise in the mire water table, leading to anaerobic conditions, was the cause of death at both Whixall Moss and Bourtanger Moor.

Based upon extrapolated dates, Turner (1964, 1965) identifies a pine decline associated with the Whixall Moss pine stump layer at c.2000 B.P. More recently, Beales (1980) has linked a fall in regional pine pollen frequencies at Crose Mere (CMCP8/CMCP9 boundary), dated to 2310 +/- 85 B.P. (Q-1233), with the Hardy pine stump layer. Barber and Twigger (1987) and Twigger (1987), commenting on Beales' (1980) work, observe that whilst a decline in pine pollen frequencies may be dated to c.2300 B.P. at Fenemere, the extinction of pine is not recorded at Fenemere until 1890 +/- 50 B.P. (SRR-2920). Although it seems likely that pine may have persisted on freer draining sandy soils for some considerable time, based upon biostratigraphical and archaeological evidence, Barber and Twigger (1987) and Twigger (1987) suggest that the dated pine decline at Crose Mere may be erroneous due to inwashed old carbon. A transition to wetter surface conditions at Whixall Moss, associated with the formation of a *Sphagnum papillosum*-*Sphagnum cuspidatum* lawn community at 2180 +/- 50 B.P. (SRR-3074), supports this interpretation.

The majority of Whixall Moss pines are preserved within a humified matrix. Though Eronen (1979), based on data from Finnish Lapland, has claimed that pines may withstand exposure for up to 700 years, in more temperate environments it seems that rapid inundation by *Sphagnum* peats is a necessary prerequisite to preservation. Hayen (1960) has reached similar conclusions working in German mires. Whilst *Sphagnum* preservation in the pre-MHC peats is poor, suggesting slow accumulation, radiocarbon dates indicate a mean peat accumulation rate between 42cm and 23cm of 13.2y/cm. Although this is higher than many post-MHC accumulation rates (Walker, 1970; Barber, 1982), it supports the view that the Whixall Moss pines were entombed comparatively rapidly.

THE ENGBERTSDIJKSVEEN

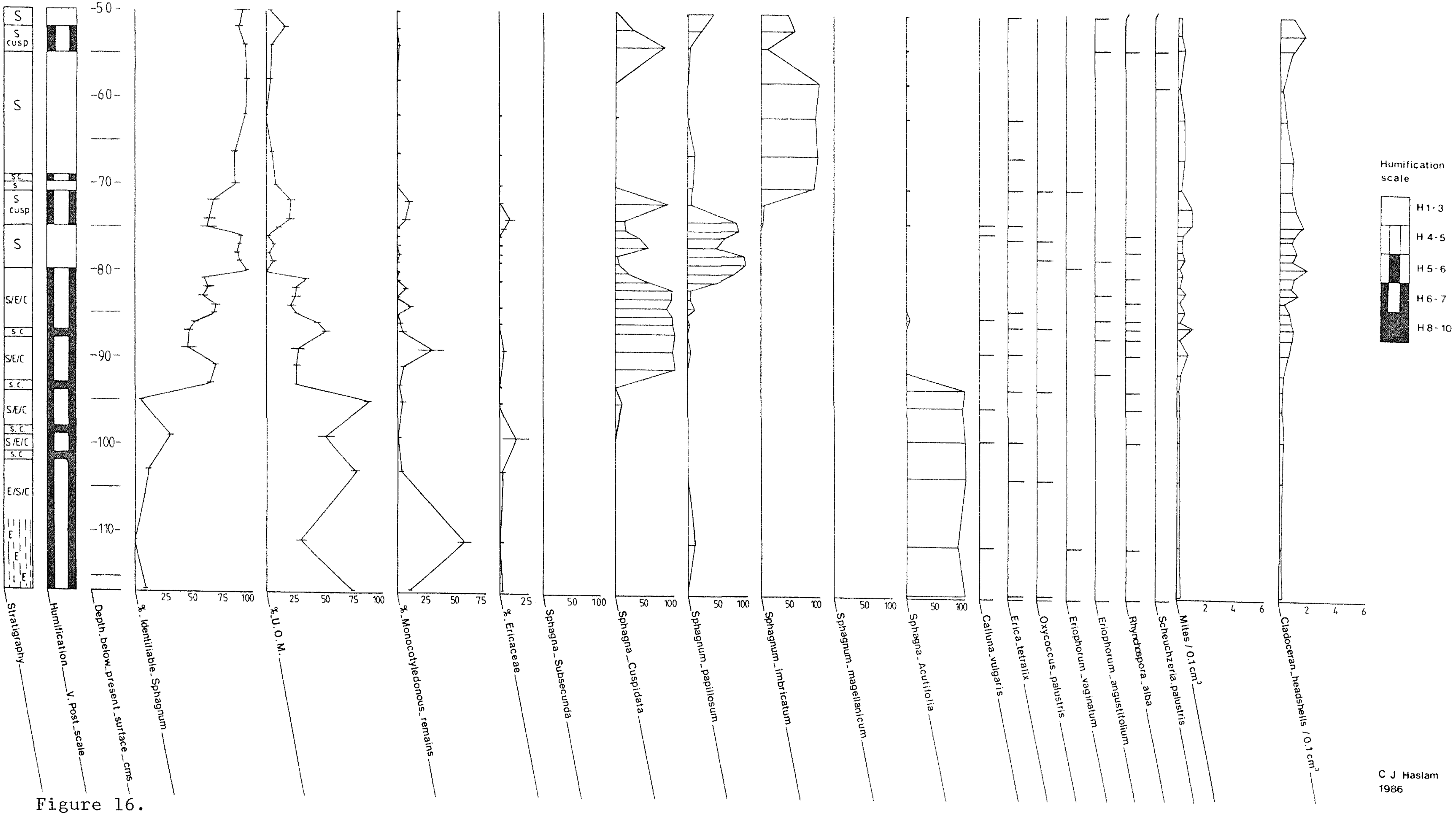

Figure 16.

5.3 THE LOW COUNTRIES OF GERMANY AND THE NETHERLANDS

5.31 THE ENGBERTSDIJKSVEEN

The macrofossil results for the Engbertsdijksveen section (figure 16) are comparable with those recorded for Engbertsdijksveen I (Van Geel, 1978) and VII (Dupont and Brenninkmeijer, 1984), Wietmarscher Moor (Van Geel, 1972) and The Meerstalblok (Dupont, 1986). This similarity, in spite of differences in local moisture conditions at each section, points to a climatic growth control.

The Subboreal-Subatlantic boundary can be placed at the 80cm level where Sphagna of the section Cymbifolia (*S. papillosum* and *S. imbricatum*) start to become important peat formers. Van Geel (1972, 1978) correlates this level with a *Fagus* rise and marked *Corylus* fall, indicating a shift towards more oceanic conditions.

The degree of decomposition in the lower pre-MHC peats is high. Ericaceae are dominant, particularly *Calluna vulgaris* and *Erica tetralix*, together with taxa of *Sphagnum* sect. *Acutifolia* (cf. *S. capillifolium*). Drier phases in this local dry hummock vegetation may be identified at 102cm, 98cm and 94cm. These are marked stratigraphically by a band of more humified peat, and in the macrofossil analyses by rises in % U.O.M.. A wet phase at 111cm is characterised by the appearance of the relatively hygrophilous *Sphagnum papillosum* and *Rhynchospora alba*. Epidermal remains of *Trichophorum caespitosum* were recorded at 93cm and 84cm. The ecological indicator value of this species is unclear (Sinker et al., 1985) though the identification of *Cenococcum geophilum*, *Arcella rotundata* and *Trigonpyxis arcula* at these levels suggest drier conditions (Van Geel, 1978).

The appearance of *Sphagnum cuspidatum* at 95cm, indicating wet local conditions, within the *Sphagnum* sect. *Acutifolia* (cf. *S. capillifolium*) peat provides evidence for sharp, temporary climatic fluctuations during this period. Similar observations have been made by Van Geel (1972, 1978) who correlates these phases with Corylus minima, indicating an increase in precipitation and/or lowering of the average summer temperature resulting in less evaporation. Casparie (1972) and Van Geel (1978) first note the appearance of Corylus fluctuations at c.3300 B.P.

Continued deterioration is marked by the replacement of Sphagnum sect. Acutifolia by Sphagnum cuspidatum at 92cm. Though unmarked stratigraphically, macrofossil analyses show a sharp rise in % identifiable Sphagnum and associated fall in % U.O.M. at this level. The presence of Sphagnum cuspidatum is indicative of extremely wet conditions or even of open water at the site. Other indicators of wet local conditions include Rhynchospora alba, Eriophorum angustifolium, Amphitrema flavum and Hyalosphenia papilio. A slightly drier phase, marked by a more humified band and a rise in % U.O.M. and Sphagnum sect. Acutifolia, is recorded at 87cm.

The relatively wet local conditions resulted in the initiation of the growth of unhumified Cymbifolia peat by the hygrophilous S. papillosum. The cladoceran population and hydrophilous rhizopods, mainly represented by Amphitrema flavum and Assulina muscorum, also show increased frequencies at this level. In both Engbertdijksveen I (Van Geel, 1978) and II (Dupont and Brenninkmeijer, 1984) a similar transition is recorded. Drier conditions at Wietmarscher Moor (Van Geel, 1972) resulted in the deposition of Sphagnum imbricatum peat. This boundary has been dated to 2815 +/- 55 B.P (GrN-7321)(Van Geel, 1978) and 2650 +/- 55 B.P (GrN-10999) (Dupont and Brenninkmeijer, 1984) at the Engbertsdijksveen and c.2400 B.P. at Wietmarscher Moor (Van Geel, 1972).

Progressive pool infill is accomplished by Sphagnum papillosum, although wetter phases at 77cm and 72cm, marked by an increase in Sphagnum cuspidatum, may be identified. A shift to drier conditions, initially at 74cm and then at 69cm, is indicated by a sharp rise in Sphagnum imbricatum. Sphagnum imbricatum dominates the remainder of the section. The occurrence of Sphagnum sect. Acutifolia (cf. S. capillifolium) as a minor peat constituent between 62cm and 57cm may indicate a less oceanic

Figure 17.

THE ENGBERTSDIJKSVEEN

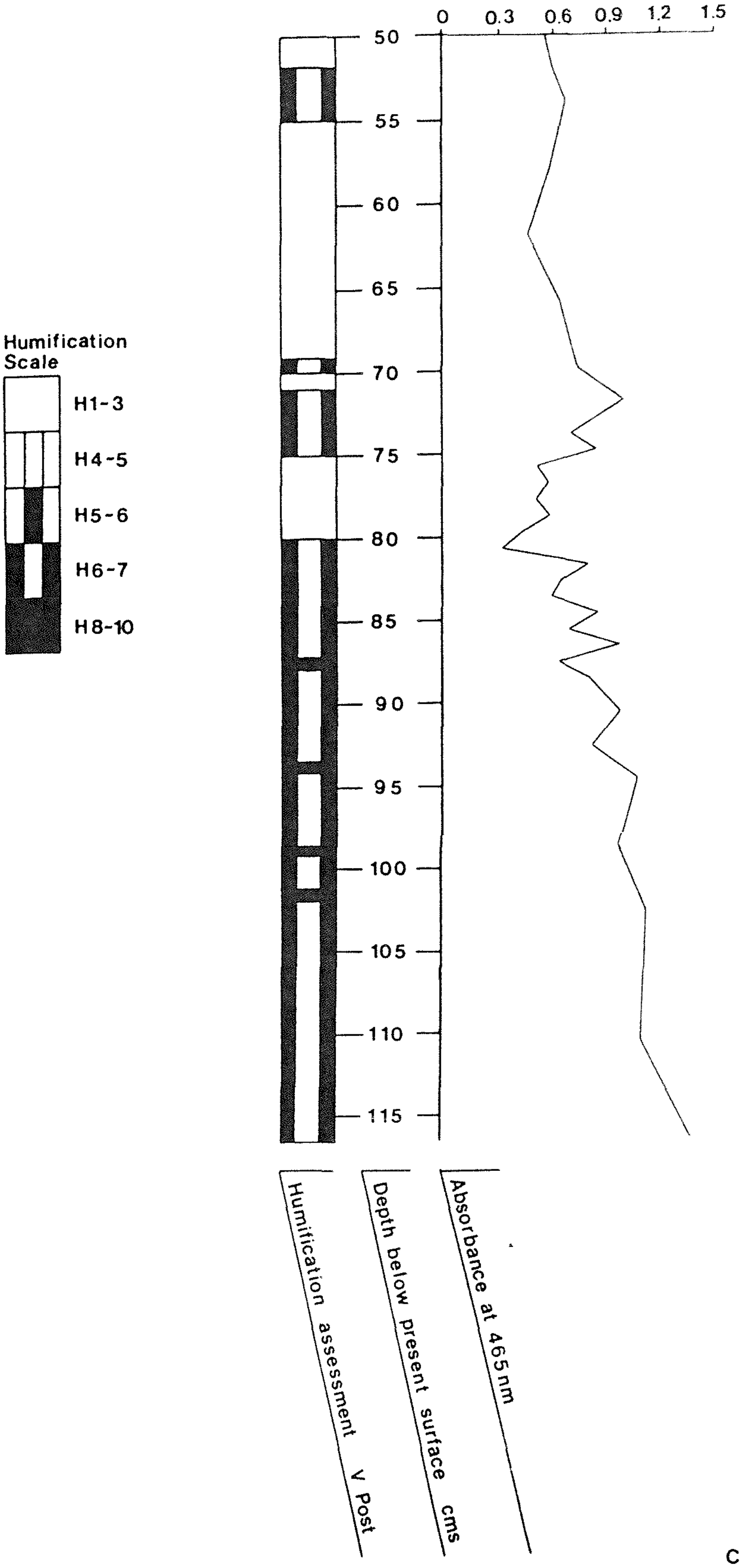

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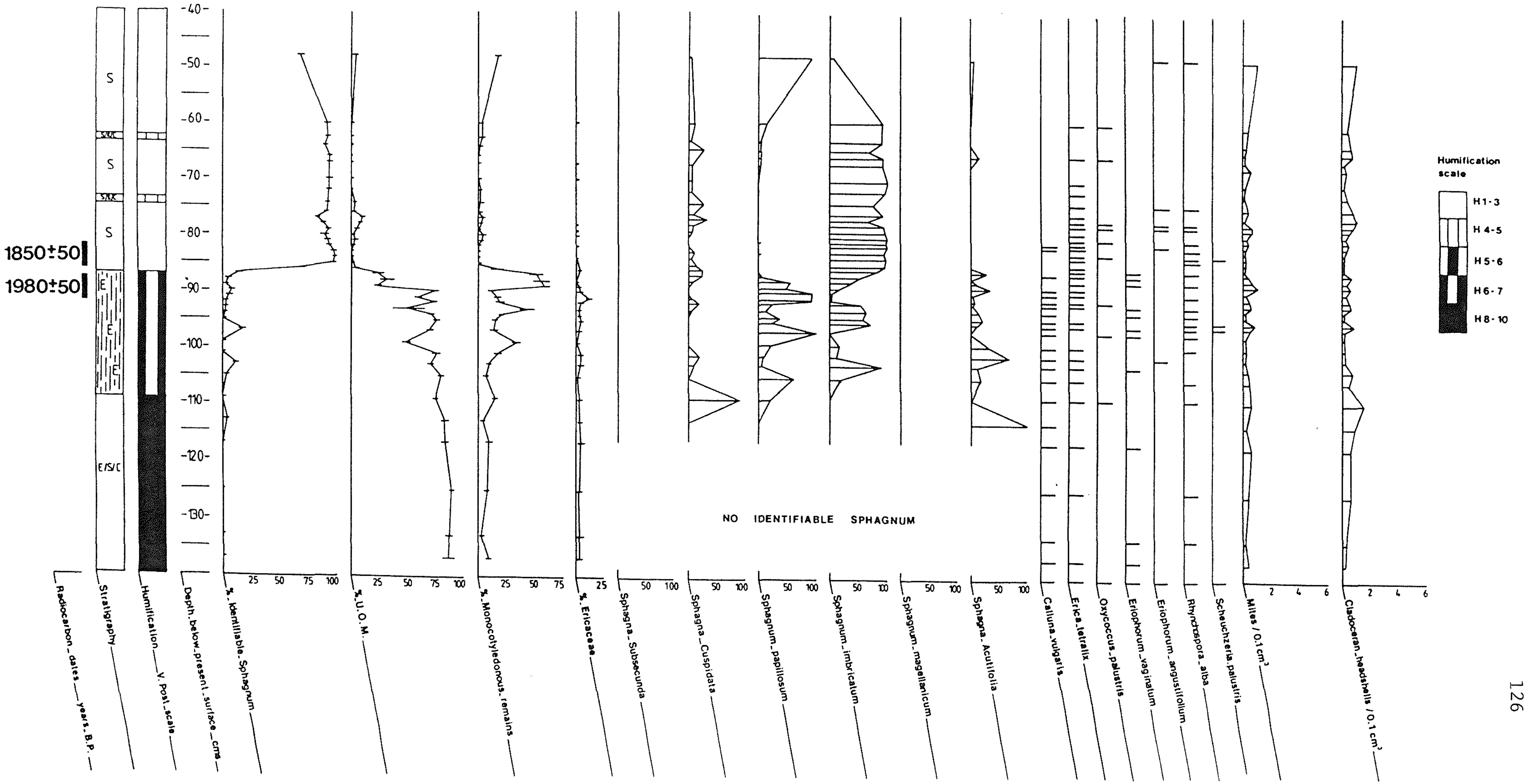
Figure 18.

JÜHRDENER MOOR



phase. Casparie (1972, p.240) notes that the recognition of sharp wet-dry fluctuations in unhumified Cymbifolia peats is particularly difficult due to the water absorption capacity of Sphagnum imbricatum, S. papillosum and S. magellanicum. Renewed pool formation with Sphagnum cuspidatum, Eriophorum angustifolium, Rhynchospora alba and Scheuchzeria palustris occurred between 55cm and 52cm. Pool infill is accomplished by a Sphagnum papillosum-S. imbricatum association.

The Engbertsdijksveen humification profile (figure 17) shows a gradual trend towards more oceanic conditions at the site, with sharp, short-term climatic oscillations. In particular, the immediate pre (90cm-80cm) and post-MHC (80cm-72cm) absorbances reveal a complex series of shifts between more and less humifying conditions, suggesting that any shift in peat formation was not the result of a simple, direct climatic deterioration. This interpretation is supported by the findings of the macrofossil investigations.

5.32.1 JUHRDENER MOOR, GERMANY

The Subboreal-Subatlantic boundary may be placed at the 87cm level where a pronounced rise in % identifiable Sphagnum occurs (figure 18). Stratigraphically this is marked by a distinct shift to unhumified peat and the establishment of Sphagnum imbricatum as the main peat former. The existence of sharp, short-term climatic fluctuations in both pre- and post-MHC peats is evident.

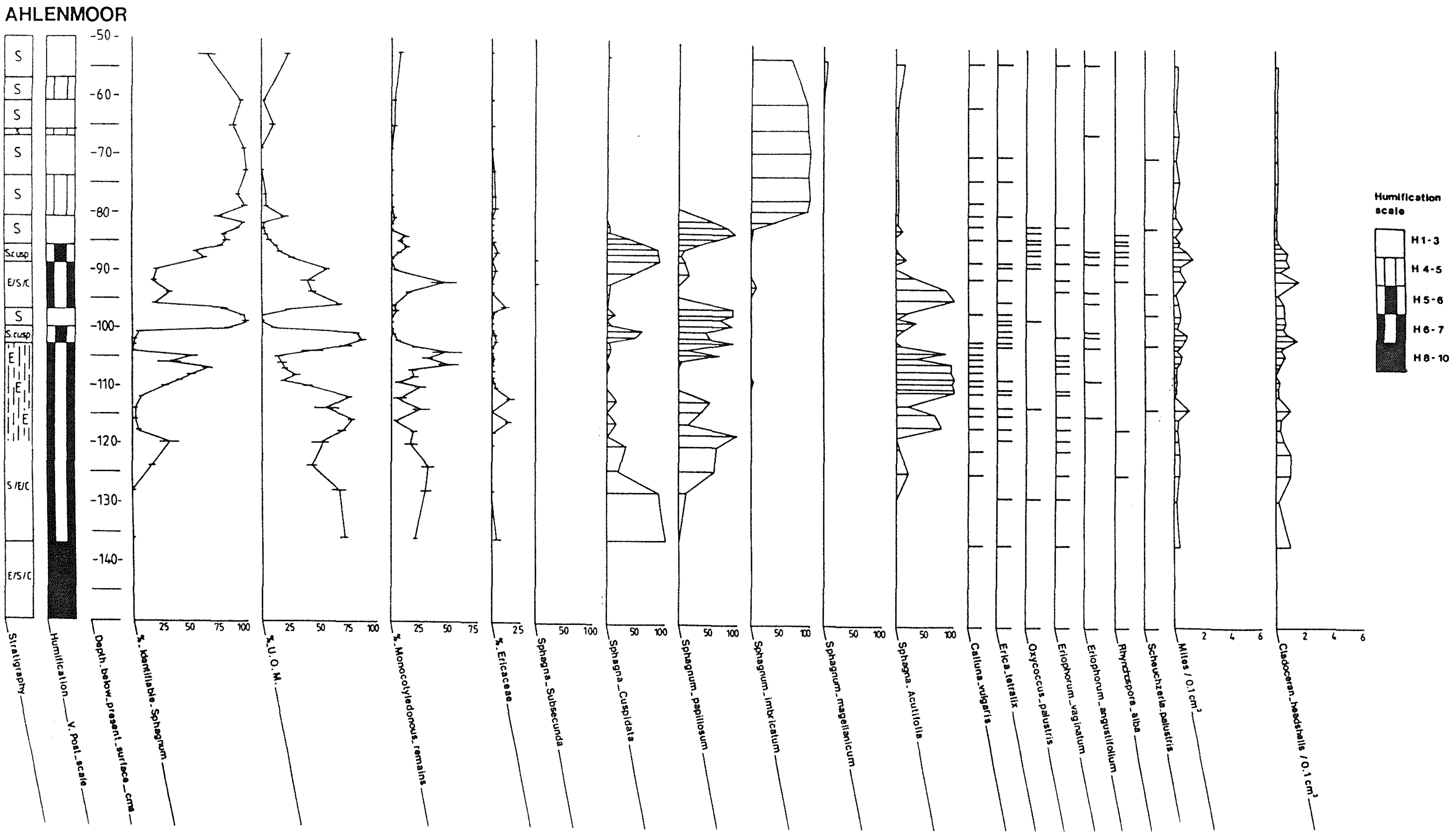
The lower levels of the section (139cm to 109cm) are characterised by a particularly humified matrix, H8-10 on the Von Post scale, in which no identifiable Sphagnum was recorded. Though isolated fragments of Rhynchospora alba were identified, high values of % U.O.M. and % Ericaceae, mainly represented by Calluna vulgaris, and the presence of Eriophorum vaginatum indicate a local dry hummock vegetation. As Van Geel (1978) notes, whilst Rhynchospora alba is typically associated with relatively wet conditions, it may persist for some time following drainage.

Sclerotia of Cenococcum geophilum, and an Arcella rotundata-Trigonpyxis arcula assemblage characterised the faunal population in these peats. Though Cenococcum geophilum grows under a variety of ecological conditions (Ferdinandsen and Winge, 1925), both Van Geel (1978) and Bakker and Smeerdijk (1982) state that it may occur in raised mires only under relatively dry conditions. The presence of Arcella rotundata and Trigonpyxis arcula in more xerophytic communities has been discussed by Grospietsch (1958) and Tolonen et al. (1985)

A shift to a marginally less humified matrix at 109cm coincides with a rise in % identifiable Sphagnum and the establishment of Eriophorum vaginatum as an important peat constituent. The moss flora, which constituted only 9% of the peat, is mainly dominated by Sphagnum cuspidatum and S. papillosum. Damp surface conditions are indicated, though it seems unlikely that full pool conditions were developed. A return to drier conditions at 104cm is suggested by successive rises in Sphagnum imbricatum and Sphagnum sect. Acutifolia (cf. S. capillifolium). Erica tetralix and Oxycoccus palustris indicate a relatively wet low hummock situation. A second shift to wetter conditions is noted at 97cm. Sphagnum papillosum, Rhynchospora alba and Scheuchzeria palustris characterize this wet lawn vegetation. A fall in % identifiable Sphagnum and rise in % U.O.M. and % Monocotyledonous remains marks a temporary 'dry' phase with Sphagnum imbricatum. Sphagnum sect. Acutifolia (cf. S. capillifolium) is a minor peat constituent. A third 'wet' phase in the immediate pre-MHC peats is associated with a Sphagnum papillosum expansion and the appearance of Trichophorum caespitosum. Sinker et al. (1985) note that the ecological indicator value of this species is unclear. The observation of fragments pertaining to both wet lawn (Juhrdener Moor, 92cm-87cm) and dry hummock (The Engbertsdijksveen, 93cm and 84cm) environments supports this interpretation.

An internal mire threshold is crossed at 87cm resulting in the deposition of poorly decomposed Sphagnum imbricatum. The peats directly above and below this boundary have been dated to 1850 +/- 50 B.P. (SRR-3167) and 1980 +/- 50 B.P. (SRR-3168) respectively. The presence of Sphagnum tenellum, Erica tetralix and Oxycoccus palustris indicates a wet low hummock environment. Low frequencies of Rhynchospora alba,

Figure 19.


AHLENMOOR
S
S.cusp
E/S/C
E
S/E/C
-50-
-60-
-70-
-80-
-90-
-100-
-110-
-120-
-130-
-140-
25 50 75 100
25 50 75
2 4 6
Humification scale
H1-3
H4-5
H5-6
H6-7
H8-10
Stratigraphy
Humification V. Post. scale
Depth below present surface cms
% Identifiable Sphagnum
% U.O.M.
% Monocotyledonous remains
% Ericaceae
Sphagna Subsecunda
Sphagna Cuspidata
Sphagnum papillosum
Sphagnum imbricatum
Sphagnum magellanicum
Sphagna Acutifolia
Calluna vulgaris
Erica tetralix
Oxycoccus palustris
Eriophorum vaginatum
Eriophorum angustifolium
Rhynchospora alba
Scheuchzeria palustris
Mites / 0.1 cm³
Cladoceran headshells / 0.1 cm³

Eriophorum angustifolium and *Scheuchzeria palustris* were also recorded at this level.

Sphagnum preservation is particularly good in the post-MHC peats, values of % identifiable Sphagnum rarely falling below 90%. Evidence for sharp dry-wet fluctuations in this unhumified matrix is ambiguous. However, the occurrence of a *Cenococcum geophilum-Arcella rotundata-Trigonpyxis arcula* association between 74cm and 64cm correlates with an expansion of *Sphagnum tenellum* indicating drier local conditions. A hygrocline phase from 60cm to the top of the section is marked by a return to a wet lawn environment with *Sphagnum papillosum* and *S. cuspidatum*.

5.32.2 AHLENMOOR, GERMANY

The Ahlenmoor section (figure 19) displays a complex series of wet-dry fluctuations. Both field humification and sequence of Sphagna display similarities with the macrofossil results obtained from other western oceanic sites. In particular, the shift from *Sphagnum cuspidatum*, through *S. papillosum*, to *S. imbricatum* recorded in the immediate pre- and post-MHC peats at The Engbertsdijksveen and Juhrdener Moor is similarly repeated at Ahlenmoor. In addition, a band of unhumified Cymbifolian peat at 98cms, similar to that in the upper matrix of the Tregaron West bog section, may also be identified.

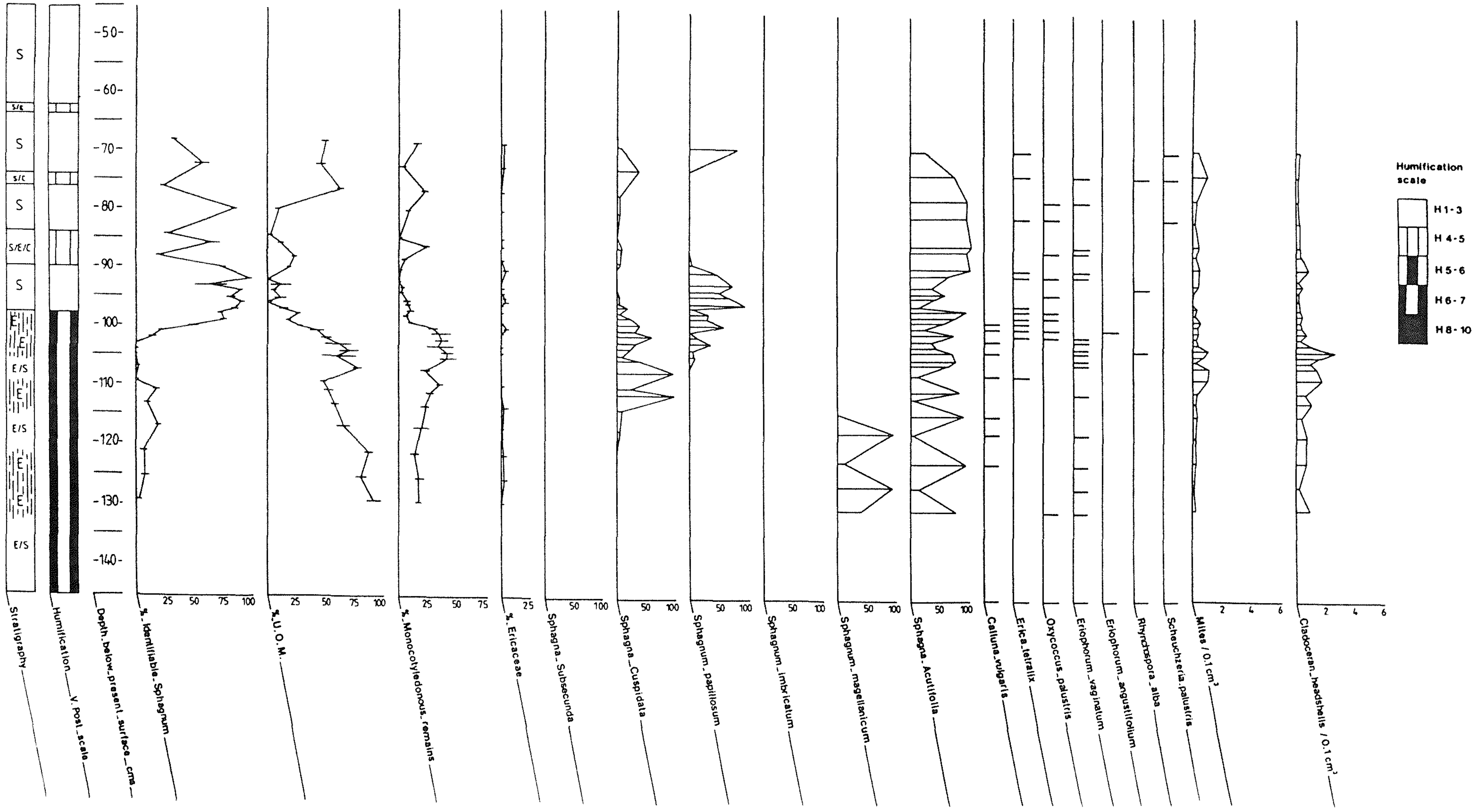
The two lowest samples have very low % identifiable *Sphagnum*, but what is recognisable is mainly *Sphagnum cuspidatum*. The replacement of *Sphagnum* sect. *Cuspidata* by a *S. papillosum-Sphagnum* sect. *Acutifolia* association above 127cm suggests a shift to drier conditions. The existence of a wet lawn community at 120cm with *Sphagnum papillosum* and occasional *Erica tetralix*, *Eriophorum vaginatum* and *Rhynchospora alba* is more certain. Following temporary desiccation at 116cm, this community is replaced by local dry hummock vegetation between 111cm and 104cm. Particularly dry conditions are indicated by the occurrence of *Sphagnum* sect. *Acutifolia*, *Calluna vulgaris* and *Eriophorum vaginatum*. This interpretation is supported by the identification of a *Cenococcum geophilum*-*Trigonpyxis arcula*-*Arcella rotundata* association in the upper levels of this phase. In contrast to Juhrdener Moor, *Sphagnum imbricatum* is absent from this succession.

A shift to wetter conditions, involving a series of minor oscillations, results in the formation of the band of unhumified Cymbifolian peat noted previously. A corresponding rise in % identifiable *Sphagnum* to almost 100% occurs. *Sphagnum papillosum* with an admixture of *S. cuspidatum* and *S. tenellum* dominates the moss flora whilst *Eriophorum angustifolium* and *Scheuchzeria palustris* are the principal higher plants in this very wet lawn environment. The hydrophilous rhizopods, *Amphitrema flavum*, *Hyalosphenia papilio* and *Assulina muscorum*, also show increased frequencies at this level. Drier conditions between 97cm and 89cm see the re-establishment of *Sphagnum* sect. *Acutifolia* (cf. *S. capillifolium*) as the dominant peat former and a rise in % U.O.M.. *Sphagnum imbricatum* is recorded as a minor peat constituent. A *Cenococcum geophilum*-*Trigonpyxis arcula*-*Arcella rotundata* association indicates dry hummock conditions. Fragments of *Aulacomnium palustre* were noted at 90cm, 96cm and 98cm. Dickson (1973) observes that this species is tolerant of a wide range of conditions in mires and thus has little indicator value, whilst Barber (1981, p.50) notes that it occurs when some drainage or mineralisation has taken place.

Renewed deterioration at 89cm, marked by a rise in % identifiable *Sphagnum* and associated fall in % U.O.M., results in pool formation. Characterised by greasy *Sphagnum cuspidatum*/algal muds, *Scheuchzeria palustris*, *Rhynchospora alba*, *Eriophorum angustifolium* and the seemingly ubiquitous *Eriophorum vaginatum* are also recorded. Particularly high values of the rhizopod *Hyalosphenia papilio* were obtained at this level. Pool infill by *Sphagnum papillosum* marks the formation of the unhumified matrix. Several dates for the peat above this boundary have been obtained by Schneekloth (1970). These range from 2140 +/- 190 B.P. (Hv-197) to 2500 +/- 100 B.P. (Hv-2034). A band of slightly more humified peat between 81cm and 74cm is associated with a rise in % U.O.M. and the establishment of *Sphagnum imbricatum* as the dominant peat former. This level coincides with a minor rise in *Sphagnum* sect. *Acutifolia*, possibly indicating a less oceanic

Figure 20.

EKEL MOOR



phase.

'Dry' shifts in the post-MHC matrix were recognised in the field at 66cm and between 61cm and 57cm. Macrofossil analyses failed to record any trend towards a drier vegetation at these levels however. This may in part reflect the buffering capacity of the Cymbifolian peat (Casparie, 1972, p.240).

5.32.3 EKEL MOOR, GERMANY

Contrary to the observations of Scheekloth and Tuxen (1978), Sphagna of the section Cymbifolia were minor peat constituents in the post-MHC matrix. No *Sphagnum imbricatum* was recorded. The dominance of *Sphagnum* sect. *Acutifolia* throughout the Subboreal-Subatlantic transition characterises the section (figure 20). This reflects the influence of continental conditions on the site.

A local dry hummock vegetation with *Sphagnum* sect. *Acutifolia* and *Eriophorum vaginatum*, in which *Oxycoccus palustris*, immigrating from the surrounding low hummock environment, was an important constituent, is suggested at the base of the section. Wetter conditions are indicated at 125cm and 118cm by the occurrence of *Sphagnum magellanicum*, typically associated with a lawn environment (Daniels and Eddy, 1984). Significantly, remains of *Polytrichum alpestre* were identified at 129cm and 125cm. According to Landwehr (1966) and Dickson (1973) *Polytrichum alpestre* forms hummocks on ombrotrophic mires. Van Geel (1978) is more specific, observing that *Polytrichum alpestre* remains are typically associated with the upper levels of hummock phases when the hummock is overgrown and conserved by a wetter type of vegetation. The marked *Sphagnum magellanicum* expansion at 125cm supports this interpretation.

Alternating wet lawn-dry hummock vegetation characterises the late Subboreal deterioration. Though fragments of *Sphagnum cuspidatum* were identified at 111cm, a *Sphagnum tenellum*-*S. papillosum* association appears more typical of wet phases. Dry shifts at 109cm and 104cm coincide with rises in % U.O.M. and increased frequencies of Sphagnum sect. Acutifolia, Calluna vulgaris and Eriophorum vaginatum. Particularly dry hummock conditions are suggested at 104cm by the occurrence of Cenococcum geophilum and Trigonpyxis arcula within a highly degraded Eriophorum tussock.

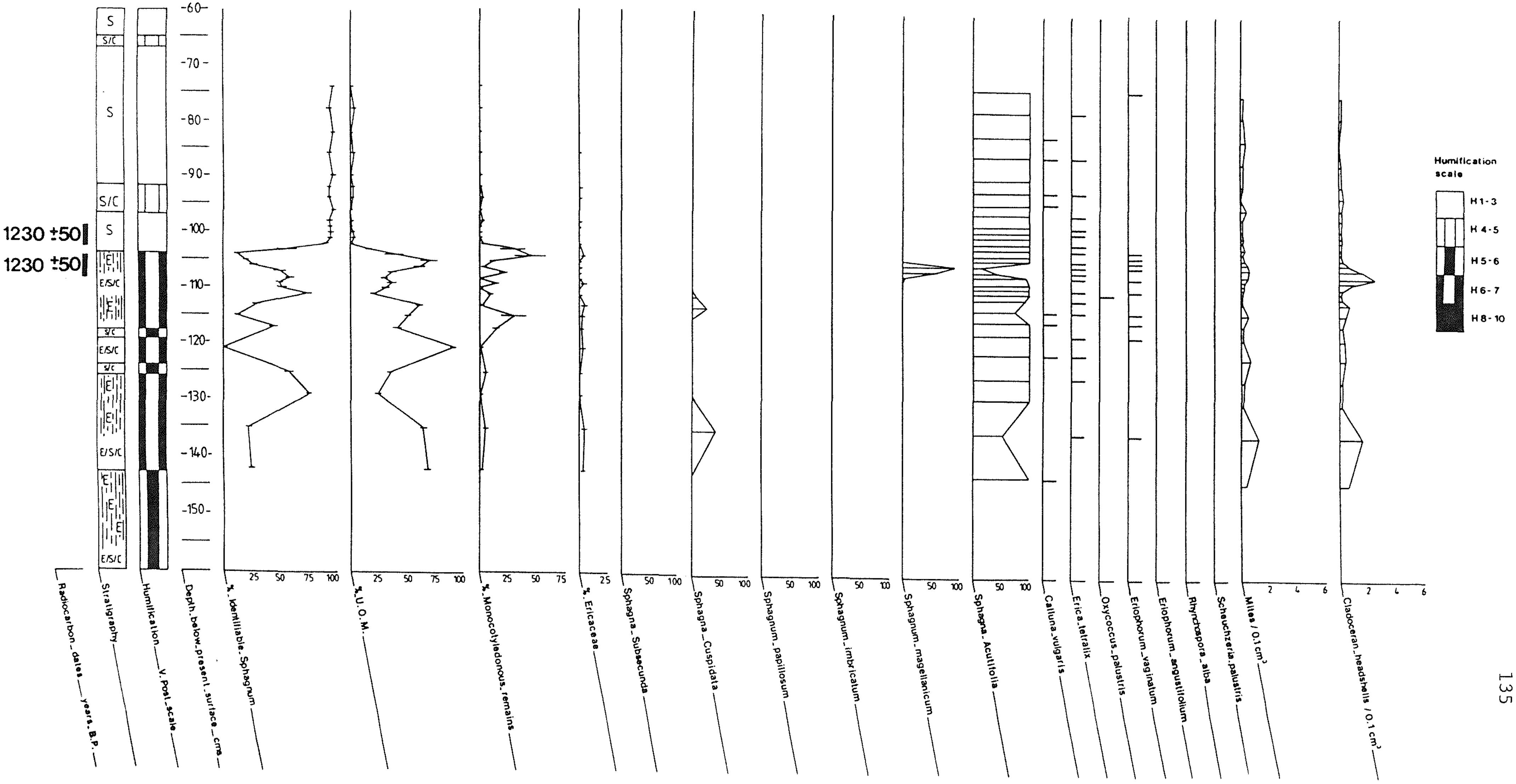
A marked rise in % identifiable Sphagnum denotes the transition to the Subatlantic. The moss flora, consisting of a Sphagnum tenellum-S. cuspidatum-S. papillosum-Sphagnum sect. Acutifolia association, records a series of sharp, short-term dry-wet fluctuations. Relatively wet local conditions at 103cm and 99cm are reflected by increased frequencies of Sphagnum cuspidatum, S. tenellum, S. papillosum, Rhynchospora alba and Eriophorum angustifolium. Assulina muscorum and Amphitrema flavum, both characteristic of moderately moist to wet Sphagnum swards, also show increased frequencies at these levels. The shift to unhumified peat formation at 98cm, dated to 2210 +/- 65 B.P. (Hv-13259)(Schwaar, personal communication), coin cides with the establishment of Sphagnum papillosum as the dominant peat former. The persistence of Sphagnum sect. Acutifolia together with Erica tetralix and Oxycocus palustris suggests a low hummock-dry lawn environment.

Marginally drier conditions at 90cm, shown by a band of more humified peat and a rise in % U.O.M., appears to initiate the replacement of Sphagnum papillosum by Sphagnum sect. Acutifolia as the main peat constituent. Though the parent species remains undetermined due to identification difficulties of subfossil remains, the rhizopod assemblage does not indicate wet local conditions. Indeed, a Cenococcum geophilum-Trigonpyxis arcula association is typical of relatively dry hummock situations. The demonstrated tendency towards a 'dry' local vegetation succession in the Ekel Moor section introduces the possibility that lowering of the average summer temperature may have been more important in inducing this stratigraphical shift than an increase in precipitation.

The appearance of Scheuchzeria palustris at 79cm followed by Eriophorum angustifolium, Sphagnum cuspidatum and S. papillosum at 72cm marks a renewed deterioration and transition to lawn conditions. Sharp

Figure 21.

LICHTENMOOR



fluctuations in % identifiable Sphagnum, % U.O.M. and % Monocotyledonous remains, though unmarked stratigraphically, provide additional evidence for an oscillatory climatic deterioration associated with the Subboreal-Subatlantic transition.

5.32.4 LICHTENMOOR, GERMANY

The macrofossil results from Lichtenmoor (figure 21) show that Sphagnum sect. Acutifolia was the major peat former in both pre- and post-MHC peats. Identification to the parent species remains undetermined, though based on differences in branch leaf basal pore size and the contrast between size of the cells in the leaf base and those at the apex it is suggested that they are probably of Sphagnum fuscum with infrequent Sphagnum capillifolium. This is in accordance with the demonstrated preference of this species for more continental conditions.

A complex series of humification changes characterise the pre-MHC matrix. The Sphagnum sect. Acutifolia (cf. S. fuscum)-Eriophorum vaginatum association indicates local dry hummock vegetation. Low frequencies of Calluna vulgaris throughout the section support this interpretation. Shifts to wetter conditions at 130cm, 117cm and 111cm are marked by rises in % identifiable Sphagnum and associated reductions in % U.O.M. The shift at 130cm appears to be recorded by variations in the macrofossil components some time before the oscillation is manifested stratigraphically, whilst at 111cm, though reduced abundance of Eriophorum vaginatum was noted in the field, no change in peat humification was observed. The advantages of detailed macrofossil analyses in revealing shifts in surface wetness are apparent.

Sphagnum tenellum and Erica tetralix invade the S. fuscum dominated low hummock at 134cm and mark a temporary shift to a wetter surface. The hydrophilous rhizopods, mainly represented by Hyalosphenia papilio and Amphitrema flavum also show increased frequencies at this level. A second shift at 117cm, though marked stratigraphically by a band of less humified

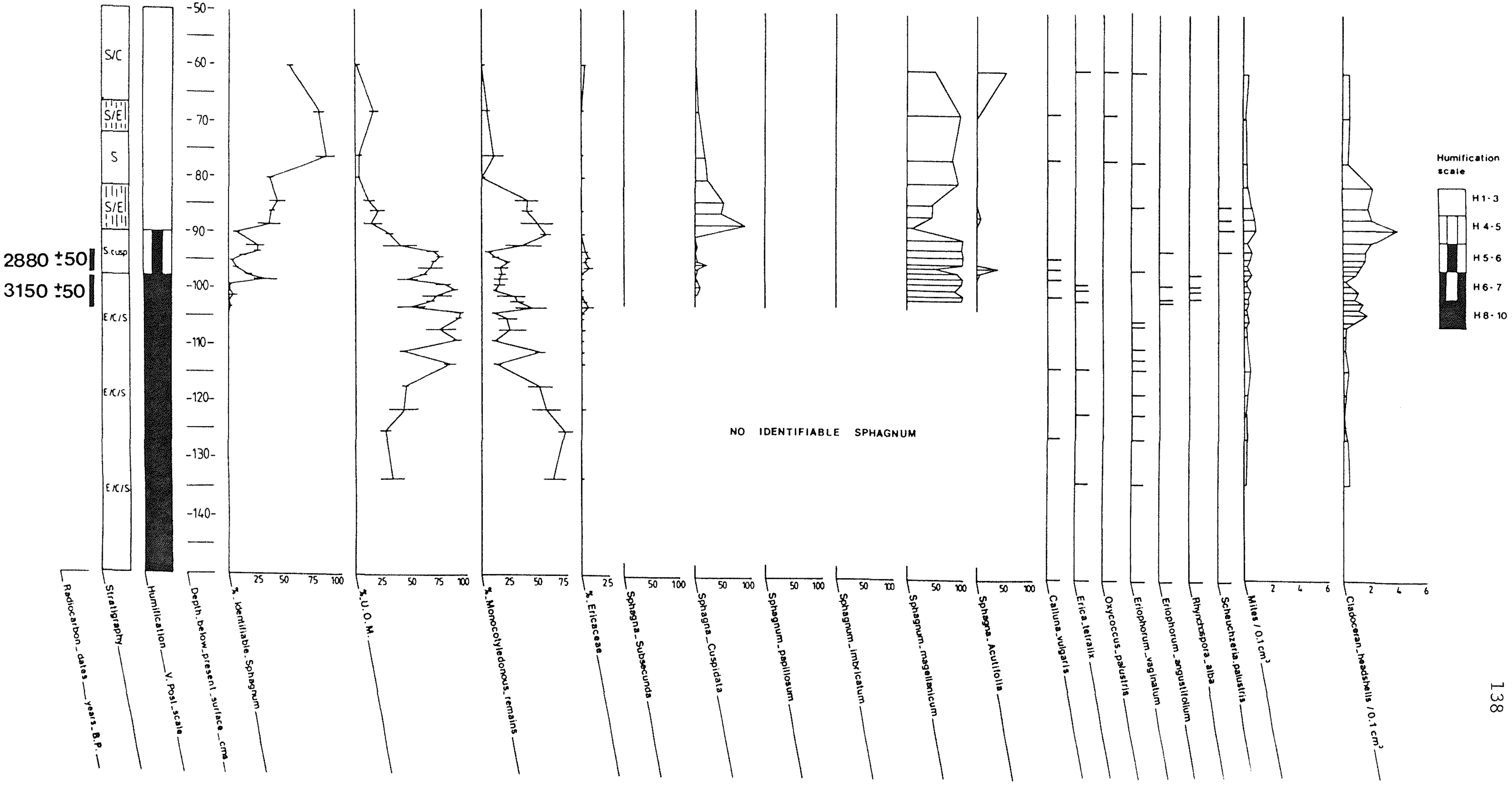
(H5-6) peat, does not elicit a change in a moss flora dominated by *Sphagnum* sect. *Acutifolia* (cf. *S. fuscum*). Hummock growth appears to have been unaffected. Renewed deterioration between 112cm and 107cm, with two prominent 'wet' phases at 111cm and 108cm, coinicides with the successive establishment of *Sphagnum tenellum* and *S. magellanicum*. Daniels and Eddy (1984) indicate that both these species display a wide tolerance range with regard to water levels. The presence of *Erica tetralix* and *Oxycoccus palustris* in the *Sphagnum tenellum-S. fuscum* association indicates an open wet, low hummock situation. Drier conditions are associated with the *Sphagnum magellanicum-S. fuscum* assemblage, and in particular, the occurrence of a *Cenococcum geophilum-Trigonpyxis arcula-Arcella rotundata* zooflora indicates relatively dry hummock conditions. Though *Sphagnum magellanicum* appears to favour oceanic situations, its presence in drier northern and eastern European mires has been commented upon by several workers (Kulczynski, 1949; Isoviita, 1966; Daniels and Eddy, 1984).

The initiation of unhumified peat formation at the 104cm level coincides with a sharp rise in % identifiable *Sphagnum* and falls in both % U.O.M. and % Monocotyledonous remains, mainly *Eriophorum vaginatum*. Together with cladoceran remains, *Amphitrema flavum* and *Assulina muscorum*, both typical of moist to wet *Sphagnum* swards, show increased frequencies at this level. *Sphagnum* sect. *Acutifolia* (cf. *S. fuscum*) is the dominant peat former. The peats directly below and above this boundary have been dated to 1230 +/- 50 B.P. (SRR-3170) and 1230 +/- 50 B.P. (SRR-3169) respectively. The macrofossil assemblage, *Sphagnum fuscum* with *Erica tetralix* and occasional *Calluna vulgaris*, indicates the existence of an open 'dry' low hummock vegetation. Recorded frequencies of zoofossils remain low throughout the post-MHC matrix and fragments of *Aulacomnium palustre* were noted at 101cm, 93cm and 82cm. A band of more humified peat between 97cm and 92cm is not reflected by changes in the macrofossil assemblage.

The most striking feature of the Lichtenmoor section is the demonstrated tendency towards a 'dry' hummock vegetation. Formation of open lawn or pool conditions did not occur. *Sphagnum fuscum*, the principal peat former, commonly forms dense, usually low and wide but occasionally higher hummocks in open situations (Isoviita, 1966; Smith, 1978). It appears therefore, that the climatic oscillation promoting the deposition of an

Figure 22.

TOTES MOOR



unhumified matrix may not have involved a marked shift towards increased surface wetness and the formation of open pool/wet lawn conditions at this site.

5.32.5 TOTES MOOR, GERMANY

The Totes Moor section displays a simple humification profile (figure 22), with a striking transition between lower humified and upper unhumified peat. The initial rise in % identifiable Sphagnum at the 98cm level was designated as the MHC. Similarity with the macrofossil results obtained from eastern Poland (Section 5.5) is apparent, reflecting the continental tendencies of this site.

Basal peats are particularly humified, H8-10 on the Von Post scale, possessing little structure and no identifiable Sphagnum. Eriophorum vaginatum, together with low frequencies of Erica tetralix and Calluna vulgaris were the only macrofossil components recorded in these peats. Numbers of zoofossils were also low. A dry hummock vegetation is indicated. Though no stratigraphic variations were noted in the pre-MHC peats, oscillations in the curve for % U.O.M. and % Monocotyledonous remains suggest the existence of temporary wet-dry shifts. 'Dry' shifts at 114cm, 109cm and 100cm coincide with peaks in % U.O.M. Remains of Molinia caerulea were noted between 103cm and 101cm. Fitter et al. (1984) state that Molinia caerulea is typically associated with a fluctuating water table. Similar observations have been made by Van Geel (1978) who concludes that dry summers and wet conditions during winter and early spring favour establishment. This provides strong evidence for sharp oscillations in the mire water table prior to MHC formation and additionally suggests that an increase in surface moisture during the effective vegetative season may not have been responsible for the shift in peat formation. More recently, Van Geel and Dallmeijer (1986) have indicated that the development of Molinia vegetation at The Engsbertsdijksveen may be attributable to localised burning. Whether climatic or anthropogenic factors were responsible for this burning remain unclear.

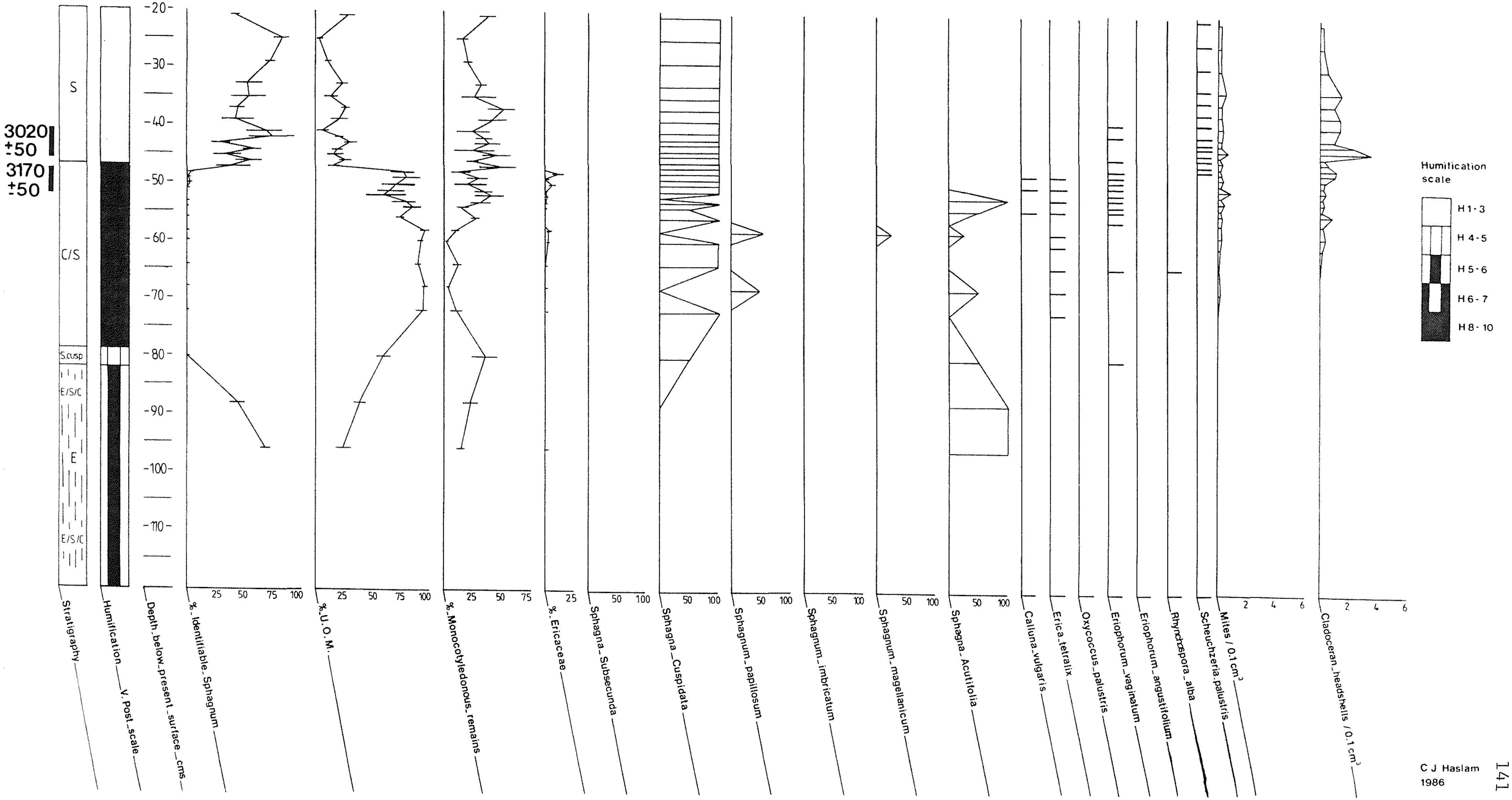
The rise in % identifiable Sphagnum at 98cm coincides with the identification of Sphagnum magellanicum as the dominant moss. Though preservation was poor, fragments of Sphagnum sect. Cuspidata and Sphagnum sect. Acutifolia were also isolated. This association is typical of more eastern continental mires and has been described in detail by Kulczynski (1949) and more recently by Liwski et al. (1984). It seems likely that Sphagnum sect. Cuspidata is represented by S. recurvum, and Sphagnum sect. Acutifolia by S. warnstorfii. Calluna vulgaris, Erica tetralix, Eriophorum angustifolium and Rhynchospora alba were also recorded at this level. A lawn/low hummock situation is suggested. The peats directly below and above this stratigraphic transition have been dated to 3150 +/- 50 B.P. (SRR-3172) and 2880 +/- 50 B.P. (SRR-3171) respectively.

Temporary dry phases at 95cm and 90cm are characterised by a fall in % identifiable Sphagnum and the establishment of more xerophytic communities. Aulacomnium palustre was noted at 95cm and Polytrichum alpestre with a Cenococcum geophilum-Arcella rotundata association was recorded at 90cm. As noted previously (Section 5.32.3), Polytrichum alpestre is typically associated with the upper levels of hummock phases when the hummock vegetation is overgrown and conserved by a wetter type of vegetation (Van Geel, 1978). The expansion of Sphagnum sect. Cuspidata (cf. S. recurvum) and Scheuchzeria palustris at 89cm supports this interpretation. Kulczynski (1949, p.74) refers to this association as a 'meadow raised mire' characterised by the absence of Sphagnum magellanicum low hummocks. Amphitrema flavum and the cladoceran population show increased frequencies at this level.

A gradual return to drier conditions, and the re-establishment of low hummocks dominated by Sphagnum magellanicum with Eriophorum vaginatum, Calluna vulgaris and infrequent Erica tetralix, is indicated between 85cm and 80cm. This association is referred to as the 'forest raised mire' by Kulczynski (1949). Although a pine stump layer is present in the lower pre-MHC matrix, no subfossil trees were identified in the post-MHC peats.

Figure 23.

GIFHORN MOOR



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5.32.6 GIFHORN MOOR, GERMANY

The abrupt transition between humified and unhumified peat at Gifhorn Moor is striking (figure 23) and has been commented upon by several workers (Schneekloth, 1965; Overbeck, 1975). A zone of highly degraded peat with little recognisable structure, similar to that identified at Totes Moor (150-98cm, Section 5.32.5), characterises the pre-MHC matrix. Macrofossil preservation at these levels was poor, *Sphagnum* identification frequently being based on one or two branch leaf fragments. Recorded fluctuations in the moss flora must therefore be interpreted with caution.

Eriophorum vaginatum with *Sphagnum sect. Acutifolia* (cf. *S. capillifolium/ S. fuscum*) and infrequent *Calluna vulgaris* is associated with the lower levels of the section. Values of % identifiable *Sphagnum* are moderately high but show a gradual decrease towards the zone boundary at 82cm. A hummock situation is suggested. Field observations indicated transgression of this hummock by *Sphagnum cuspidatum* pool peats. Macrofossil analyses, whilst showing an expansion of *Sphagnum* sect. *Cuspidata* and associated decline in *Sphagnum* sect. *Acutifolia*, also record a fall in % identifiable *Sphagnum* at this level. Any trend towards increased surface wetness was temporary therefore.

Between 79cm and 47cm a degraded matrix is associated with particularly high values of % U.O.M. A series of wet-dry shifts is recorded by the moss flora, though as noted earlier, ecological interpretation is problematic given the low values of % identifiable *Sphagnum*. Drier local conditions are indicated at 68cm by the shift from *Sphagnum* sect. *Cuspidata* to a *S. papillosum*-*Sphagnum* sect. *Acutifolia* association. The parent species for both *Sphagnum* sect. *Cuspidata* and *Sphagnum* sect. *Acutifolia* remains undetermined due to poor preservation. A temporary 'wet' phase at 60cm, coinciding with a rise in *Sphagnum* sect. *Cuspidata* and the appearance of *Rhynchospora alba*, is followed by a return to drier low hummock vegetation with a *Sphagnum papillosum*-*Sphagnum sect. Acutifolia*-*S. magellanicum* association. Rhizopod frequencies rise for the first time at this level, *Cenococcum geophilum* and *Trigonpyxis arcula* indicating relatively dry conditions. The presence of *Eriophorum vaginatum* and *Calluna vulgaris* with infrequent *Erica tetralix* supports this interpretation.

A rise in % identifiable *Sphagnum* at 50cm coincides with the establishment of *Sphagnum* sect. *Cuspidata* as the dominant peat former and the onset of wetter surface conditions. Shallow pool/very wet lawn conditions are suggested by the abundance of *Scheuchzeria palustris* remains. Although Ericaceae, mainly represented by *Calluna vulgaris*, were rapidly eradicated from this environment, *Eriophorum vaginatum* persists for some time following the water-table rise. Similar observations have been made elsewhere (Casparie, 1972; Barber, 1981). The establishment of *Scheuchzeria palustris* coincides with the transition to an unhumified matrix. The peats directly below and above this transition have been dated to 3170 +/- 50 B.P. (SRR-3174) and 3020 +/- 50 B.P. (SRR-3173). Overbeck et al. (1957) dated the peat below the MHC to 2100 +/- 100 B.P. (Hv-71/85) and the immediate post-MHC peats to 2045 +/- 110 B.P. (Hv-72/88) in a core taken towards the western margin of the mire. The considerable age difference for the same stratigraphic feature is problematic. However, the marginal nature of Overbecks' (1957) site and the resultant possibility that local edaphic and hydrological factors may have influenced 'fresh' *Sphagnum* peat initiation needs to be explored more fully.

An oscillatory shift in peat formation is suggested by the curves for % identifiable *Sphagnum* and % U.O.M. A 'wet' shift at 47cm is followed by a second, more marked, shift at 42cm, whilst rises in % U.O.M. indicate 'dry' phase shifts at 44cm and 37cm. Increased frequencies of *Scheuchzeria palustris* are associated with intermediate conditions. This may possibly reflect a preference for wet lawn rather than open pool conditions by this species. The hygrophilous rhizopods, mainly represented by *Hyalospenia papilio* and *Amphitrema flavum*, show increased frequencies in the post-MHC matrix, and the peak in cladoceran remains at 42cm provides additional evidence for pool formation at this level. *Assulina seminulum*, a less hydrophilous rhizopod, was recorded at 36cm. The *Scheuchzeria palustris*-*Sphagnum cuspidatum* association, typical of a continental 'meadow raised mire' (Kulczynski, 1949), dominates the entire post-MHC matrix.

Figure 24.

GIFHORN MOOR

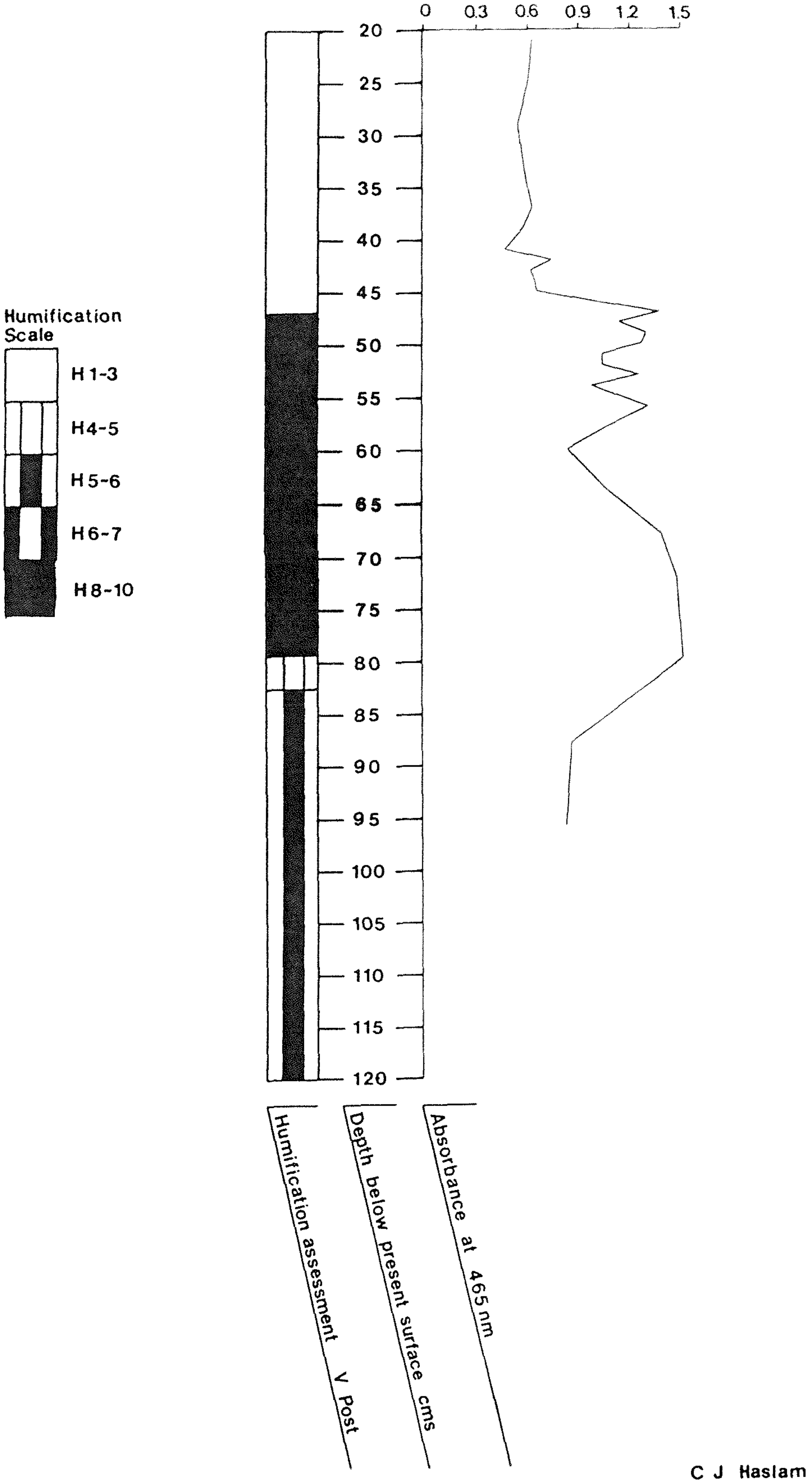

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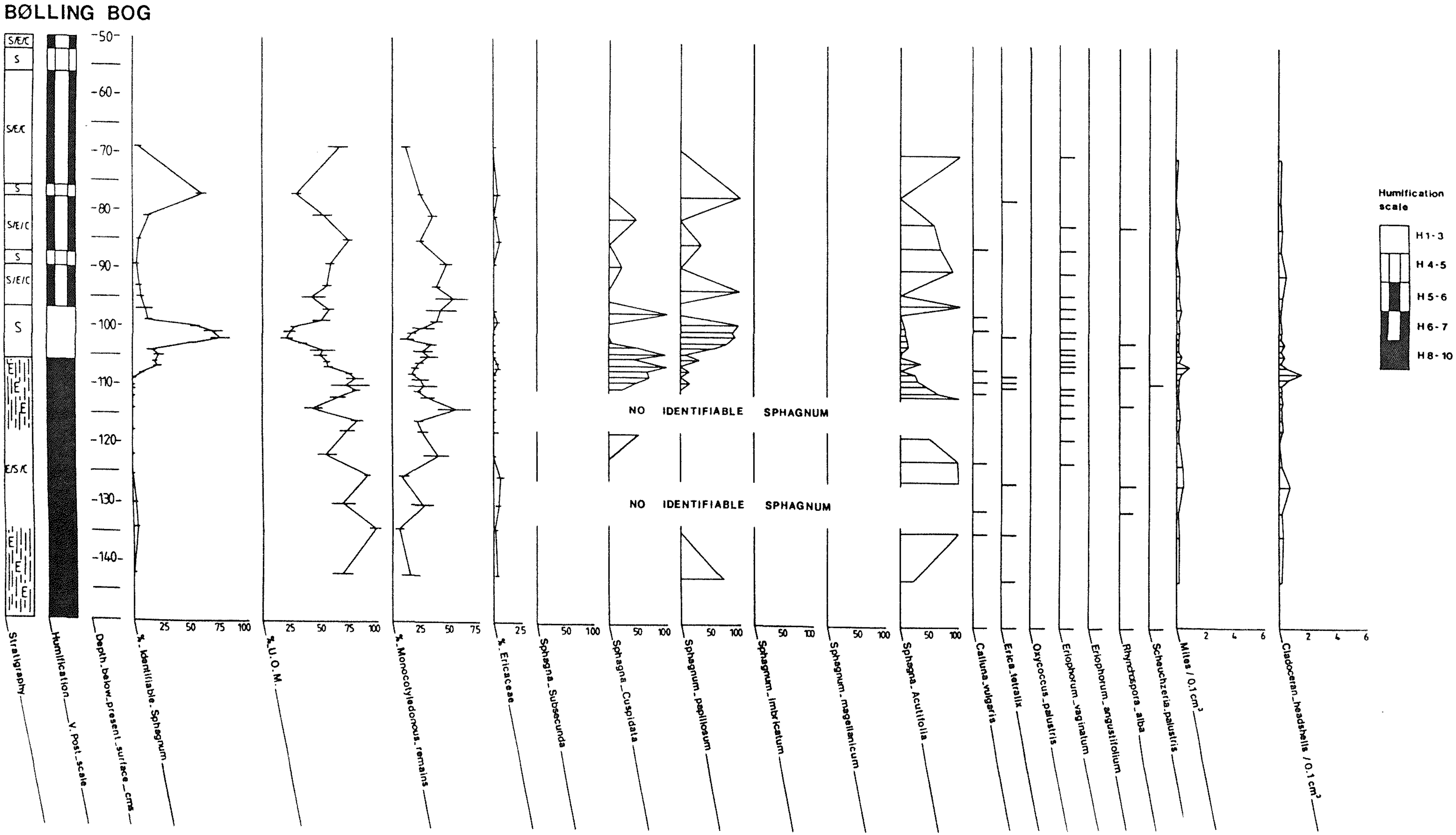
Figure 25.


BØLLING BOG
S/E/C
S
S/E/C
S
S/E/C
S
S/E/C
S
E
E/S/C
E
-50-
-60-
-70-
-80-
-90-
-100-
-110-
-120-
-130-
-140-
NO IDENTIFIABLE SPHAGNUM
NO IDENTIFIABLE SPHAGNUM
25 50 75 100
25 50 75 100
25 50 75
25
50 100
50 100
50 100
50 100
50 100
50 100
2 4 6
2 4 6
Stratigraphy
Humification V. Post scale
Depth below present surface cms
% Identifiable Sphagnum
% U.O.M.
% Monocotyledonous remains
% Ericaceae
Sphagna Subsecunda
Sphagna Cuspidata
Sphagnum papillosum
Sphagnum imbricatum
Sphagnum magellanicum
Sphagna Acutifolia
Calluna vulgaris
Erica tetralix
Oxycoccus palustris
Eriophorum vaginatum
Eriophorum angustifolium
Rhynchospora alba
Scheuchzeria palustris
Mites / 0.1 cm³
Cladoceran headshells / 0.1 cm³
Humification scale
H 1-3
H 4-5
H 5-6
H 6-7
H 8-10

Humification analyses (figure 24) support the findings of the macrofossil investigation. High absorbances are associated with the pre-MHC peats, though 'wet' shifts may be identified at 60cm, 54cm, 52cm and 48cm, corroborating the tentative conclusions drawn from fluctuations in the moss flora. The transition to an unhumified matrix coincides with a sharp fall in absorbance. 'Wetter' phases at 46cm and 42cm may also be identified.

5.4 SCANDINAVIA

5.41 BOLLING BOG, DENMARK

A complex stratigraphy records a shift to wetter surface conditions at the 106cm level (figure 25). This level was accordingly designated as the MHC and coincides with the initiation of the growth of Cymbifolia peat by the relatively hygrophilous Sphagnum papillosum. A tendency towards 'dry' local conditions is indicated by the profile. Similar observations, based on the examination of several long sections, were made by Iversen (unpublished data). The reasons for this are unclear given the oceanic nature of the site.

Low values of % identifiable Sphagnum are associated with the highly humified (H8-10 on the Von Post scale) pre-MHC peats. Local hydrological interpretations based upon variations in the very low abundances of the various Sphagna are necessarily tentative. Sphagnum papillosum dominates the moss flora at the base of the section. The isolation of Polytrichum alpestre, typical of hummock transgression phases (Van Geel, 1978), suggests a temporary shift to wet lawn conditions from a low hummock environment. A return to drier conditions is associated with a rise in % U.O.M. and the expansion of Sphagnum sect. Acutifolia (cf. S. capillifolium). Although no identifiable Sphagnum was recorded between 134cm and 126cm, a hummock situation with Calluna vulgaris, Erica tetralix and Sphagnum sect. Acutifolia is suggested. Remains of Aulacomnium palustre were also found at this level.

A rise in Sphagnum sect. Cuspidata is recorded at 118cm, though there is no additional evidence to suggest a shift to wetter conditions. Indeed, immediately above this level no identifiable Sphagnum was recorded. At 116cm tissue fragments of what is believed may be Ledum palustre were encountered. Although Ledum palustre is frequently confused with the epidermis of Myrica gale and Erica tetralix, identifications kindly undertaken by Prof. Dr. G. Grosse-Brauckmann, Institut fur Botanik, Darmstadt and Dr A. Obidowicz, Zaklad Paleobotaniki IB PAN, Krakow suggest that the tissue is indeed that of Ledum palustre. It is particularly interesting to find Ledum remains in a peat deposit which lies outside the contemporary distribution of this species. Typically associated with forested raised mires in eastern continental Europe, it tolerates cold winters and warm, dry summers (Obidowicz, 1977). Though Ledum palustre has been found growing on drained mire surfaces in the Bremen-Hamburg region (Grosse-Brauckmann, personal communication), it is restricted to drier situations and is rare. Its possible occurrence further north points to a markedly more continental climate in Denmark during the late Subboreal than was formerly assumed.

% identifiable Sphagnum rises for the first time at 108cm. This coincides with the formation of a Trichophorum caespitosum tussock similar to that identified at Juhrdener Moor (Section 5.32.1) in an analogous stratigraphic position. Sphagnum sect. Acutifolia (cf. S. capillifolium) dominates the moss flora together with Calluna vulgaris, Erica tetralix and Eriophorum vaginatum. A Cenococcum geophilum-Arcella rotundata-Trigonpyxis arcula rhizopod assemblage indicates relatively dry hummock conditions. In a sequence similar to that identified at The Engbertsdijksveen (Section 5.31), Juhrdener Moor (Section 5.32.1) and Ahlenmoor (Section 5.32.2), hummock transgression by Sphagnum sect. Cuspidata (cf. S. cuspidatum) is associated with the immediate pre-MHC peats. Both Rhynchospora alba and Scheuchzeria palustris indicate relatively wet conditions, though it seems unlikely that full pool conditions developed. The hygrophilous rhizopods, Amphitrema flavum and Hyalosphenia papilio, also show increased frequencies at this level. Slightly drier conditions are marked by the invasion of Sphagnum

Figure 26.

AGERÖDS MOSSE

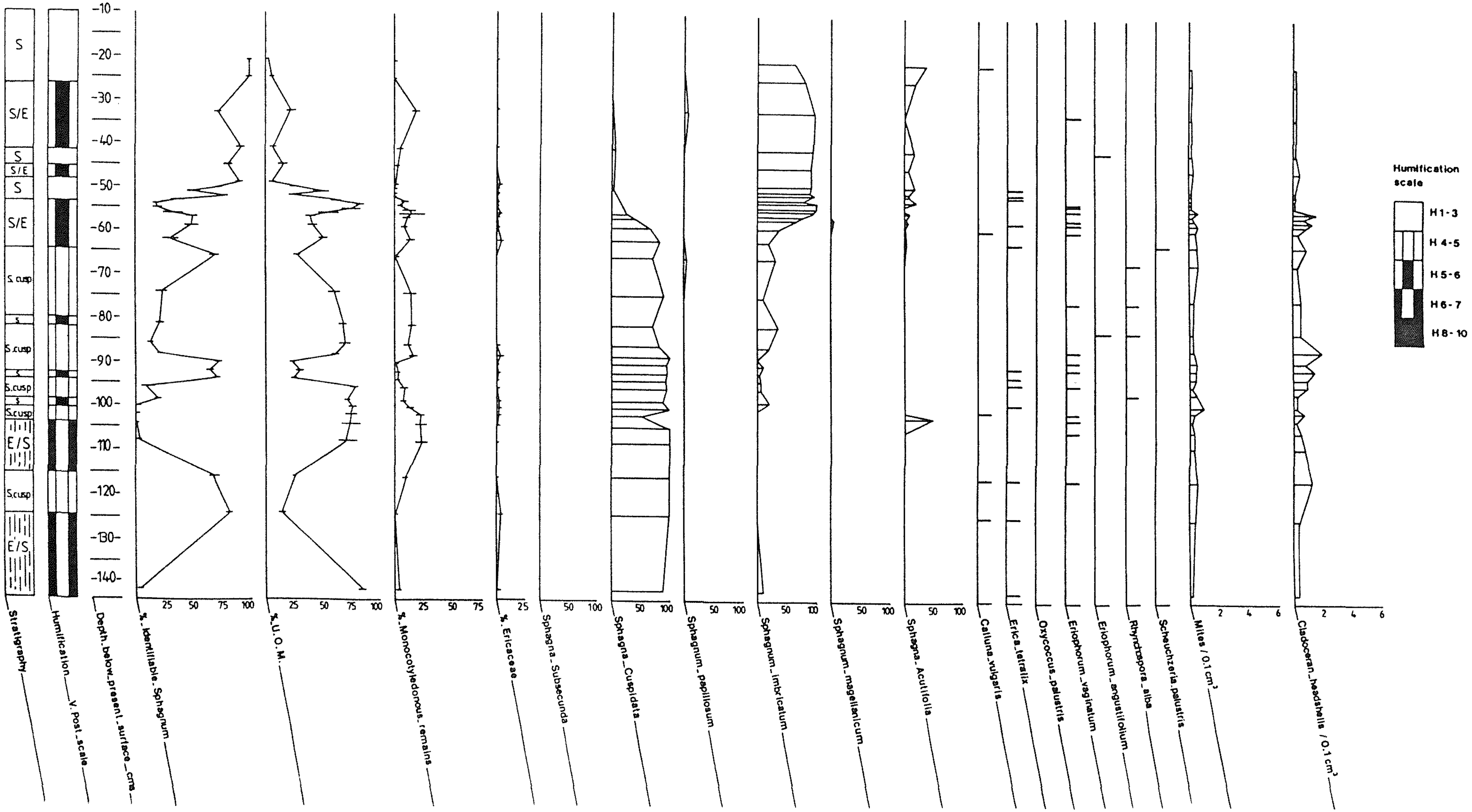
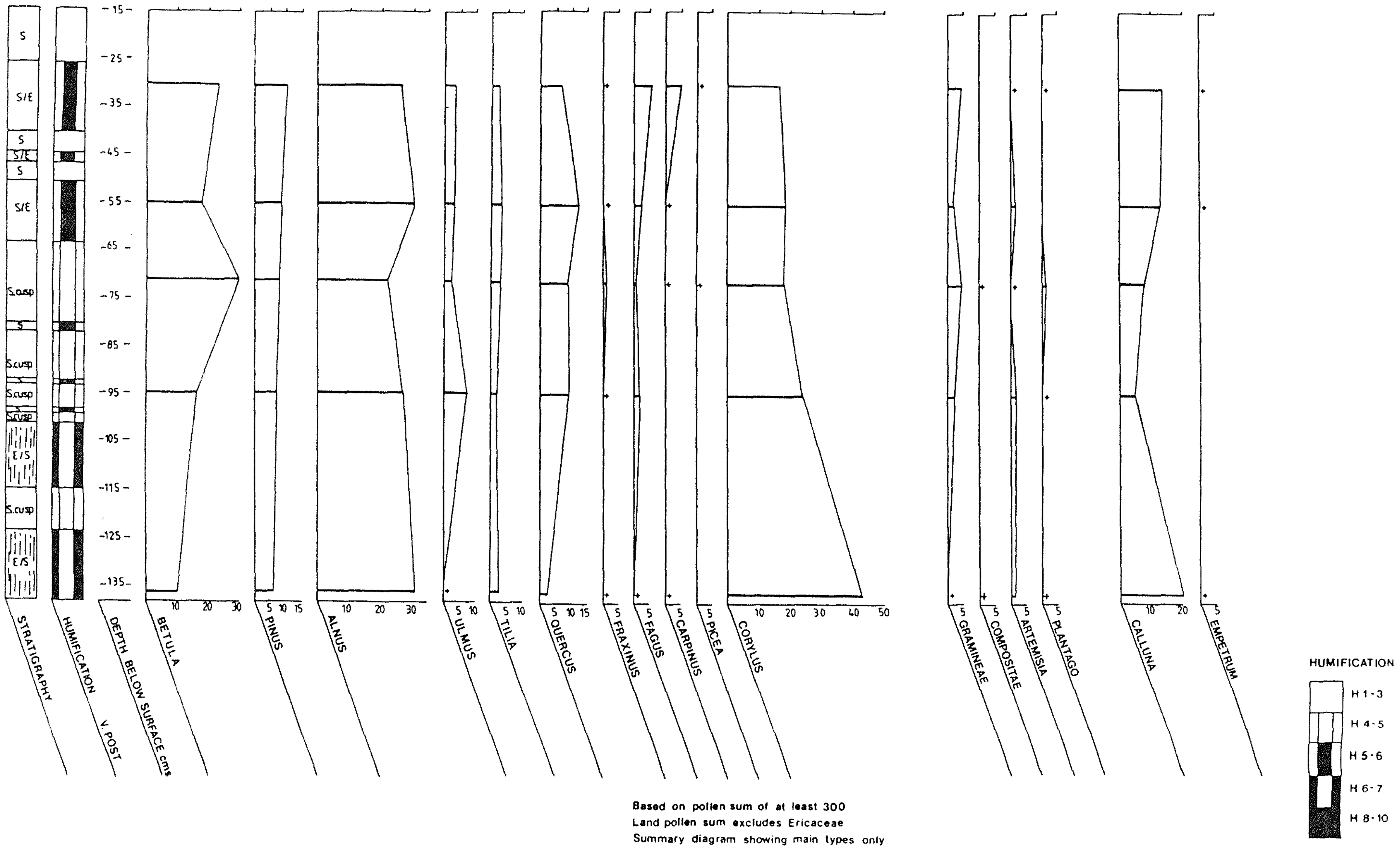


Figure 27.

AGERÖDS MOSSE, SWEDEN



Based on pollen sum of at least 300
Land pollen sum excludes Ericaceae
Summary diagram showing main types only

papillosum and the deposition of an unhumified matrix. The peat immediately above and below this transition has been dated to 2430 +/- 110 B.P. (K-735) and 2380 +/- 100 B.P. (K-736) respectively (Aaby, 1978).

In contrast to Dutch and German coastal mires, *Sphagnum imbricatum* fails to establish itself following the *Sphagnum papillosum* phase. This may in part reflect the transition to drier local conditions, as indicated by a rise in % U.O.M. at 96cm, and the expansion of *Sphagnum* sect. *Acutifolia* (cf. *S. capillifolium*). Relatively dry conditions at this level are indicated by the presence of *Cenococcum geophilum*, *Calluna vulgaris* and *Eriophorum vaginatum*. The climatic instability of this period is reflected in the repeated transition between a humified matrix dominated by *Sphagnum* sect. *Acutifolia* (cf. *S. capillifolium*) with *Eriophorum vaginatum* and infrequent *Sphagnum papillosum*, and a less humified peat with a *Sphagnum cuspidatum*-*S. papillosum* association. These 'wet' shifts are recorded at 90cm, 87cm and 56cm in a generally 'dry' stratigraphy.

5.42 AGERODS MOSSE, SWEDEN

Stratigraphic investigations by Nilsson (1964a) identified seven recurrence surfaces at this site. The most pronounced shift in peat formation was correlated with Granlunds' RY III, and subsequently radiocarbon dated to 2205 +/- 85 B.P. (St-985)(Nilsson, 1964b). The peats directly below and above this boundary were dated to 2270 +/- 85 B.P. (St-983) and 1995 +/- 80 B.P. (St-986) respectively, indicating a temporary cessation of peat accumulation. The stratigraphic section recorded by the author (figure 26) similarly displays a series of wet-dry shifts. Uncertainty as to the location of the MHC prompted the construction of a skeleton pollen diagram for the site. These results are presented in figure 27. Nilsson (1964a) observed a rise in the *Fagus* and *Carpinus* curves at the Subboreal-Subatlantic transition, and attributed this to more oceanic conditions. The consistent appearance of *Carpinus* and marked expansion of *Fagus* at c.55cm (figure 27) was therefore denoted as the Subboreal-Subatlantic transition. This level coincides with the initiation in the growth of Cymbifolia peat by Sphagnum imbricatum (as also noted by Nilsson, 1964a, 1964b).

The relatively wet local conditions of the Agerods Mosse section are characterised by a series of shifts to pool conditions in the pre-MHC peats. Sphagnum cuspidatum is the dominant peat former during these phases. Drier periods between 143cm-125cm and 115cm-105cm are associated with rises in % U.O.M. and the expansion of Eriophorum vaginatum into what was most likely a wet lawn environment. Low frequencies of Erica tetralix and Calluna vulgaris probably derive from surrounding hummock situations. A short term 'dry' shift at 100cm is marked by a peak in % U.O.M. and the invasion of Sphagnum sect. Acutifolia (cf. S. capillifolium) and Sphagnum imbricatum into the wet lawn habitat dominated by Sphagnum cuspidatum. Whilst Sphagnum sect. Acutifolia becomes extinct, Sphagnum imbricatum maintains a position as a minor peat constituent in association with Sphagnum cuspidatum. The presence of Rhynchospora alba suggests a very wet lawn situation, with Eriophorum vaginatum and Erica tetralix immigrating from the surrounding low hummocks during marginally drier phases. The semi-aquatic nature of Sphagnum imbricatum at this level is worthy of comment, and provides another argument for the supposition that this species may exist in both semi-aquatic and hummock 'ecads' (cf. Green, 1968).

Although temporary wet shifts are recorded at 85cm and 74cm by the occurrence of Eriophorum angustifolium and the deposition of algal pool muds, a gradual trend towards drier local conditions is indicated by the expansion of Sphagnum imbricatum. The shift in the rhizopod assemblage from hygrophilous species such as Amphitrema flavum and Hyalosphenia papilio to less hydrophilous species such as Assulina seminulum supports this interpretation. Sphagnum papillosum briefly enters the wet lawn habitat at 65cm but is excluded by the competitive superiority of Sphagnum cuspidatum and S. imbricatum and a shift to wetter conditions at 62cm. This level coincides with the occurrence of Scheuchzeria palustris remains. Drier local conditions at 55cm, as indicated by a sharp rise in % U.O.M., facilitate the rapid expansion of Sphagnum imbricatum. The replacement of Sphagnum cuspidatum by Sphagnum tenellum as the

Figure 28.

AGERÖDS MOSSE

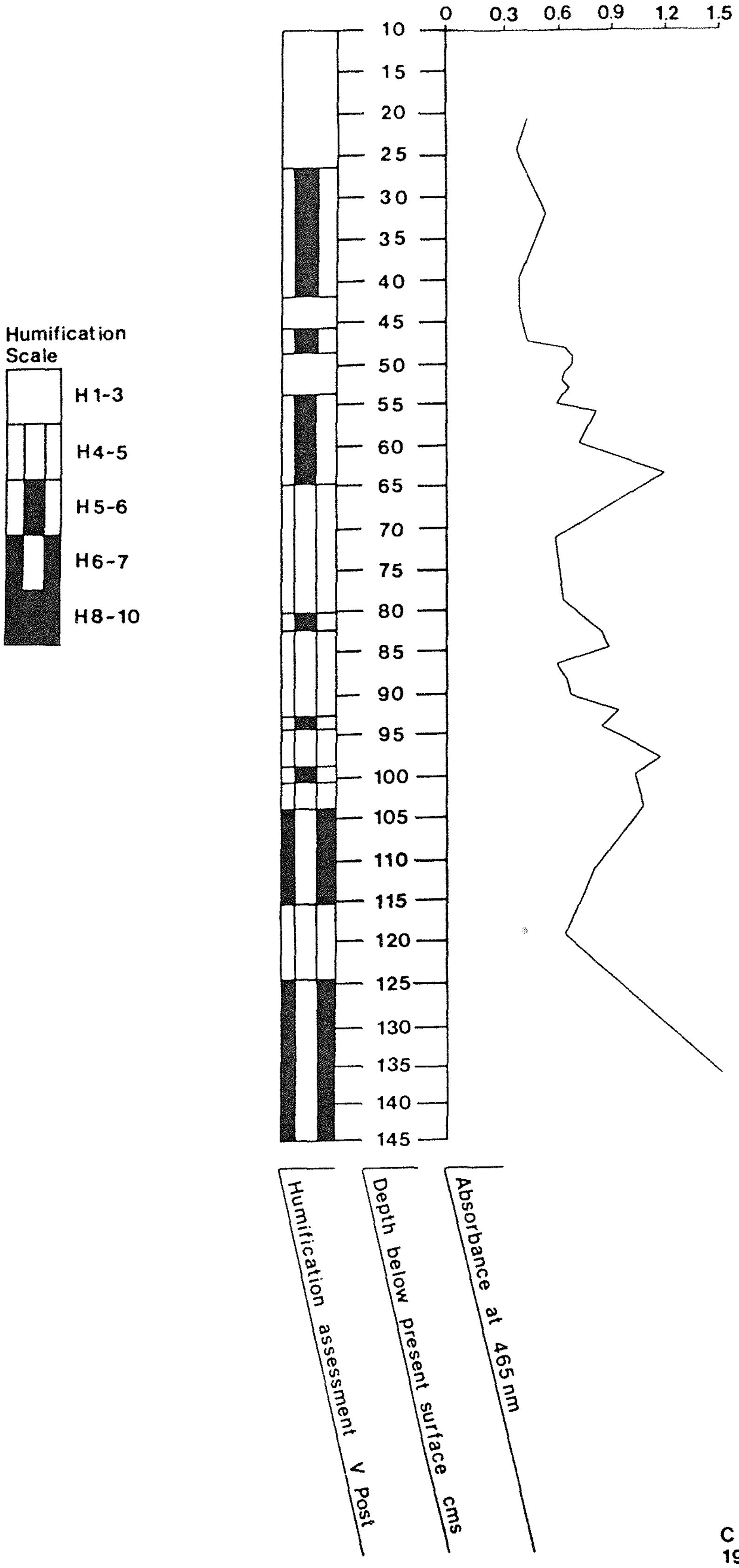


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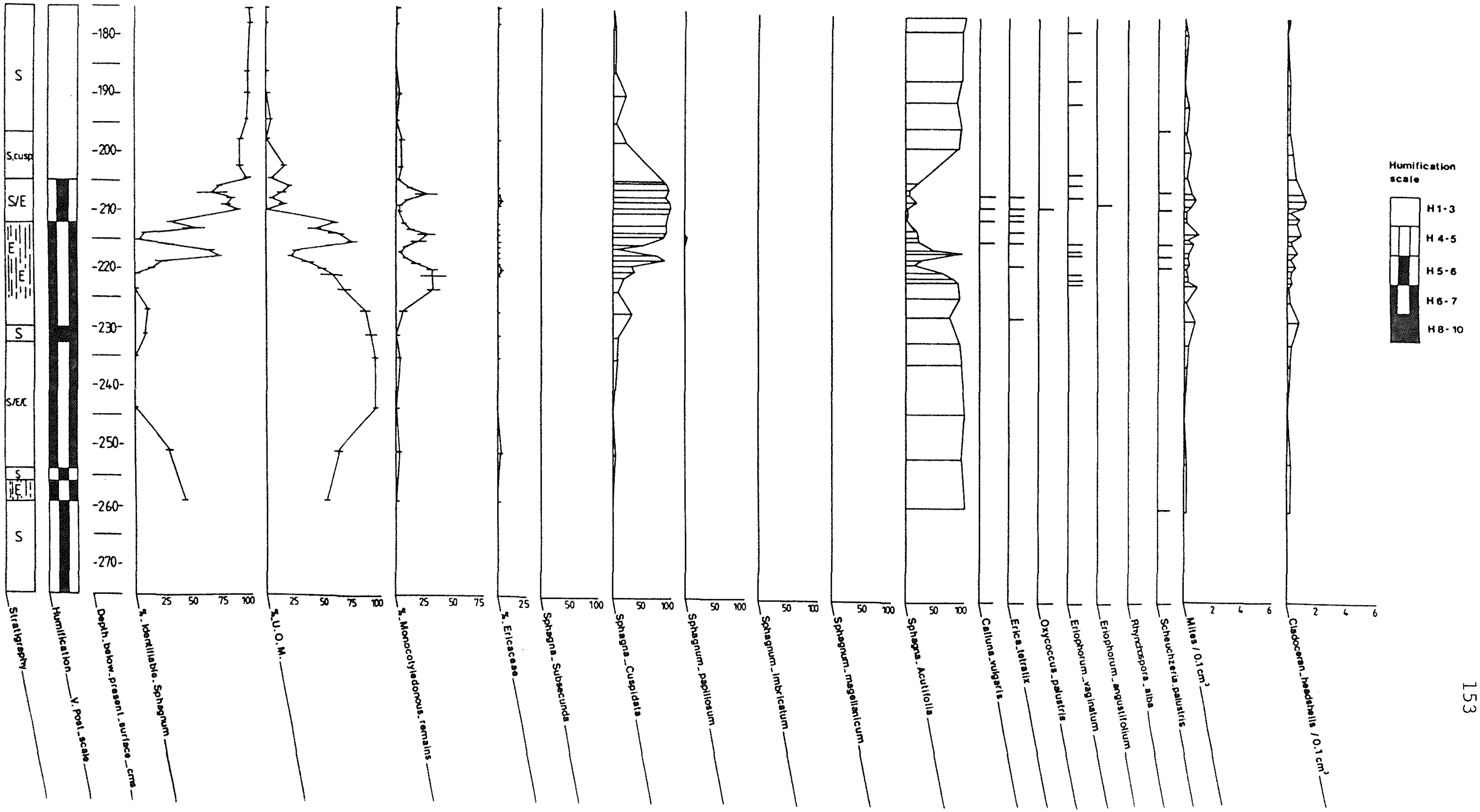
Figure 29.

YGGERYDS MOSSE



habitat co-dominant with Sphagnum imbricatum mark a transition to low hummock conditions. Eriophorum vaginatum and Erica tetralix with infrequent Sphagnum cuspidatum, S. magellanicum and Sphagnum sect. Acutifolia (cf. S. capillifolium) were also recorded at this level. A less oceanic phase at 52cm may be correlated with a rise in % U.O.M. and a minor expansion of Sphagnum sect. Acutifolia (cf S. capillifolium). In general however, the recognition of less oceanic phases within the post-MHC matrix remains problematic. Whilst reduced values of % identifiable Sphagnum are associated with bands of more humified peat, little change is recorded by the moss flora. Casparie (1972, p.240) attributes this phenomenon to the water absorption capacity of the Cymbifolia peat.

The sensitivity of Agerods Mosse to changes in the environmental milieu is reflected in the humification profile for this site (figure 28). Absorbances are generally low indicating the relatively wet local conditions of the section. In the pre-MHC matrix, peaks in absorbance display close correspondence with bands of more humified peat and local 'dry' indicators isolated in the macrofossil analyses. Sphagnum cuspidatum pool peats are associated with troughs in the curve. An oscillatory shift in peat formation involving a series of wet-dry shifts is suggested. The relationship between absorbance and variations in local hydrological conditions appears less clear in the post-MHC matrix. In particular, the bands of humified peat between 48cm-46cm and 42cm-26cm are not marked by increased absorbances. This most probably reflects the high values of % identifiable Sphagnum that were recorded at these levels, and suggests that assessment of decomposition degree should not be based upon field observation alone.

5.42 YGGERYDS MOSSE, SWEDEN

Macrofossil results for Yggeryds Mosse (figure 29) show a simple transition to unhumified peat formation at the 212cm level. This coincides with a rise in % identifiable Sphagnum and the temporary displacement of Sphagnum sect. Acutifolia by Sphagnum sect. Cuspidata as the dominant peat former. There are no available radiocarbon dates for this transition.

The basal glacial sand and gravels were encountered at 343cm. Above this, a layer of fen peat, rich in *Betula*, *Pinus*, *Eriophorum vaginatum* and *Carex* spp. remains, grades into an ombrotrophic matrix at 300cm. A band of poorly humified peat, not identified by Granlund (1932), extends to 260cm before itself grading into a humified matrix. Macrofossil analyses were undertaken on the immediate pre- and post-MHC peats and were not extended to include this lower unhumified band.

The pre-MHC peats are dominated by *Sphagnum* sect. *Acutifolia*. The parent species remains undetermined, though based upon basal branch leaf pore sizes, it is suggested that *Sphagnum fuscum* was more frequent than *S. capillifolium*. A *Sphagnum fuscum*-*S. capillifolium* hummock community, sometimes mixed with *Eriophorum vaginatum* is typical of drier bog surfaces in more continental areas of Sweden (Svensson, 1965; 1986). Following drier local conditions between 233cm and 231cm, associated with a band of more humified peat and peak in % U.O.M., a more hygrophilous community becomes established, probably marking the onset of the late Subboreal deterioration. Hollow vegetation with *Sphagnum cuspidatum* and *S. balticum* gradually replaces the *Sphagnum fuscum*-*S. capillifolium* association. *Sphagnum tenellum* was also found but seems rarely to have been dominant. The existence of sharp, short-term climatic fluctuations during this period is indicated by the identification of 'wet' shifts at 226cm and 217cm, associated with rises in % identifiable *Sphagnum* and an expansion of the *Sphagnum cuspidatum*-*S. balticum* association, and drier phases at 222cm and 215cm, coinciding with the establishment of *Eriophorum vaginatum* and return to the *Sphagnum fuscum*-*S. capillifolium* hummock association.

MHC formation marks a change from a mixed mire surface with both hydrophilous and xerophilous communities, towards a more uniform and wetter mire surface dominated by a *Sphagnum cuspidatum*-*S. balticum* association with infrequent *Sphagnum* sect. *Acutifolia* and *S. papillosum*. Vascular plants associated with these wet lawn conditions include *Erica tetralix*, *Eriophorum angustifolium* and *Scheuchzeria palustris*. Although *Carex limosa* is a characteristic species of this association, no subfossil fragments were recorded. The hygrophilous rhizopods, mainly represented by

Amphitrema flavum and *Hyalosphenia papilio*, also show increased frequencies at these levels. *Calluna vulgaris* remains probably originated from surrounding hummock centres. A temporary 'dry' phase at 207cm coincides with a rise in % U.O.M. and minor expansion of the *Sphagnum fuscum-S. capillifolium* association.

A hummock community dominated by *Sphagnum* sect. *Acutifolia* (cf. *S. fuscum*) with a sparse field layer of *Eriophorum vaginatum* replaces the *Sphagnum cuspidatum-S. balticum* hollow assemblage at 198cm, indicating a return to drier local conditions. The identification of *Cenococum geophilum* and *Trigonpyxis arcula* at 196cm supports this interpretation. Hummock conditions prevail throughout the post-MHC matrix, though a temporary shift to wetter conditions, indicated by an expansion of the *Sphagnum cuspidatum-S. balticum* hollow association and the occurrence of *Scheuchzeria palustris*, may be identified at 190cm. *Sphagnum* preservation is generally good, indicating a wet, low hummock situation.

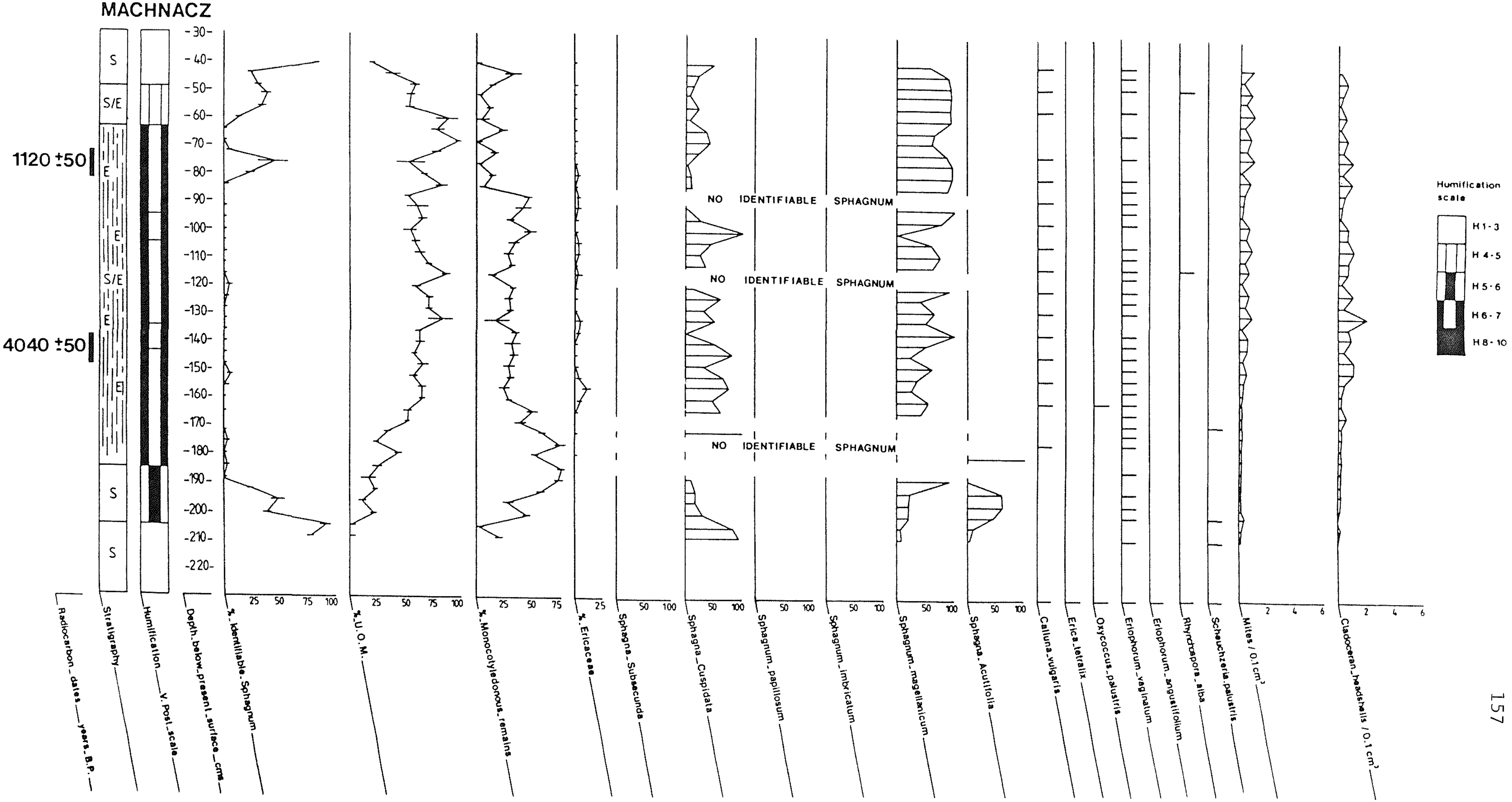
5.5 POLAND

Both Polish profiles were characterised by the absence of a recognisible MHC-type feature. A *Sphagnum recurvum-S. magellanicum* association with *Eriophorum vaginatum* and Ericaceae (mainly *Calluna vulgaris* with *Andromeda polifolia*) dominates the ombrotrophic matrix. This association is typical of continental forested raised mires (Kulczynski, 1949; Liwski et al., 1984). Macrofossil preservation is poor, reflecting the highly degraded nature of the peat. The identification of *Sphagnum* is frequently based upon one or two leaf fragments, and recorded fluctuations in the moss flora must therefore be interpreted with caution.

5.51 MACHNACZ

The transition to an ombrotrophic matrix at 187cm coincides with a marked

Figure 30.


MACHNACZ
1120 ±50
4040 ±50
S
S/E
E
-30-
-40-
-50-
-60-
-70-
-80-
-90-
-100-
-110-
-120-
-130-
-140-
-150-
-160-
-170-
-180-
-190-
-200-
-210-
-220-
NO IDENTIFIABLE SPHAGNUM
25
50
75
100
2
4
6
Radiocarbon_dates___years_B.P.
Stratigraphy
Humification___V. Post. scale
Depth_below_present_surface_cms
%. Identifiable_Sphagnum
%. U.O.M.
%. Monocotyledonous_remains
%. Ericaceae
Sphagna_Subsecunda
Sphagna_Cuspidata
Sphagnum_papillosum
Sphagnum_imbricatum
Sphagnum_magellanicum
Sphagna_Acutifolia
Calluna_vulgaris
Erica_tetralix
Oxycoccus_palustris
Eriophorum_vaginatum
Eriophorum_angustifolium
Rhynchospora_alba
Scheuchzeria_palustris
Mites / 0.1 cm³
Cladoceran_headshells / 0.1 cm³
Humification scale
H 1-3
H 4-5
H 5-6
H 6-7
H 8-10

fall in % identifiable Sphagnum (figure 30). The lower fen and mesotrophic peats are typically composed of Sphagnum obtusum, S. riparium, Scheuchzeria palustris, Drepanocladus aduncus, Drepanocladus fluitans and Calliergon giganteum with infrequent Carex limosa, Sphagnum recurvum and S. capillifolium (F. Grabika, personal communication).

The invasion of Sphagnum magellanicum and Eriophorum vaginatum characterise the shift to a humified peat. In western Europe, Sphagnum magellanicum is typically associated with wet lawn or low hummock situations, usually mixed with Sphagnum papillosum and S. capillifolium (Smith, 1978; Daniels and Eddy, 1984). In more continental regimes however, the species dominates dry hummock situations in association with Sphagnum recurvum. A similar association can be seen in New Forest valley mires which may also experience summer drought (Clarke and Barber, 1987). A shift to wetter surface conditions often coincides with the replacement of Sphagnum magellanicum by S. cuspidatum to form what Kulczynski (1949) refers to as a 'meadow raised mire' vegetation.

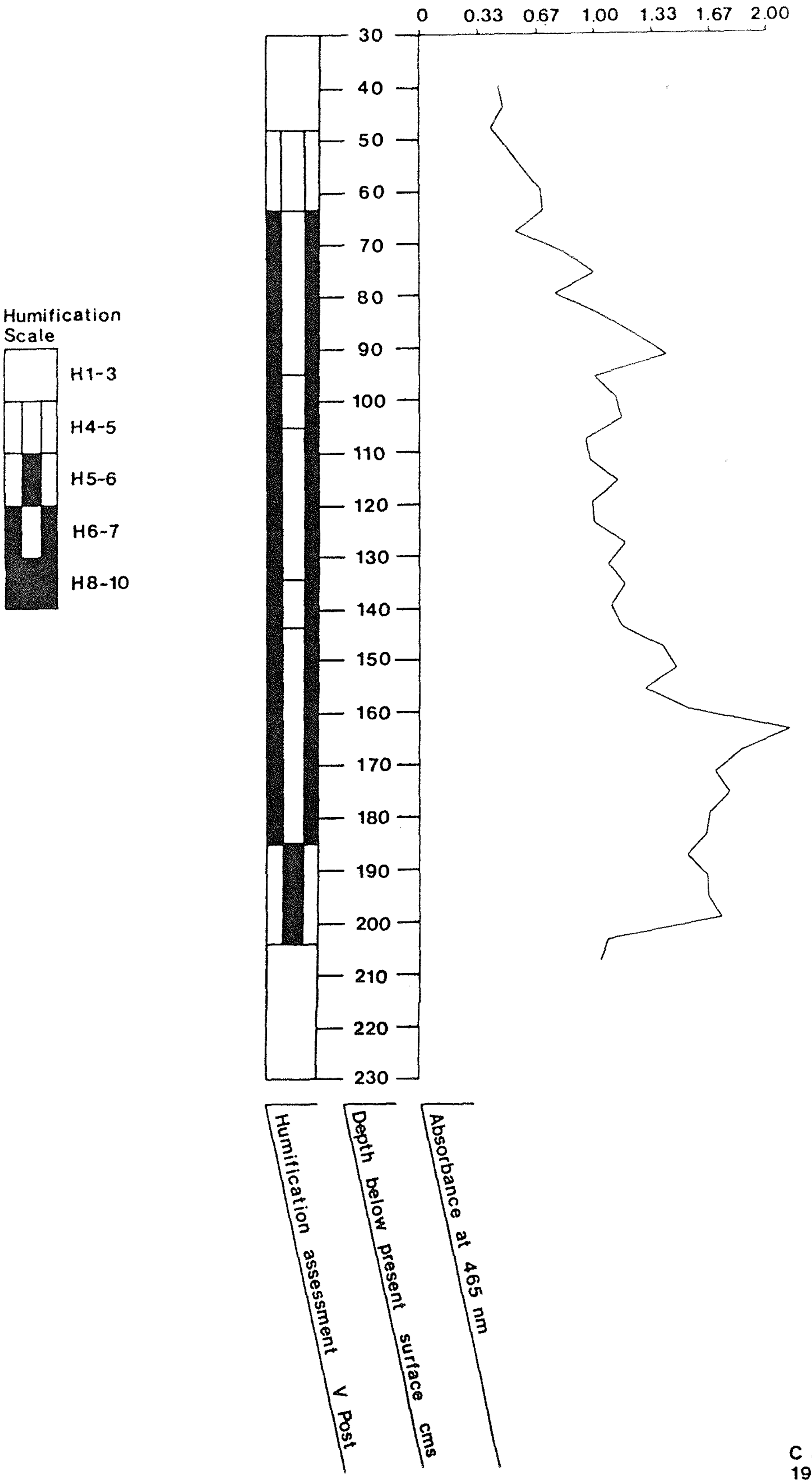
'Wet' shifts in an otherwise dry local stratigraphy are tentatively identified at 154cm, 100cm and 78cm. Associated with temporary rises in % identifiable Sphagnum and expansion of a Sphagnum recurvum-S. cuspidatum association, these shifts may also be correlated with increased frequencies of Scheuchzeria palustris and Rhynchospora alba. There is no marked response by either the rhizopod or cladoceran assemblage. Drier phases at 143cm, 136cm, 107cm and 96cm, indicated by bands of particularly humified peat, coincide with rises in % U.O.M. and an expansion of the Sphagnum magellanicum-S. recurvum hummock association. Fragments of Pinus sylvestris (presence of needles and coralloid structures of bluntly ending roots) were identified at these levels with the aid of Van Geel et al. (1980/1981).

The rise in % identifiable Sphagnum at 63cm marks the acrotelm/catotelm boundary as defined by Ingram (1978) and Malmer and Holm (1984), and should not be confused with a permanent transition to unhumified peat formation.

Particularly high absorbances are associated with the humification profile

Figure 31.

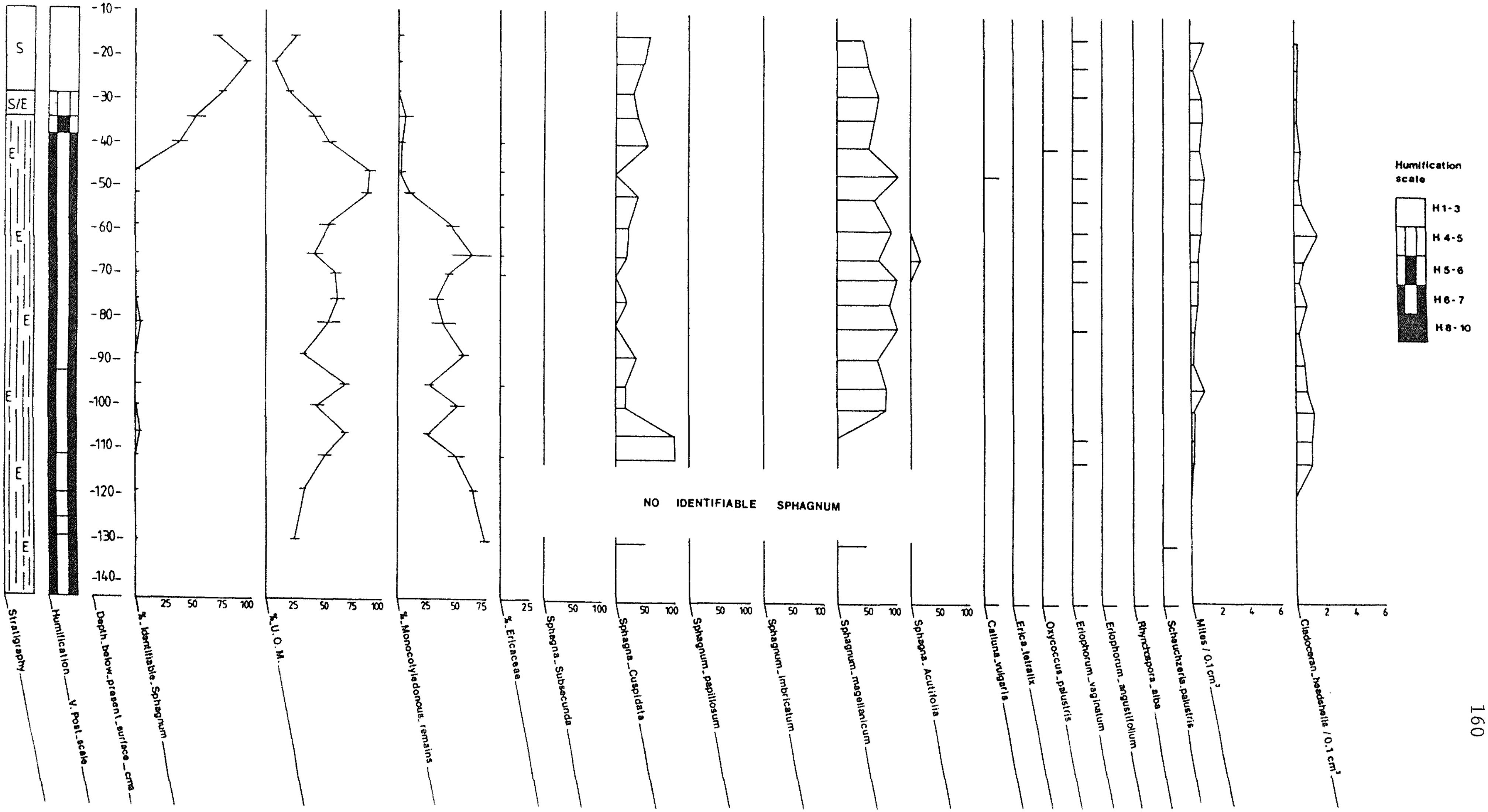
MACHNACZ



C J Haslam
1986

Figure 32.

KURIANSKA BAGNO



for this site (figure 31). Drier phases, as indicated by sharp rises in absorbance, may be identified at 163cm and 95cm against a general trend of increasing absorbance with depth. The possibility of sharp, short-term wet-dry shifts is suggested by the oscillatory nature of the curve.

Despite the absence of an MHC-type feature at this site it was considered important to date the peat associated with a 'wet' shift at 78cm and 'dry' shift at 145cm. Age determinations of 1120 +/- 50 B.P. (SRR-3175) and 4040 +/- 50 B.P. (SRR-3176) were obtained respectively. Extrapolations based on these dates suggest ombrotrophic peat formation at circa 4300 B.P., and an average peat accumulation rate of 43.6 y/cm.

5.52 KURIANSKA BAGNO

A similar stratigraphy to that obtained for Machnacz was recorded at Kurianska Bagno (figure 32). *Sphagnum magellanicum* and *Eriophorum vaginatum* dominate the section, indicating a tendency towards dry local hummock conditions. The presence of more xerophilous rhizopods, mainly represented by *Trigonpyxis arcula* and *Arcella rotundata*, support this interpretation. Nevertheless, wetter shifts are tentatively identified at 108cm and 86cm, coinciding with expansion phases of the *Sphagnum recurvum-S. cuspidatum* hollow association and a slight rise in % identifiable *Sphagnum*. Drier phases at 80cm and 48cm may be correlated with rises in % U.O.M. and reduced frequencies of *Eriophorum vaginatum*. Expansion of the *Sphagnum magellanicum-S. recurvum* hummock association also occurs.

The rise in % identifiable *Sphagnum* and associated decline of both % U.O.M. and % Monocotyledonous remains between 44cm and 30cm coincides with the diffuse transition between the catotelm and acrotelm.

There are no radiocarbon dates available for this profile.

5.6 SUMMARY

The macrofossil results record a complex series of fluctuations in local hydrological conditions in both pre- and post-MHC peats. With the exception of Polish sites, the onset of wetter surface conditions may be identified some time before the formation of an unhumified matrix is initiated. A series of sharp, short-term wet-dry shifts, as postulated elsewhere (Overbeck, 1952; Casparie, 1972; Van Geel, 1978; Dupont and Brenninkmeijer, 1984), appear to characterise the climatic deterioration leading to MHC formation.

Sphagnum imbricatum is the most important peat former in the early post-MHC peats of western oceanic sites. In several profiles, the shift from a Sphagnum sect. Cuspidata (cf. Sphagnum cuspidatum)-S. papillosum (-Sphagnum sect. Acutifolia (cf. S. capillifolium)) association to a Sphagnum imbricatum-Sphagnum sect. Acutifolia (cf. S. capillifolium) (-S. papillosum) association appears to be triggered by a shift to marginally drier conditions in the immediate post-MHC peats. Whilst Sphagnum imbricatum showed great phenotypic plasticity during this period, it appears to have been excluded by Sphagnum cuspidatum and S. papillosum from most very wet lawn environments and by Sphagnum sect. Acutifolia (cf S. capillifolium) from drier hummock situations. A lawn/low hummock habitat is suggested for this species. Comparable conclusions were reached by Green (1968) using contemporary material. Green (1968) also postulated that factors other than the water table may have controlled the growth of this species. Eutrophication of mire surfaces through enhanced supply of minerals brought in the increased rainfall of the early Subatlantic is cited as a possible causative mechanism. Similar arguments have been developed elsewhere (Frenzel, 1976, 1983; Overbeck, 1975; Schwaar, 1977; Keitel, 1977; Barber, 1981).

Central European sites are dominated by *Sphagnum* sect. *Acutifolia* (cf. *S. fuscum* and *S. capillifolium*). Wetter conditions in the immediate pre-MHC peats are indicated by the establishment of a *Sphagnum cuspidatum*-*S. balticum* hollow association with occasional *S. papillosum*, *S. magellanicum* and *S. tenellum*. A return to local 'dry' vegetation communities during the early post-MHC period is suggested in several profiles, raising the possibility that lowering of the average summer temperature may have been more important in inducing the shift in peat formation than an increase in precipitation alone. Both Totes Moor and Gifhorn Moor display affinities with eastern European sites. The *Sphagnum recurvum*-*S. magellanicum* assemblage recorded at Totes Moor is similar to that observed at both Machnacz and Kurianska Bagno, whilst the *Sphagnum cuspidatum*-*Scheuchzeria palustris* association identified in the post-MHC matrix at Gifhorn is similar to the continental 'meadow raised mire' vegetation described by Kulczynski (1949).

The macrofossil analyses provide a detailed picture of hydrological changes associated with the formation of the MHC at each mire. Several workers (Overbeck, 1952, 1975; Aaby, 1976; Van Geel, 1978; Barber, 1981; Dupont and Brenninkmeijer, 1984; Dupont, 1986) have demonstrated an increasing precipitation and/or a decrease in average temperature linked with the formation of the 'fresh' Sphagnum peat. In an attempt to explore these arguments more fully, a series of multivariate analyses were performed on the semi-quantitaive macrofossil data set. The results of these studies are presented in the following section.

SECTION 6 TOWARDS A MODEL OF CLIMATIC CHANGE FOR THE LATER HOLOCENE

6.1 INTRODUCTION: THE USE OF MULTIVARIATE TECHNIQUES

Recent years have seen the increased use of quantitative methods in biological and geological sciences. Birks and Gordon (1985) note however, that whilst there has been a growing awareness of the possibilities that statistical methodologies can contribute to Quaternary palaeoecology, scepticism still remains regarding the size of this contribution (see for example Ogden, 1977a, 1977b; Moore and Webb, 1978). Since each sample in palaeoecological community data sets is almost invariably described by the abundances of a number of species, multivariate analysis provides relatively objective, easy summarization of the data, facilitating both structure recognition and the relation of community variation to environmental gradients. Birks and Gordon (1985) and Prentice (1986b) review the available techniques to palaeoecological situations.

Guided by discussions with I.C. Prentice, H.J.B. Birks, M. Clarke and R.H.W. Bradshaw, sample ordinations involving a simple weighted averaging method and detrended correspondence analysis were applied in an attempt to produce a comparative index of ecological change for all study sites. With the exception of weighted averaging, ordination serves to summarize community data by organizing data on species abundances exclusively, apart from environmental data, leaving environmental interpretation to a subsequent, independent stage. Reviewing the theoretical and methodological background to ordination, Gauch (1982) argues that although ordination involves separate environmental interpretation, the comparison of community and environmental patterns is made easier by the preliminary elucidation of community gradients using ordination. The results of these studies are detailed below.

6.2 AN INDEX OF RELATIVE HYDROLOGICAL CONDITIONS BASED UPON WEIGHTED AVERAGES ORDINATION

6.21 INTRODUCTION: THE WEIGHTED AVERAGES ALGORITHM

The use of weighted averages dates back to the studies of Ellenberg (1948), Whittaker (1948) and Curtis and McIntosh (1951). Whittaker (1956) observed that species typically display unimodal response curves with respect to environmental gradients. Similar observations have been made elsewhere (Hill, 1973b; Gauch and Whittaker, 1976; Ellenberg, 1979; Gauch, 1982). Each species is therefore largely confined to a specific interval along an environmental variable. The value most preferred by a species is termed its 'indicator value' or optimum (Ellenberg, 1979, 1982). The indicator values may subsequently be used to predict values of an environmental variable from species composition, simply by averaging the indicator values of species that are present in a sample (Ellenberg, 1979; ter Braak and Looman, 1986). For quantitative data, the average is weighted by species abundance. The weighted averages algorithm may therefore be defined as:

$$Sj = \left(\frac{\sum Aij\ Wi}{\sum Aj} \right) I$$

Where,
Sj is the ordination score for sample j, Aij denotes the abundance of species i in sample j, Aj is the total abundance of macrofossil components in sample j and Wi is the weight for species i. The summations are over all species I.

This technique has been adopted by several workers (see for example Dix and Smeins, 1967; Shimwell, 1971; Persson, 1981) and can be shown theoretically to be efficient in environmental calibrations (ter Braak, 1985; ter Braak and Barendregt, 1986; ter Braak and Looman, 1986). The challenge is to obtain adequate ecological insight to produce meaningful species weights.

6.22 THE APPLICATION OF WEIGHTED AVERAGE ORDINATION TO RAISED MIRE HABITATS

Whilst Sphagnum species often display overlapping distributions in raised mire habitats, they are, on close examination, ecological specialists (Vitt and Slack, 1984). Previous work (Andrus, 1974; Vitt and Slack, 1975; Horton et al., 1979; Clymo and Hayward, 1982) has suggested that Sphagna are distributed according to such environmental parameters as cation content of mire water, shade, height above water table and pH. Several workers (Ratcliffe and Walker, 1958; Damman and Dowhan, 1981; Clymo and Hayward, 1982; Hayward and Clymo, 1983; Vitt and Slack, 1984) have observed that the height above the water table gradient is particularly critical in determining habitat occupation for several species. The known factors responsible for gradient differentiation include inter-specific differences in desiccation tolerance, desiccation resistance, water-holding capacity and photosynthetic responses at differing water contents (Andrus, 1983). Sphagnum species have very high water-holding capacities that also differ interspecifically (Norr, 1974; Vitt and Slack,1975; Clymo and Hayward, 1982), but no clear correlation can be demonstrated with hummock-hollow distribution (Titus and Wagner, 1984). The explanation lies rather with several characteristics of the plants that affect their ability to deal with desiccation. Numerous studies have reported morphological (Vitt and Slack, 1975, 1984; Clymo and Hayward, 1982) and physiological (Titus et al., 1983; Wagner and Titus, 1984; Titus and Wagner, 1984) adaptations for either conserving water or dealing with temporary deficiency.

Early studies on the Silver Flowe, Scotland (Ratcliffe and Walker, 1958) demonstrated a transition from pools and wet hollows dominated by Sphagnum cuspidatum and S. subsecunda, through lawns with a Sphagnum *papillosum*-*S. magellanicum*-*S. tenellum* association to hummocks with *S. capillifolium*. Ratcliffe and Walker (1958) note that "most of those species commonly regarded as typical hummock plants have a vertical range extending down to water level" and that "*Sphagnum papillosum*, generally recognised as one of the main hummock builders, is here also an important pool plant, with large flaccid forms extending well below the water surface". Comparable results have been obtained by Hayward and Clymo (1983), who modelled the effects of light-flux and water-table depth on the growth of *Sphagnum capillifolium*, *S. papillosum* and *S. recurvum*. Although *S. capillifolium* was shown to be most successful in hummock situations, its ability to grow in situations close to the water-table was demonstrated. However, in competition with *S. papillosum* and *S. recurvum* it is rapidly out-competed. Both *S. papillosum* and *S. recurvum* displayed little phenotypic plasticity with regard to water level fluctuation, being confined to lawn and low hummock environments. Similarly broad niche breadths have been reported for *Sphagnum magellanicum* and *S. recurvum* in north American raised mires by Vitt and Slack (1975, 1984). However Boatman (1983) states that it is perhaps doubtful whether information based upon measurements of extreme values is of great importance ecologically. Boatman (1983) believes that the 'average range' of a species is more meaningful. Developing earlier work by Goode (1970) and Boatman (1977), Boatman (1983) demonstrated that the productivity of *S. capillifolium* was optimized in hummocks, and that growth rates of *S. papillosum* were greatest in open lawns. Though wet conditions appeared to be sub-optimal for *Sphagnum cuspidatum*, Boatman (1977, 1983) postulated that the greater competitive ability of *S. papillosum* excluded it from lawn habitats.

In general, the vertical distribution of *Sphagnum* species along a hollow-hummock gradient reported by Ratcliffe and Walker (1958) and Boatman (1983) for the British Isles are essentially the same as literature reports (Lumiala, 1944; Malmer, 1962; Vitt et al., 1975; Pakarinen, 1979; Talbot and Pakarinen, 1979; Damman and Dowhan, 1981; Andrus et al., 1983; Vitt and Slack, 1984) for other areas. Detailed comparisons are not possible, however, because of taxonomic or sampling differences.

Based on these studies, the various macrofossil components were assigned indicator values related to the major moisture gradient (pool-lawn-hummock). Following Dupont (1986), % U.O.M., % Ericaceae and the absolute cover percentages of *Sphagnum* were classified in six groups according to their position along the hummock-hollow gradient: % U.O.M. and Ericaceae 8, *Sphagnum* sect. *Acutifolia* 6, *Sphagnum imbricatum* 5, *Sphagnum magellanicum* 3, *Sphagnum papillosum* 2 and *Sphagnum* sect. *Cuspidata* 1. The classes 7 and 4 remained empty to emphasize the relative difference between U.O.M./ Ericaceae and the *Sphagnum* species (between 8 and 6) and between hummock-building *Sphagnum* and the *Sphagnum* species of wetter habitats (between 5 and 3). Several compromises were reached in this classification.

Firstly, Ericaceae contained *Calluna vulgaris*, an indicator of relatively dry local conditions (Overbeck, 1952; Hayen, 1966; Casparie, 1972; Barber, 1981; Kashimura, 1985) and *Erica tetralix* and *Oxycoccus palustris*, both tolerant of waterlogging (Van Geel, 1978; Gloaguen, 1987). Fragments of *Calluna vulgaris* were most frequently encountered in the macrofossil analyses, and given the generally low cover abundances of Ericaceae, it was decided to weight towards the 'dry' end of the moisture gradient.

Sphagnum imbricatum and *Sphagnum magellanicum* also presented problems. *Sphagnum magellanicum* is typically associated with open carpet situations in western oceanic Europe (Ratcliffe and Walker, 1958; Isoviita, 1966; Daniels and Eddy, 1984). In more continental conditions a hummock situation is preferred (Osvald, 1923; Kulczynski, 1949; Malmer, 1962; Liwski et al., 1984). Since values of % identifiable *Sphagnum* are frequently low in more eastern sites where *Sphagnum magellanicum* forms the co-dominant with *Sphagnum* sect. *Cuspidata* (Totes Moor, Section 5.3.6; Machnacz, Section 5.51; Kurianska Bagno, Section 5.52), it was decided that an indicator value based upon its western distribution was more appropriate. The position of *Sphagnum imbricatum* remains unclear. Several workers (King and Morrison, 1956; Tallis, 1961; Malmer, 1962; Green, 1968; Damman and Dowhan, 1981; Svensson, 1987) have reported a preference for hummock situations on contemporary mire surfaces. Palaeoecological investigations (see for example Casparie, 1972; Van Geel, 1978; Barber, 1981; Bakker and Smeerdijk, 1982; Dupont, 1986) suggest however that this species may be associated with oceanic conditions in subfossil situations. The results of the current study suggest a low hummock habitat for

Figure 33.

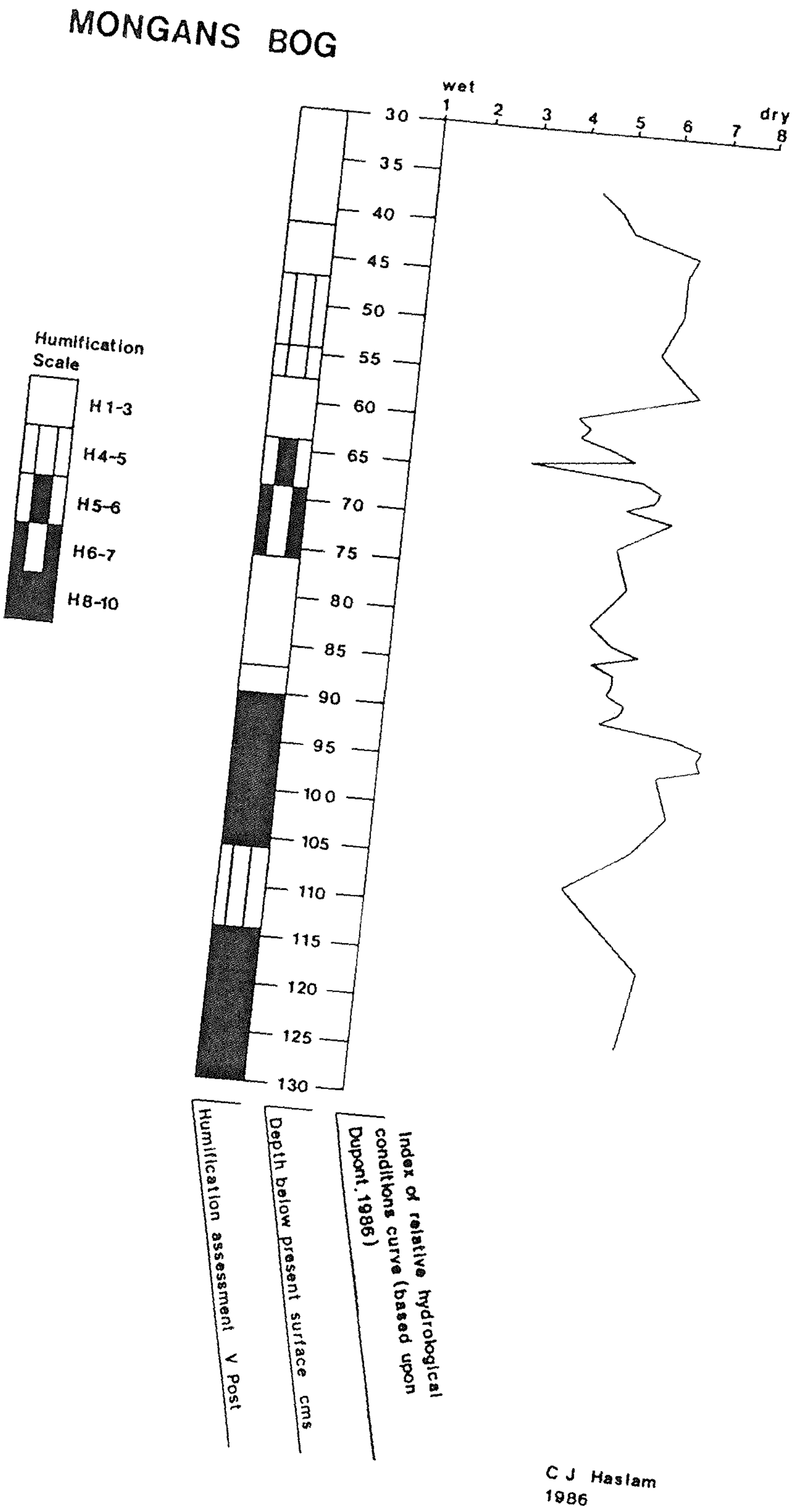
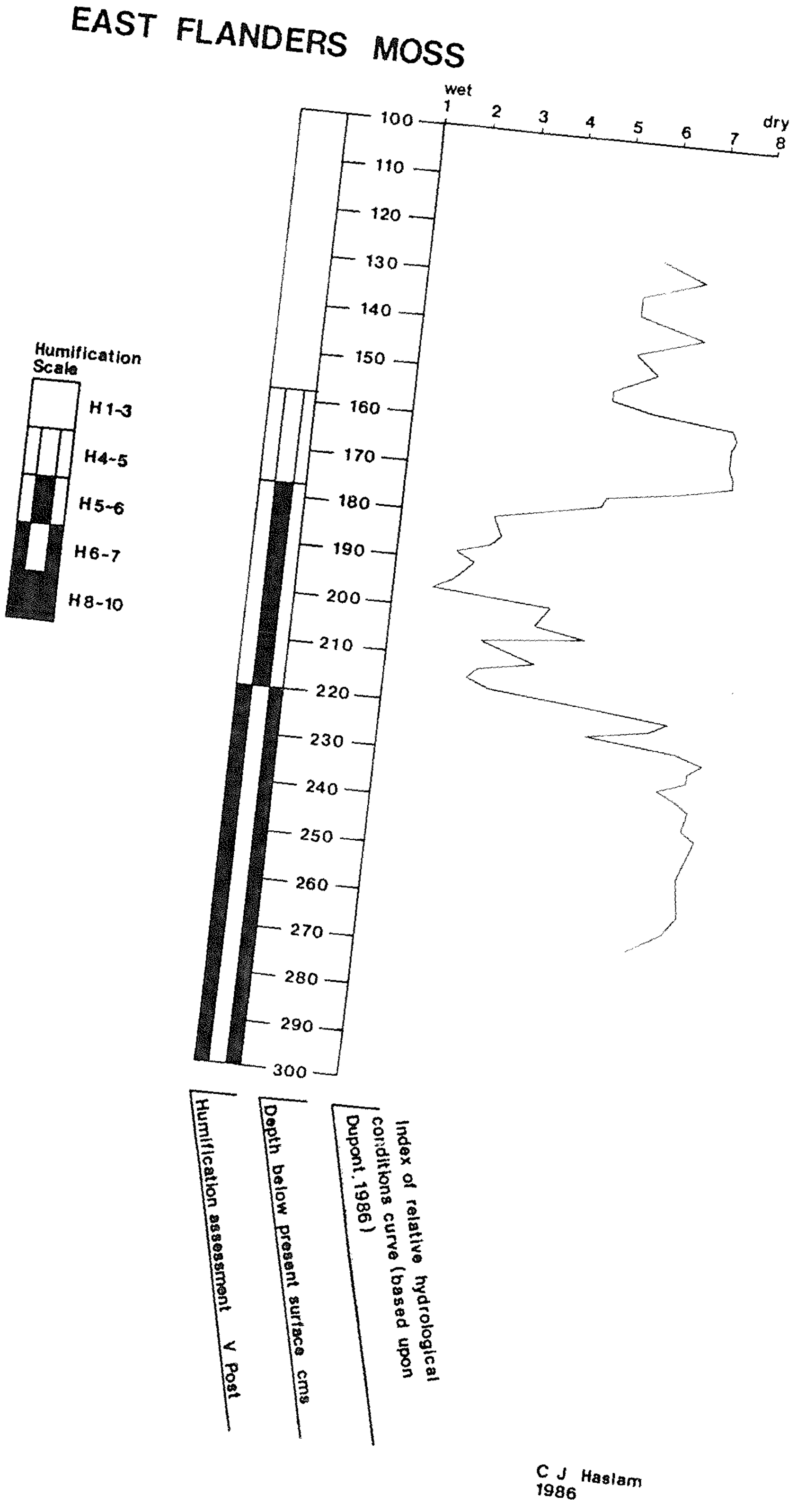

MONGANS BOG
wet
dry
1
2
3
4
5
6
7
8
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
Humification Scale
H1-3
H4-5
H5-6
H6-7
H8-10
Humification assessment V Post
Depth below present surface cms
Index of relative hydrological conditions curve (based upon Dupont, 1986)
C J Haslam
1986

Figure 34.

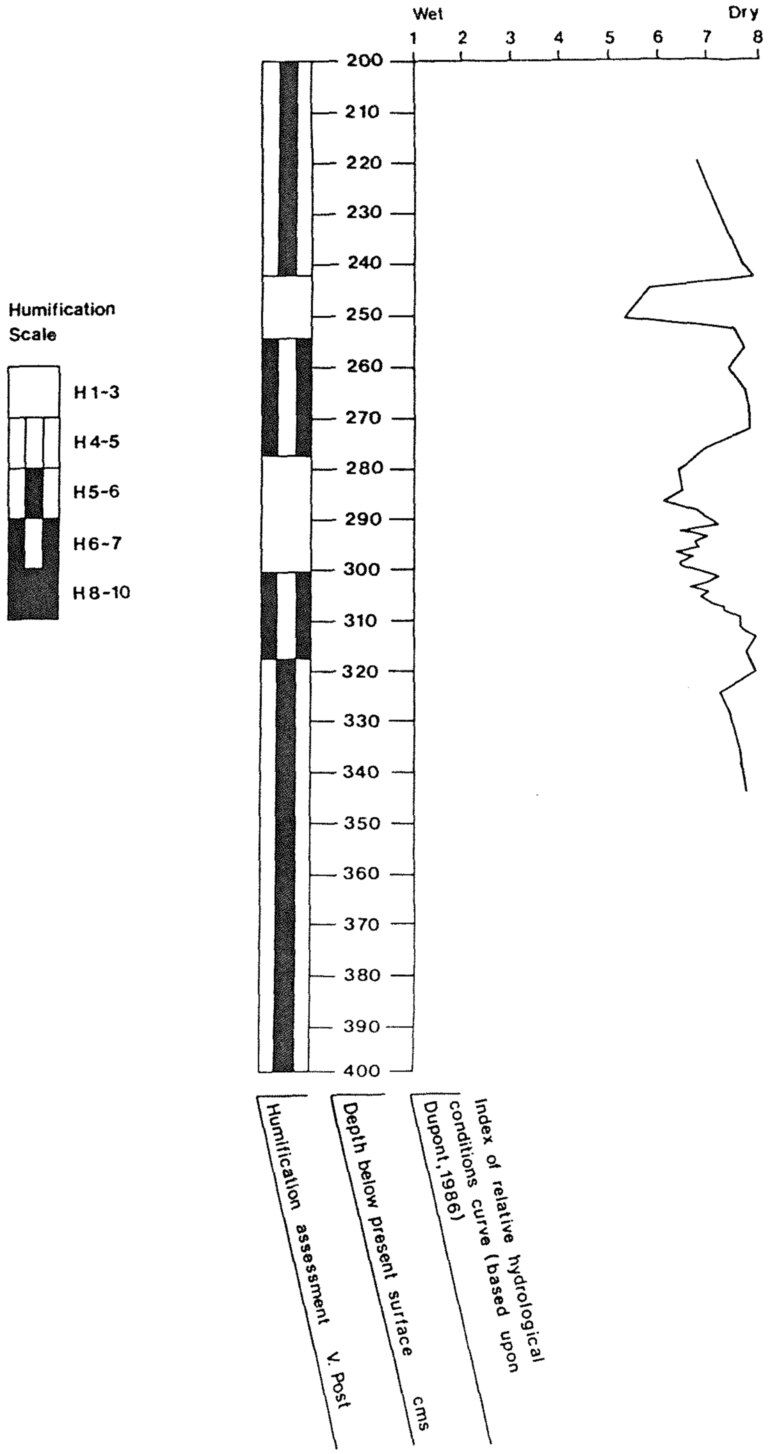


EAST FLANDERS MOSS

C J Haslam
1986

Figure 35.

TREGARON SOUTH EAST BOG



C. J. Haslam
1987

Figure 36.

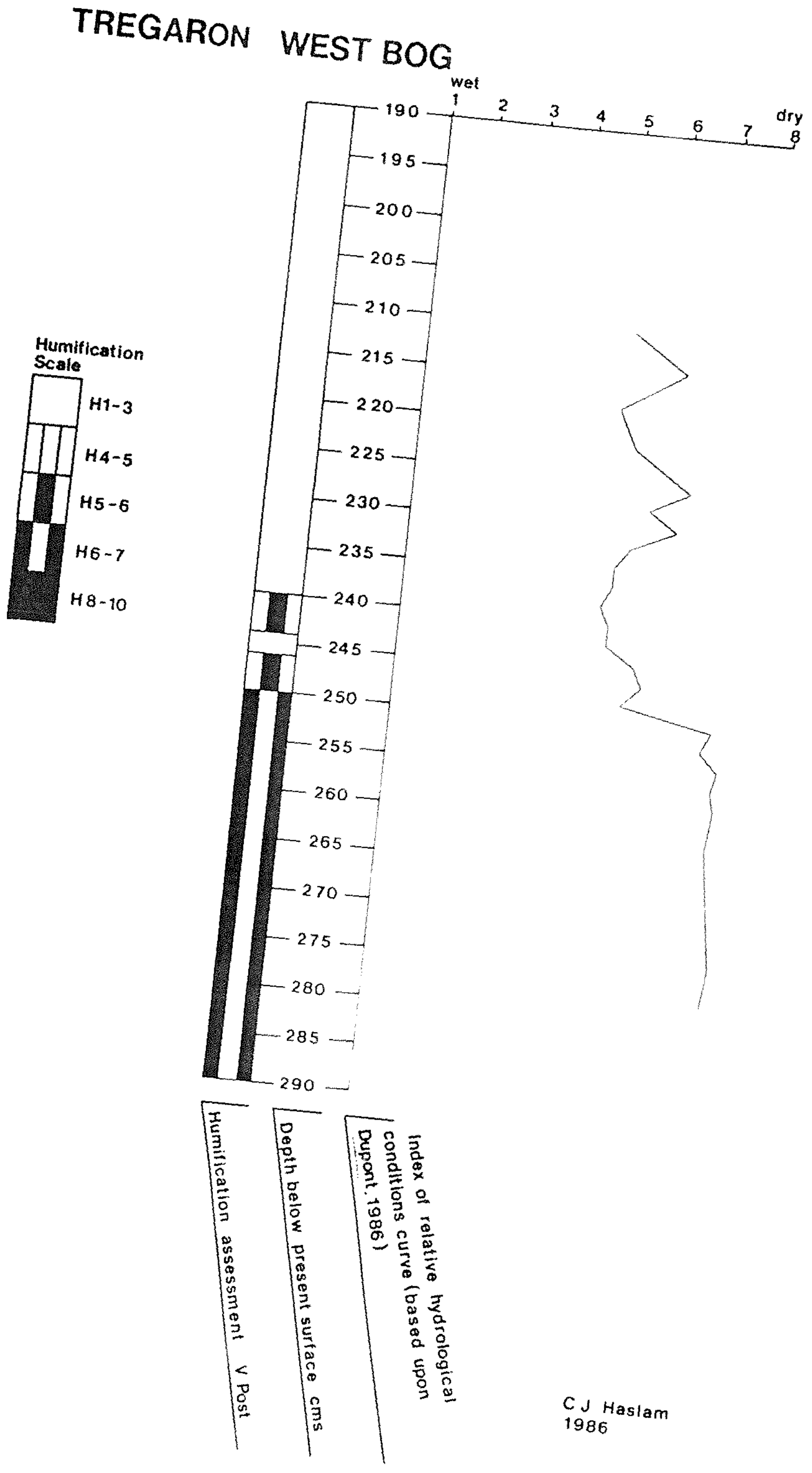
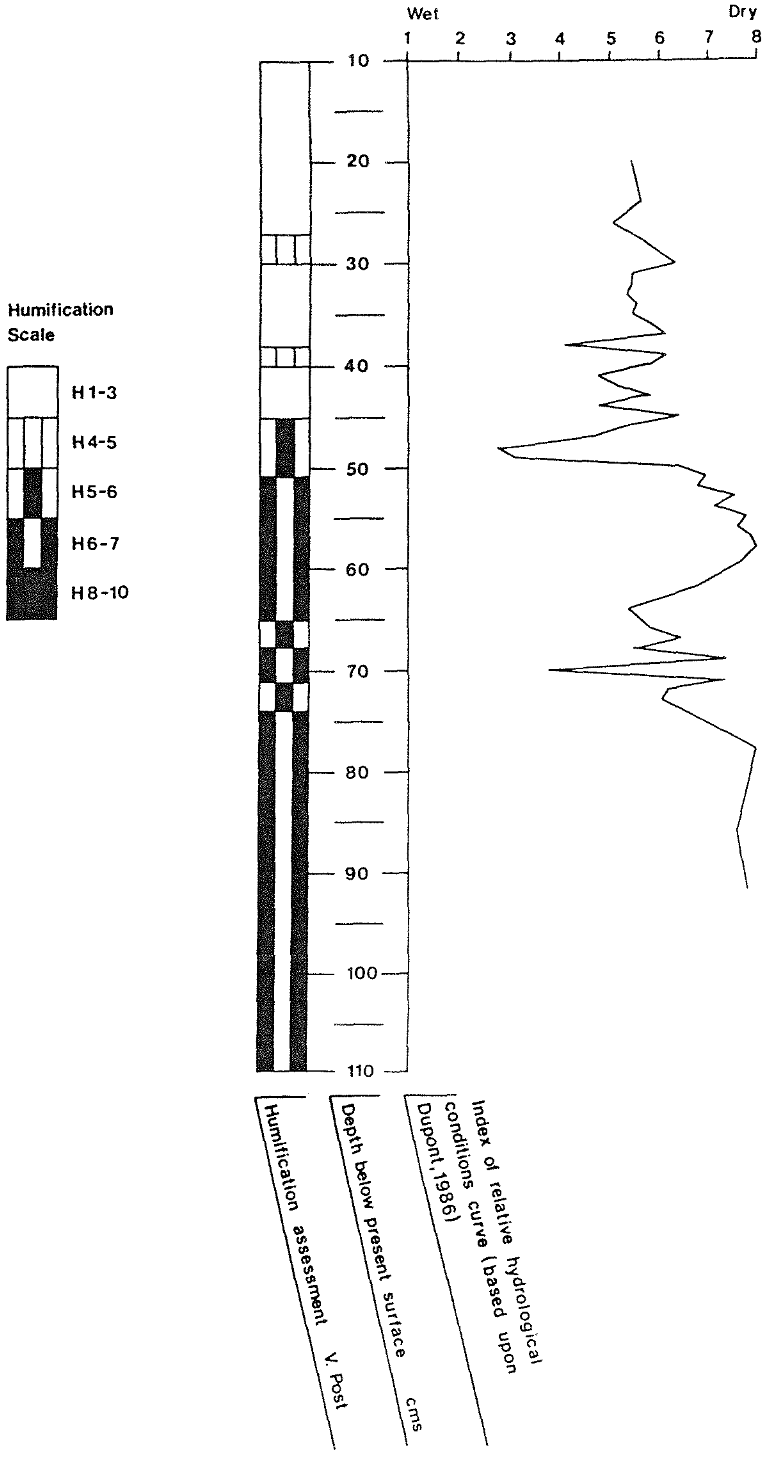

TREGARON WEST BOG
wet
1
2
3
4
5
6
7
dry
8
190
195
200
205
210
215
220
225
230
235
240
245
250
255
260
265
270
275
280
285
290
Humification Scale
H1-3
H4-5
H5-6
H6-7
H8-10
Humification assessment V Post
Depth below present surface cms
Index of relative hydrological conditions curve (based upon Dupont, 1986)
C J Haslam
1986

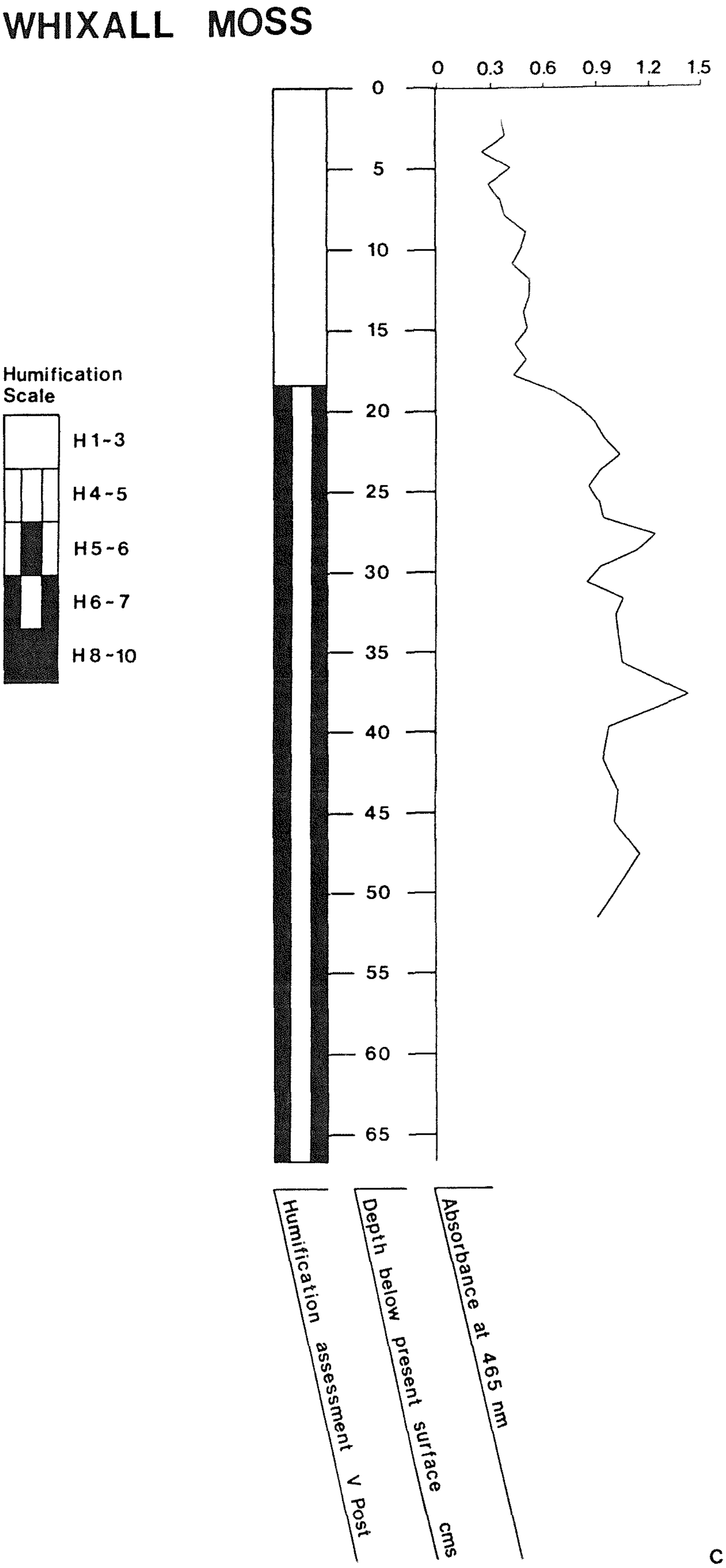
Figure 37.

BOLTON FELL MOSS



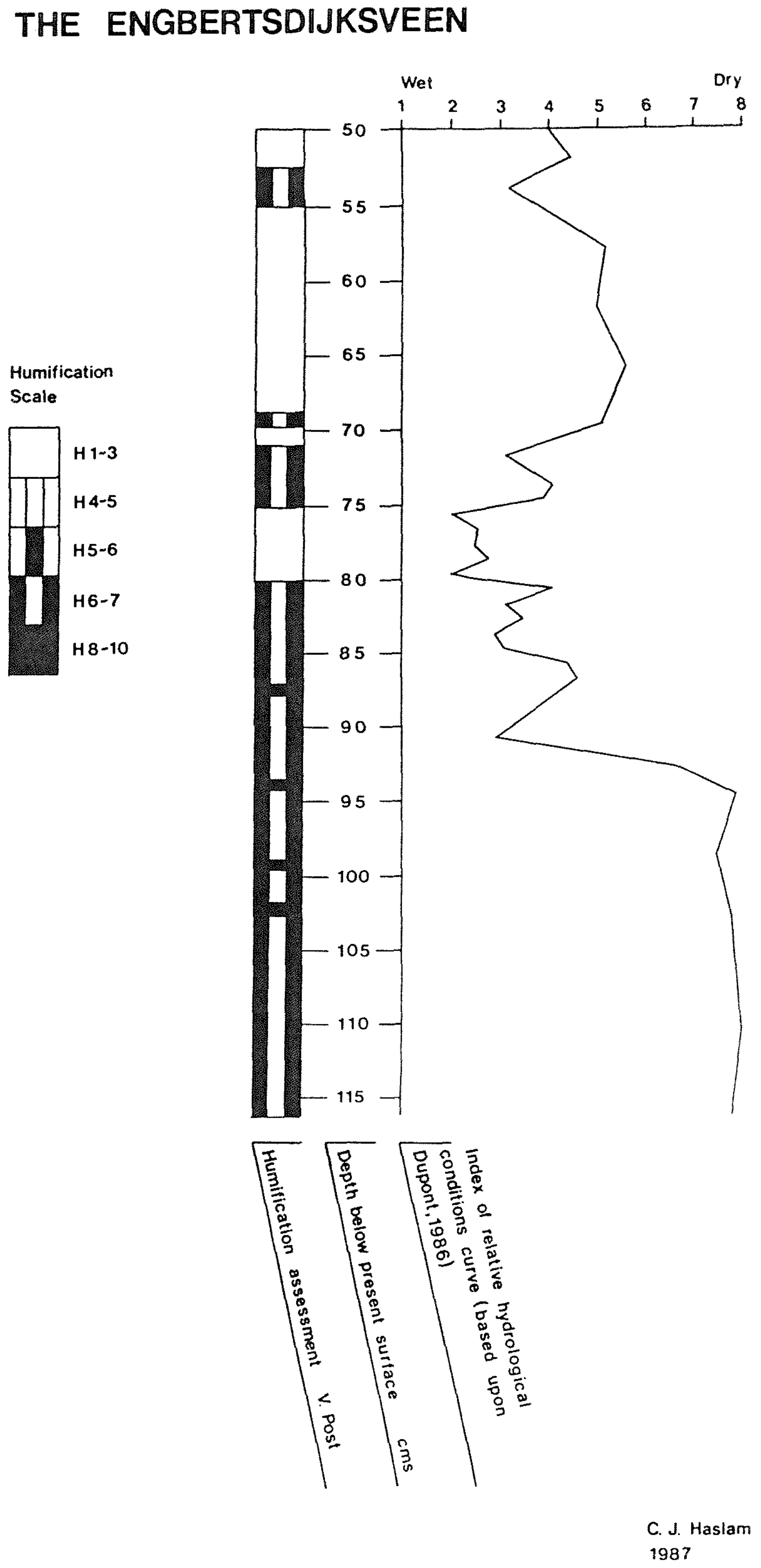
C. J. Haslam
1987

Figure 38.



C J Haslam
1986

Figure 39.


THE ENGBERTSDIJKSVEEN
Wet
Dry
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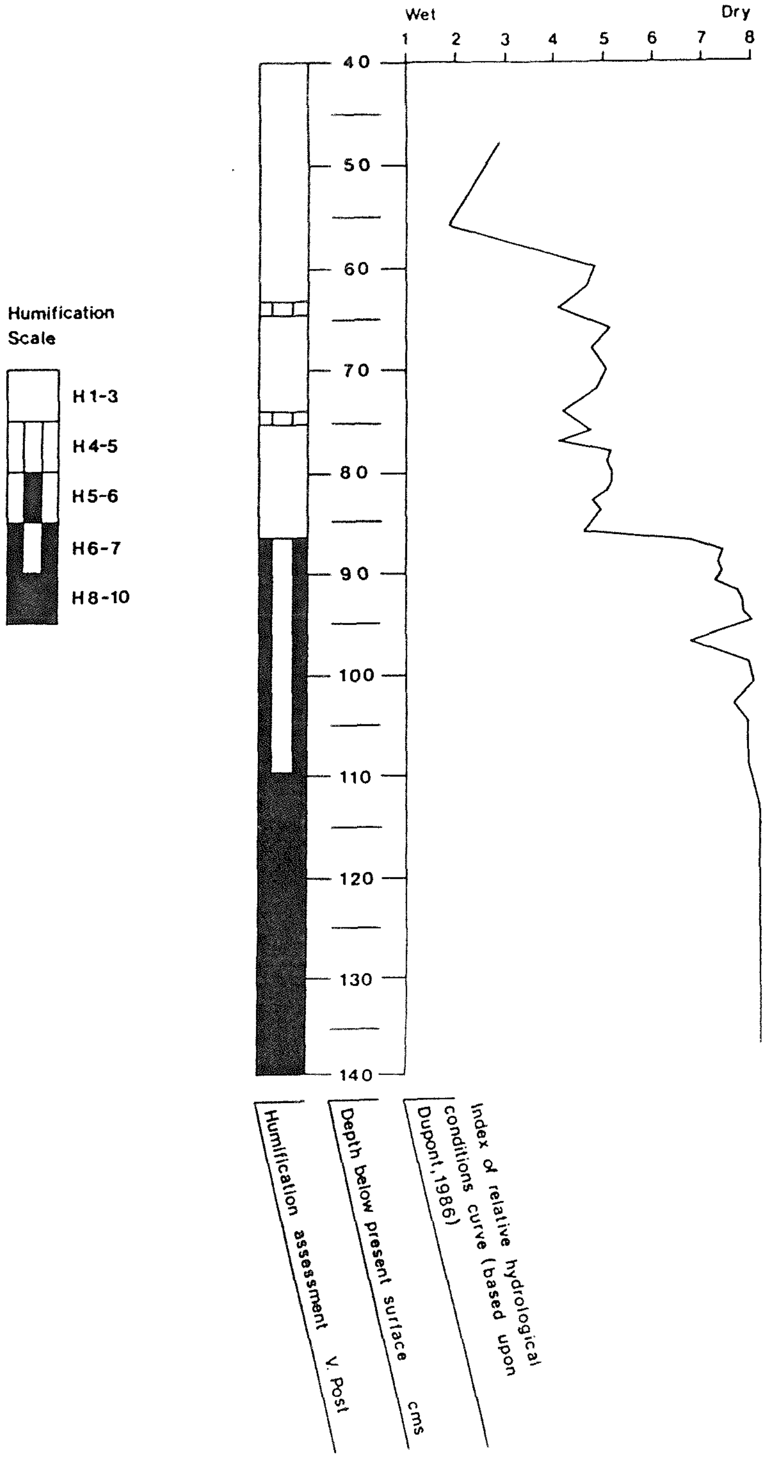
3
4
5
6
7
8
50
55
60
65
70
75
80
85
90
95
100
105
110
115
Humification Scale
H 1-3
H 4-5
H 5-6
H 6-7
H 8-10
Humification assessment V. Post
Depth below present surface cms
Index of relative hydrological conditions curve (based upon Dupont, 1986)
C. J. Haslam
1987

Figure 40.

JÜHRDENER MOOR



C. J. Haslam
1987

Figure 41.

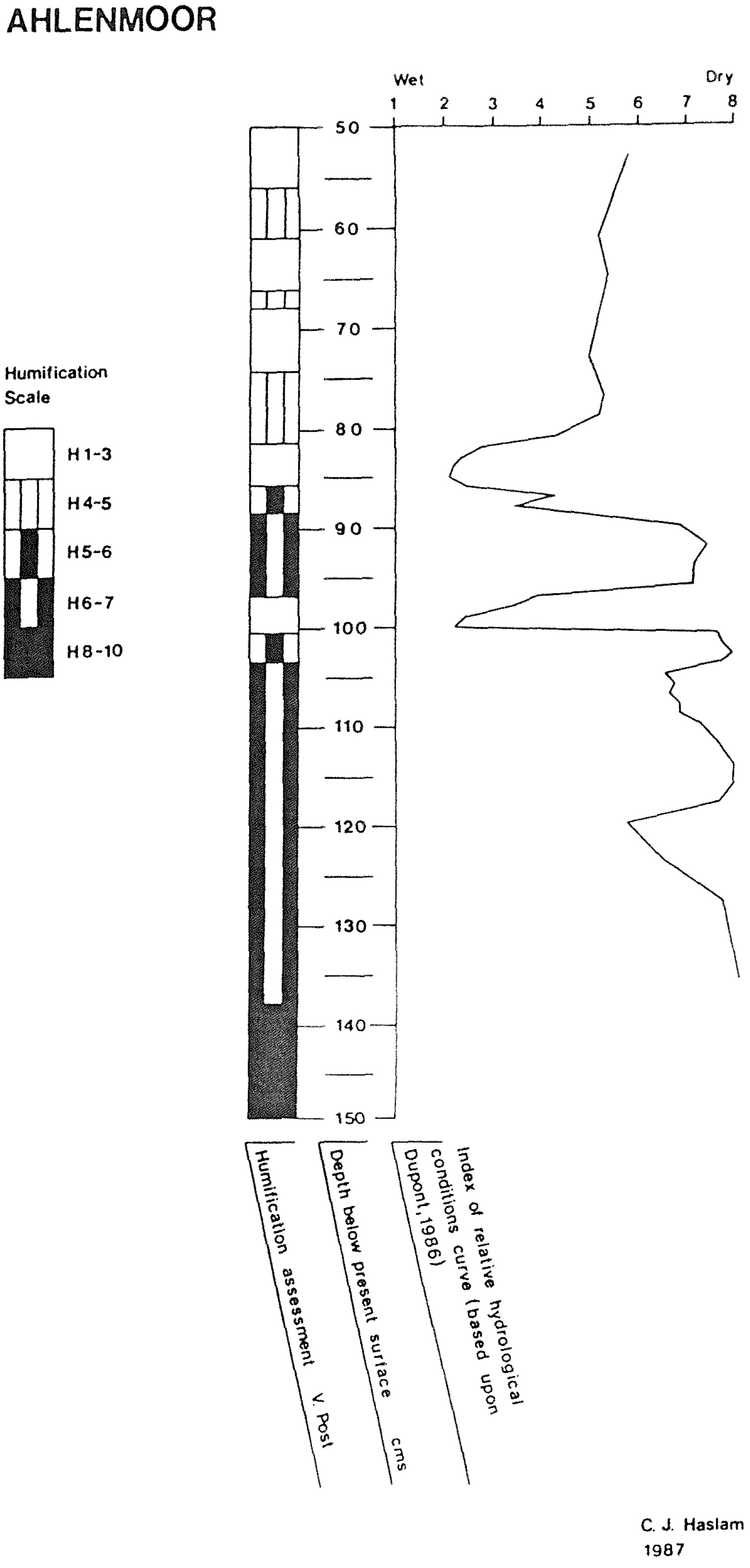

AHLENMOOR
Humification Scale
H1-3
H4-5
H5-6
H6-7
H8-10
Wet
Dry
1
2
3
4
5
6
7
8
50
60
70
80
90
100
110
120
130
140
150
Humification assessment V. Post
Depth below present surface cms
Index of relative hydrological conditions curve (based upon Dupont, 1986)
C. J. Haslam
1987

Figure 42.

EKEL MOOR

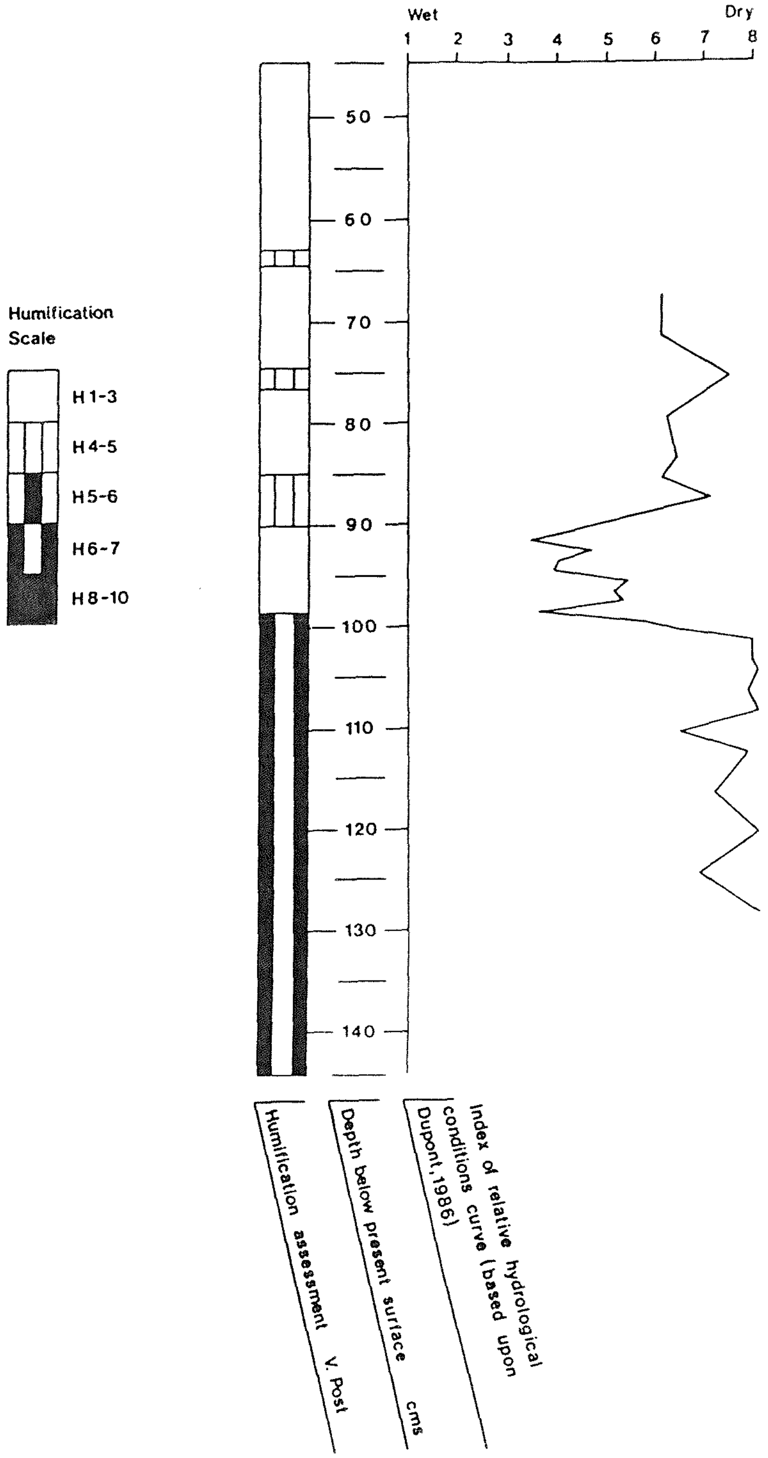


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Figure 43.

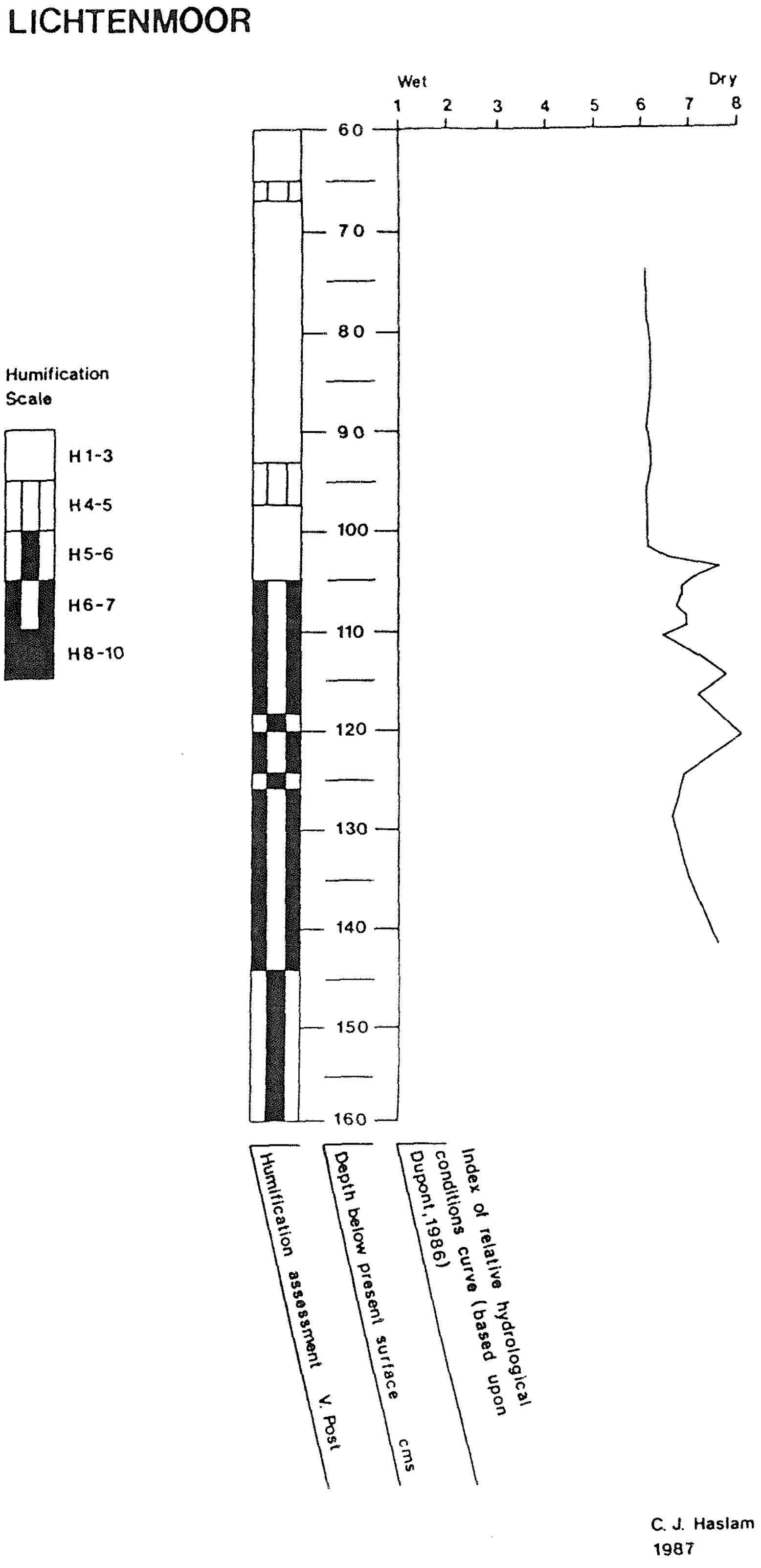
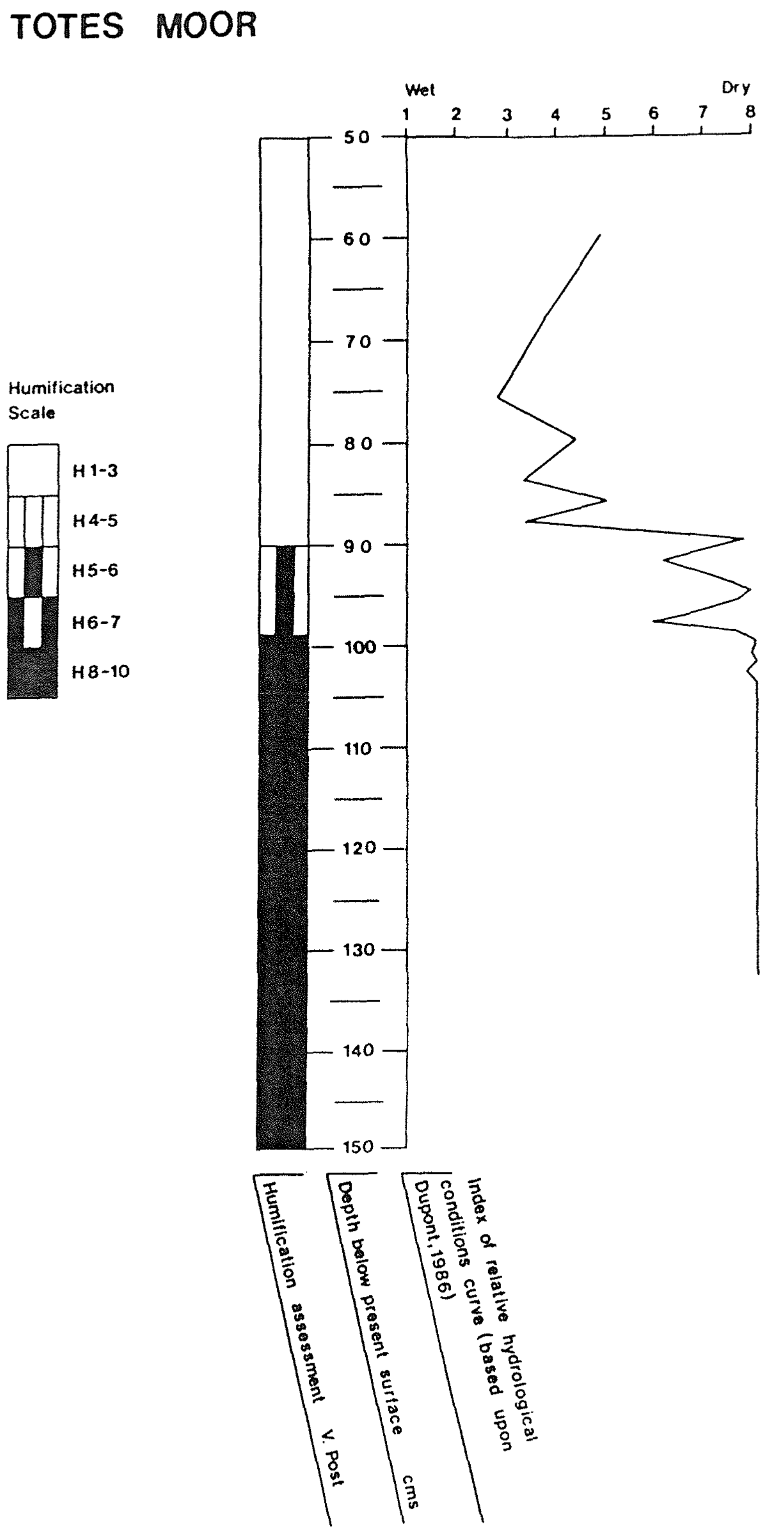
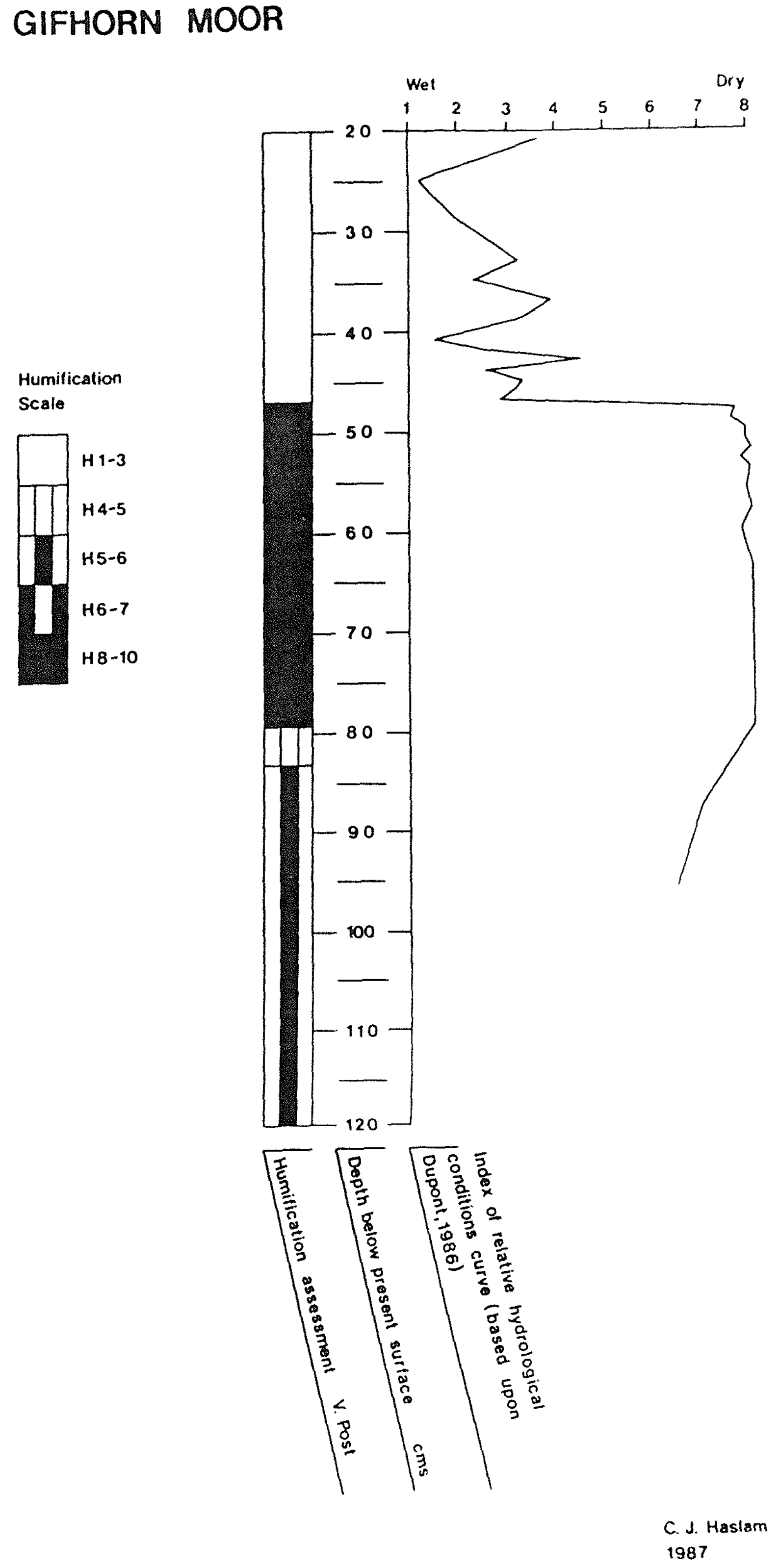

LICHTENMOOR
Wet
Dry
1
2
3
4
5
6
7
8
60
70
80
90
100
110
120
130
140
150
160
Humification Scale
H 1-3
H 4-5
H 5-6
H 6-7
H 8-10
Humification assessment V. Post
Depth below present surface cms
Index of relative hydrological conditions curve (based upon Dupont, 1986)
C. J. Haslam
1987

Figure 44.



C. J. Haslam
1987

Figure 45.


GIFHORN MOOR
Wet
Dry
1
2
3
4
5
6
7
8
20
30
40
50
60
70
80
90
100
110
120
Humification Scale
H 1-3
H 4-5
H 5-6
H 6-7
H 8-10
Humification assessment V. Post
Depth below present surface cms
Index of relative hydrological conditions curve (based upon Dupont, 1986)
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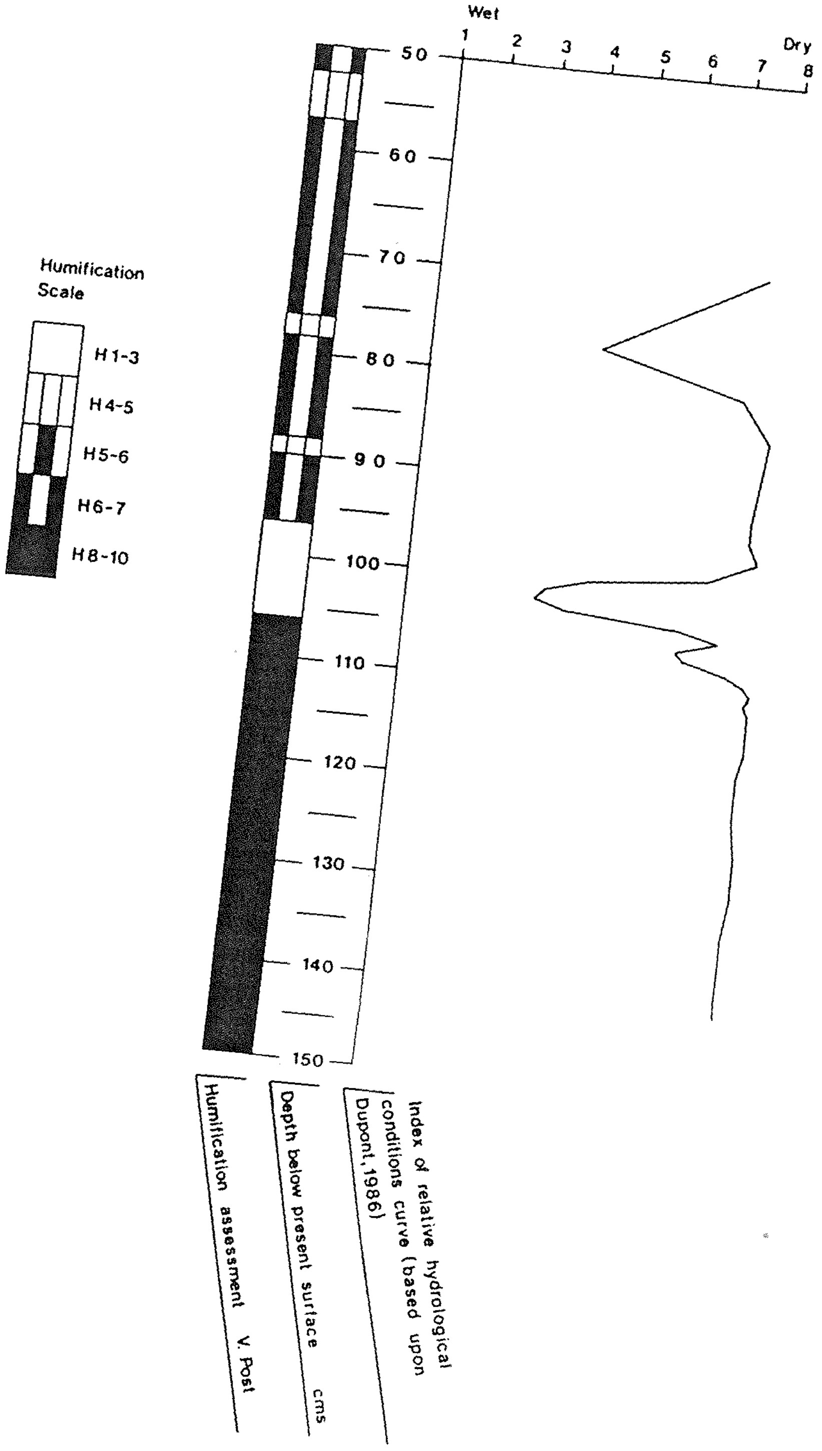
1987

Figure 46.

BØLLING BOG



C. J. Haslam
1987

Figure 47.

AGERÖDS MOSSE

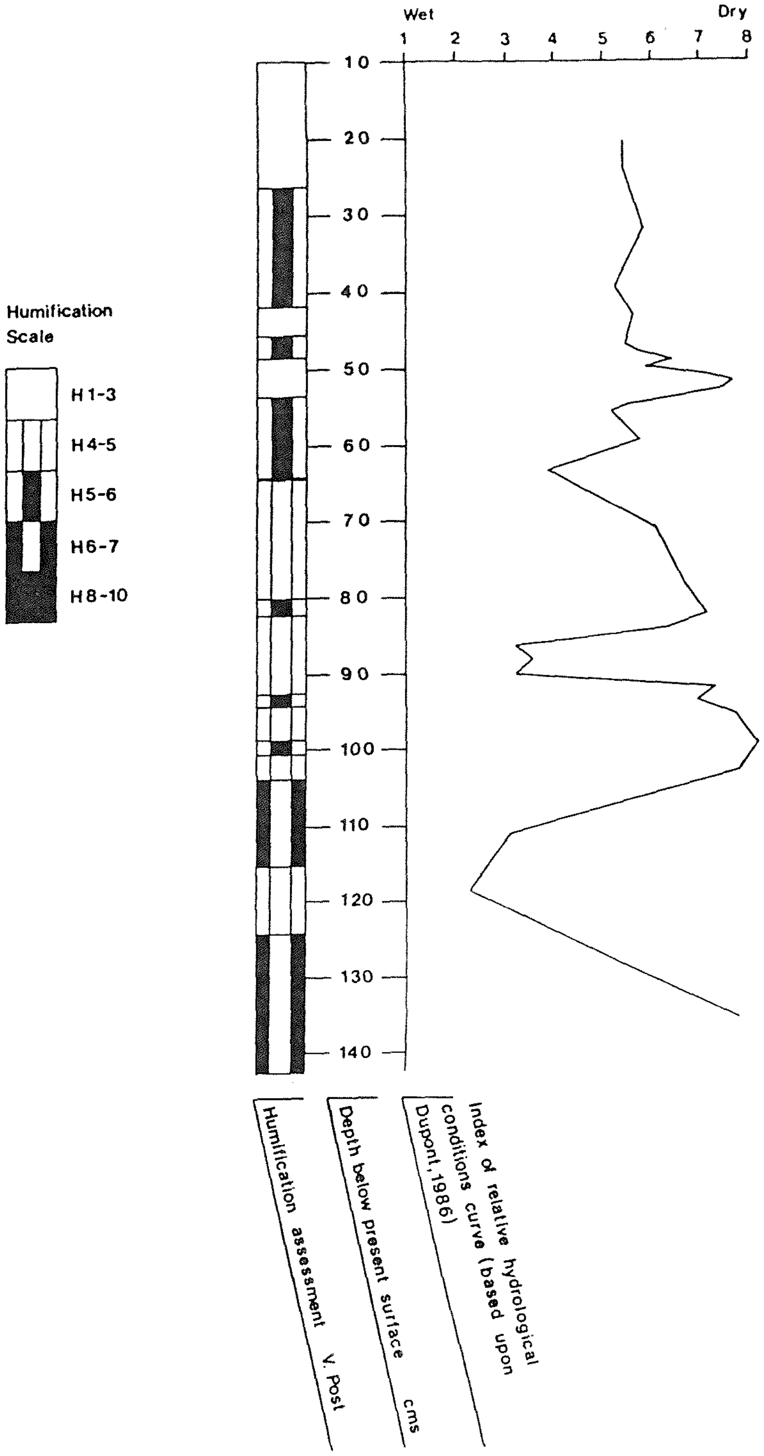


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Figure 48.

YGGERYDS MOSSE

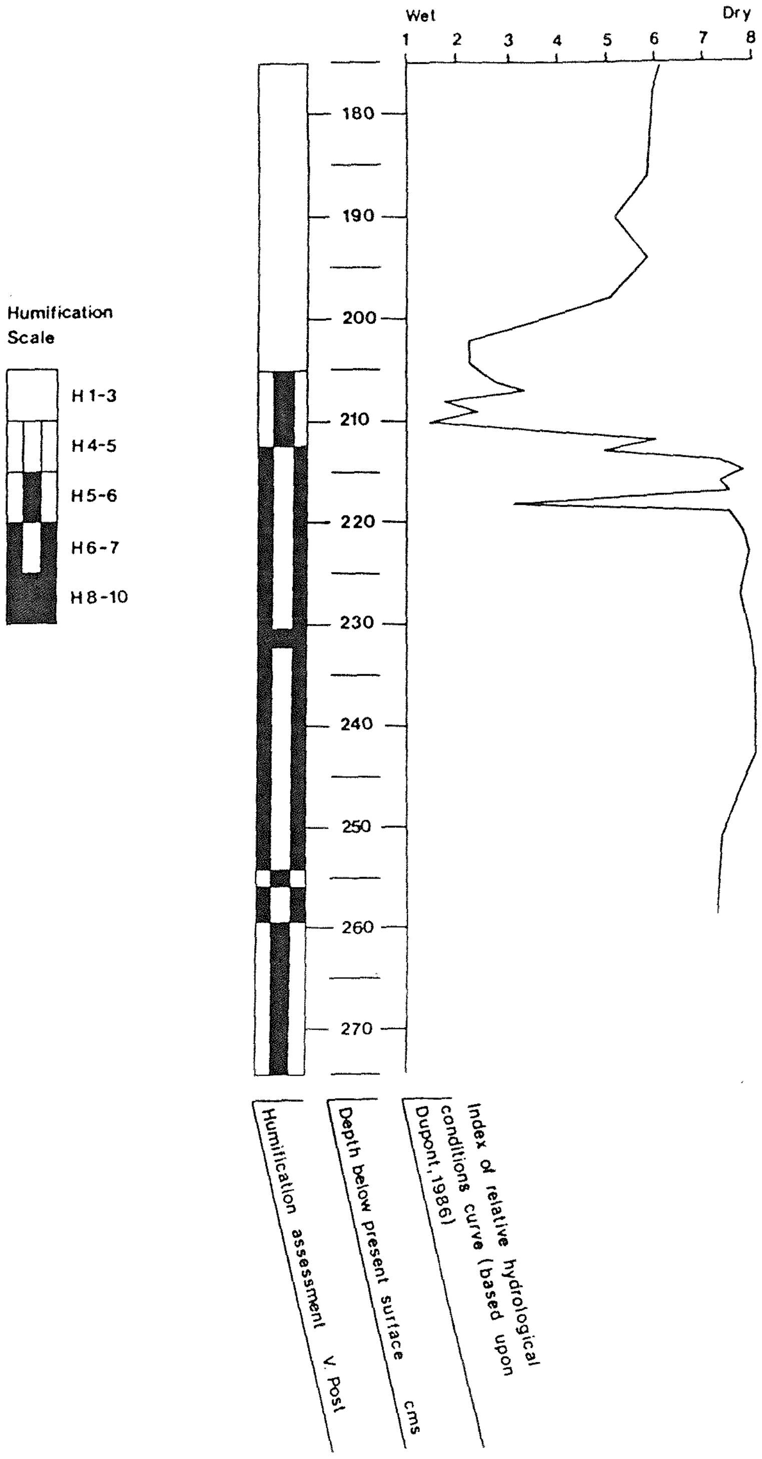

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Figure 49.

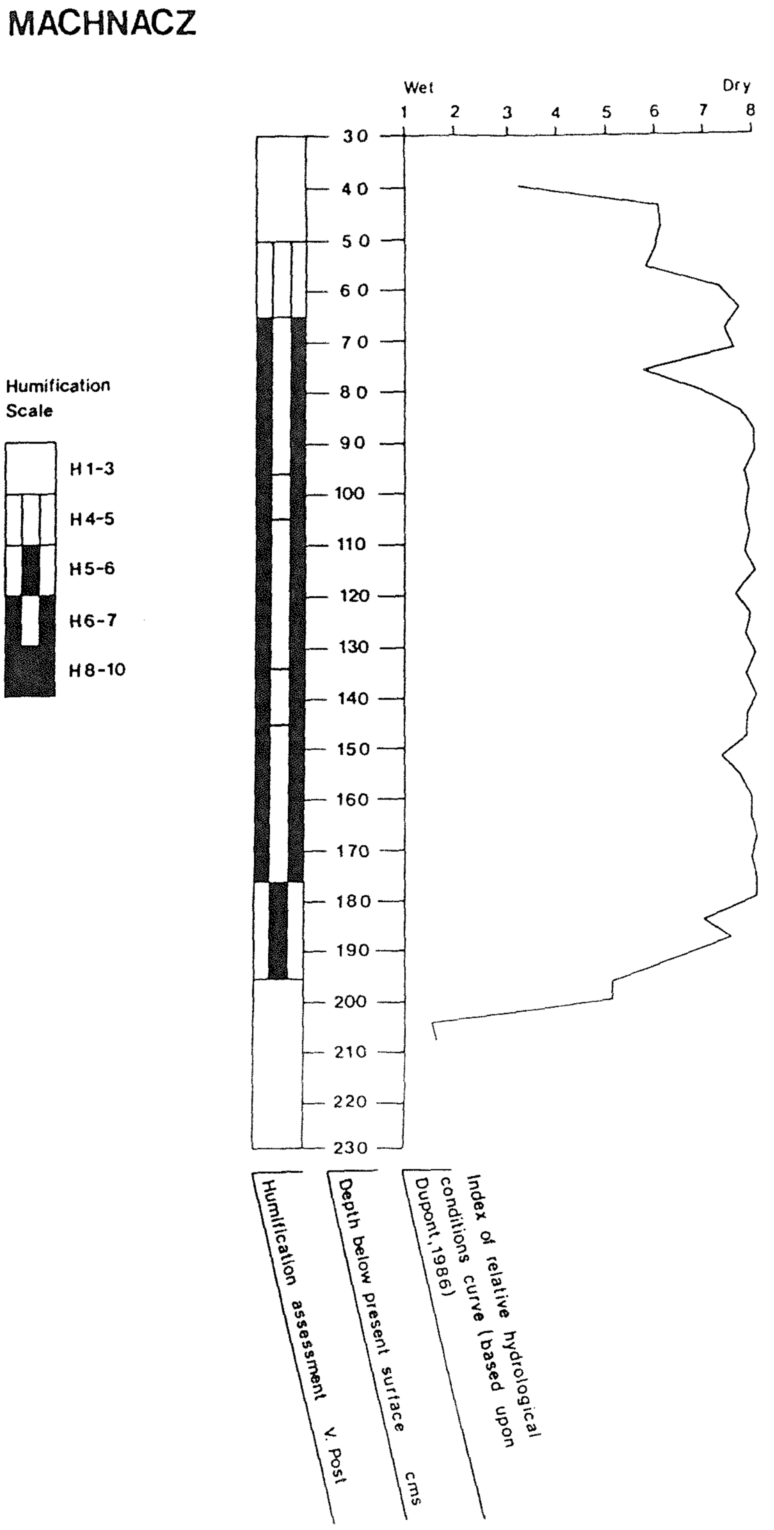

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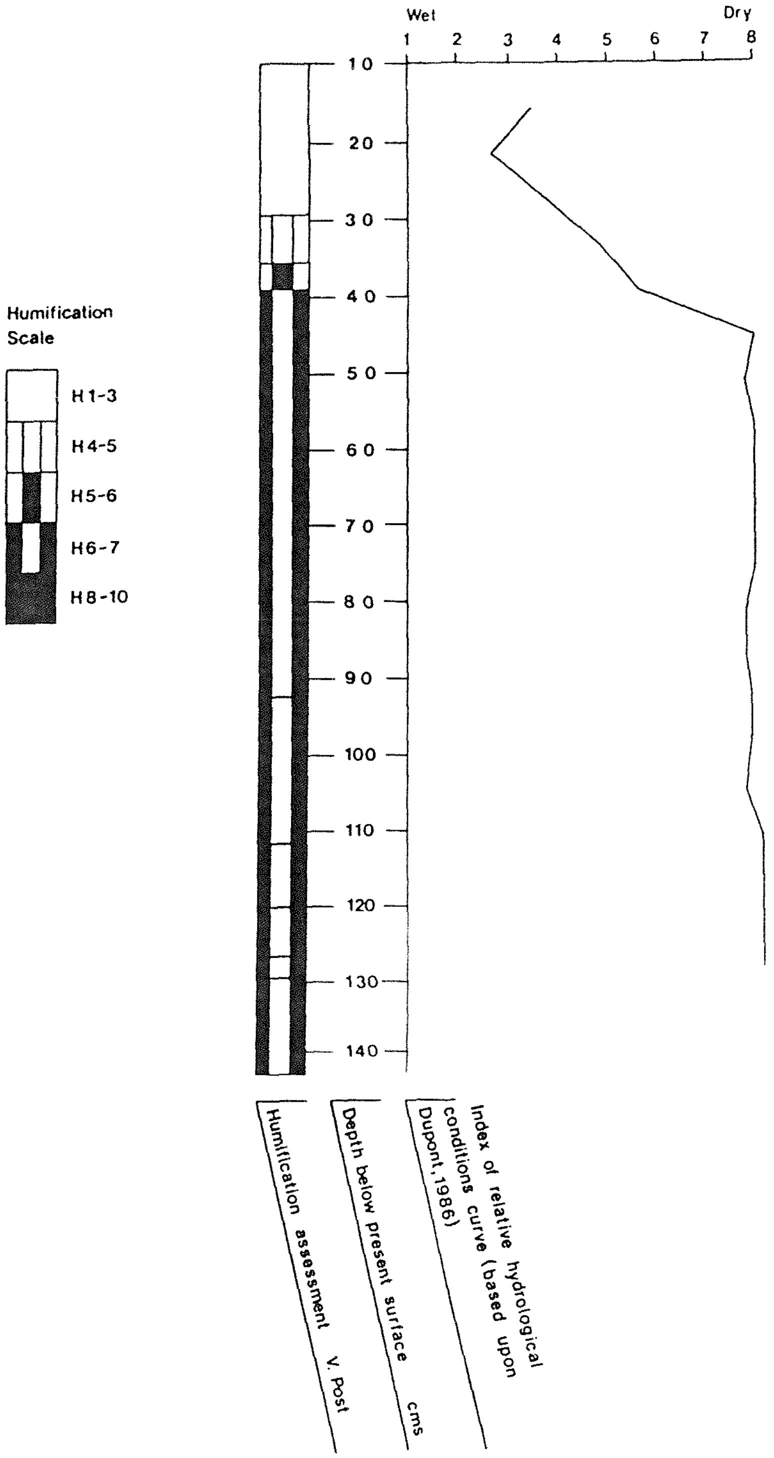
Figure 50.

KURIANSKA BAGNO



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1987

Sphagnum imbricatum. An indicator value of 5 was therefore assigned to this species.

Finally, no individual species cover abundance values were available for monocotyledonous remains. Since a range of hydrological conditions are represented by these components they have been excluded from this classification.

The resultant curves of relative hydrological conditions (wet-dry) are directly comparable both within and between sample sites, providing a simple index of ecological change for the time period associated with MHC formation. The results of these weighted average ordinations are presented in figures 33 to 50.

6.23 INDICES OF RELATIVE HYDROLOGICAL CONDITIONS: RESULTS AND DISCUSSION

The humidity curves are in general accordance with the observations made from the macrofossil analyses (see Section 5). In particular, relative fluctuations in the hydrological curves provide another argument for the supposition of sharp, short-term dry-wet fluctuations during the MHC period at each site. With the exception of Polish sites, a shift towards increased surface wetness is apparent in the immediate post-MHC matrix.

In western oceanic sites (Mongans Bog figure 33, Tregaron South East and West Bogs figures 35 and 36) any shift in relative hydrological conditions remains small, reflecting the strong maritime influences upon these sites. Oceanic conditions and the absence of marked fluctuations in surface wetness favoured the establishment of Sphagnum imbricatum. The phenotypic plasticity of this species with regard to water level oscillations has been demonstrated both experimentally (Green, 1968) and palaeoecologically (Barber, 1981 p.199), this feature enabling it to remain the habitat dominant through both minor wet and dry shifts. 'Wet' shifts were probably marked by a transition to lawn conditions and the dominance of semi-aquatic ecads, whilst 'dry' shifts saw the expansion of hummock ecads. Although macrofossil results indicate increased frequencies of lax high water level ecads associated with wetter periods, the evidence remains ambiguous. Further studies are required to clarify any relationship. A pronounced 'dry' phase in the immediate pre-MHC matrix at Mongans Bog is associated with the establishment of Sphagnum sect. Acutifolia (cf. S. capillifolium). Sphagnum imbricatum apparently displayed limited ability to tolerate conditions of extreme dryness. A similar, but less marked, dry phase may be identified in the Tregaron West bog profile. This is not associated with a Sphagnum sect. Acutifolia expansion.

At both Flanders Moss (figure 34) and The Engbertsdijksveen (figure 39) the onset of wetter surface conditions may be recognised some time before the formation of unhumified Cymbifolia peat is initiated. The sharp, but oscillatory, shift to wetter conditions has been dated at Flanders Moss to 4200 +/- 60 B.P. (SRR-3042) and coincides with a phase where Sphagnum imbricatum was absent (see Section 5.22). A comparable sequence has been noted at Bolton Fell Moss, where the Sphagnum imbricatum decline has been dated to 3270 +/- 50 B.P. (SRR-3039). The shift to wetter conditions at The Engbertsdijksveen is associated with the replacement of Sphagnum sect. Acutifolia with a Sphagnum cuspidatum-Sphagnum papillosum association (see Section 5.31). Drier periods within this phase may be identified, and at Flanders Moss coincide with temporary expansions of Sphagnum sect. Acutifolia (cf. S. capillifolium). The Sphagnum sect. Acutifolia (cf. S. capillifolium)-S. cuspidatum (-S. papillosum) association has been noted in the pre-MHC peats of several other sequences (Bolton Fell Moss 5.2.4, Whixall Moss 5.2.5, Juhrdener Moor 5.32.1, Ahlenmoor 5.32.2). In these sections, the incursion of Sphagnum cuspidatum into a generally 'dry' stratigraphy during wet shifts is more characteristic. The reasons for this atypical assemblage remain unclear. Van Geel (1972, 1978), commenting upon a similar association isolated in the pre-MHC peats at Wietmarscher Moor and The Engsbertsdijksveen I, hypothesised that a series of sharp, wet-dry fluctuations were responsible. The results of the current study support this interpretation. It seems however, that habitat conditions were likely to be sub-optimal for each species: wet lawn conditions favouring Sphagnum cuspidatum whilst Sphagnum sect. Acutifolia (cf. S. capillifolium) would be at a competitive advantage in low hummock habitats.

Although *Sphagnum capillifolium* is known to occur in lawn situations, productivity is generally reduced leading to a loss of competitive ability (Ratcliffe and Walker, 1958; Andrus et al., 1983; Boatman, 1983; Hayward and Clymo, 1983; Andrus, 1986). In areas where competition from hollow species is not too intense the species may proliferate (Andrus et al., 1983). Clymo (1970) and Hayward and Clymo (1982) offer some support for this proposition, showing that *Sphagnum capillifolium*, a hummock former on the mires studied, survived when transplanted to hollows. The ability of *S. capillifolium* to persist in lawn situations, resisting competition from the more hygrophilous Sphagna such as *Sphagnum magellanicum*, *S. papillosum* and *S. imbricatum*, may rest in the periodic return to drier local conditions. Experimental evidence (Vitt et al., 1975; Hayward and Clymo, 1982, 1983) indicates that prolonged high water-tables place *S. capillifolium* at a competitive disadvantage. The ability of *S. cuspidatum* to invade low hummock situations is more uncertain.

Several workers (Boatman, 1977; Damman and Dowhan, 1981; Andrus et al., 1983) have demonstrated that conditions in mire surface pools may be sub-optimal for *S. cuspidatum*. Boatman (1977) observed that smothering by algae and a low rate of new shoot production limited the ability of *S. cuspidatum* to colonise these habitats. Vitt et al. (1975) and Clymo and Hayward (1982) argue however that this species displays little potential to invade drier lawn environments and is rapidly excluded by *S. papillosum* and *S. magellanicum*. Whilst Clymo (1970, 1973) and Hill (1978) indicate that there is little evidence to suggest the species is particularly desiccation tolerant, transplantation experiments at Moor House, northern England by Clymo and Reddaway (1971) have shown that *S. cuspidatum* may survive in hummock conditions, though with much reduced productivities. The occurrence of shoots of hollow species in hummock situations has been noted by Rydin (1985, 1986) and is attributed to lateral water movement through branches of neighbouring plants with better water transport capacities. Observing that *Sphagnum balticum* often occurs at quite high levels above the water table, but then only as single shoots in hummocks of *S. fuscum* or *S. capillifolium*, Rydin (1985) concluded that providing absolute growth rates remained similar, co-existence could continue until a change in local hydrological conditions was effected. Although accurate measurement of productivity is difficult, calculated dry mass growth rates for Sphagnum cuspidatum and S. capillifolium in a hummock situation at Moor House (Clymo and Reddaway, 1971) indicate similar relative performances. Accordingly, a relationship analogous to the Sphagnum fuscum-S. balticum association described by Rydin (1985, 1986) is suggested for the Sphagnum capillifolium-S. cuspidatum subfossil low hummock association isolated by the current study.

Aaby (1976) has studied changes in the degree of humification in Danish raised mires. He detected an apparent periodicity of 260 years. Subsequent work on fluctuations in the Corylus curve in Wietmarscher Moor and The Engbertsdijksveen (Van Geel, 1978) recorded cycles in the order of 150-200 historical years. Approximate periodicities of 40, 85, 145, 200, 350, 500, 600, 800 and 1450 years were detected in curves of pollen types and macrofossil remains by Wijmstra et al. (1984). Several of these periods appear to correspond with known sunspot cycles: 22, 40, 80, 150, 200 and possibly 1000 years (Dewey, 1960; Eddy, 1976). Schleser (1985) has analysed variations in 15-N from a raised mire in northern Germany, and claims to identify cyclic variations with periodicities of about 170 and 280 years. More recently, based upon relative deuterium temperature curves from the Meerstalblok, The Netherlands, Dupont (1986) has reported periodicities of 41, 142, 206, 342, 511 and 696 years. These agree with observations by Neftel et al.(1981) on 14-C variations and those of Wijmstra et al. (1984). The fluctuations identified in the pre-MHC peats of the current study appear distinctly shorter.

Extrapolations based upon the available radiocarbon dates for the British Isles suggest cyclic 'wet' phase shifts in the order of 40-50 radiocarbon years at Flanders Moss. This compares with 30-110 radiocarbon years at Bolton Fell Moss and 60-120 radiocarbon years at Whixall Moss. Wet-dry fluctuations in the post-MHC matrix at Mongans Bog display a periodicity of 30-80 radiocarbon years. It is suggested that these shifts were of sufficient sharpness and severity to exclude other competing Sphagna from the Sphagnum sect. Acutifolia (cf. S. capillifolium)-S. cuspidatum association. At Juhrdener Moor (figure 40) and Ahlenmoor (figure 41), where S. papillosum plays an important role in the pre-MHC succession, it seems likely that either wet phase shifts were less severe or less frequent. More extensive studies are needed if this is to be confirmed.

The humidity curve for Agerods Mosse (figure 47) displays a series of particularly marked wet-dry shifts. The presence of Sphagnum cuspidatum in the lower pre-MHC peats during periods of extreme dryness is unusual. Low frequencies of competing Sphagna such as Sphagnum imbricatum, Sphagnum sect. Acutifolia and S. papillosum, suggest the existence of a wet hollow habitat. Periodic drying during 'dry' phase shifts would expose basal pool muds and lead to a relatively slow rate of peat accumulation. It would seem that the invasion of Sphagnum imbricatum is associated with a more gradual shift to wetter conditions at 98cm. The greater competitive ability of Sphagnum cuspidatum prevented peripheral hollow invasion by Sphagnum imbricatum. An oscillatory transition to slightly drier surface conditions in the immediate pre-MHC peats promoted the establishment of Sphagnum imbricatum as the habitat dominant. The productivity of this species was sufficient to prevent inundation by rising mire water tables and a return to incipient pool conditions during the early Subatlantic.

Generally dry relative hydrological conditions are indicated by the Bolling Bog humidity curve (figure 46). 'Wet' shifts at 106cm and 78cm coincide with the deposition of an unhumified Cymbifolia (S. papillosum) matrix. The band of unhumified peat between 90-89cm is not recorded by the weighted averages ordination. High frequencies of Eriophorum vaginatum and Calluna vulgaris throughout the profile indicate a hummock situation. However, the presence of Sphagnum cuspidatum and Sphagnum papillosum as important components of the moss flora point to low hummock conditions which underwent periodic inundation. A pronounced and permanent shift to wetter surface conditions associated with the Subboreal-Subatlantic transition did not occur in the Bolling profile.

Comparable conclusions may be drawn from the humidity profiles for Ekel Moor (figure 42) and Yggeryds Mosse (figure 48). Oscillatory wet-dry fluctuations characterise the pre- and post-MHC peats at these sites. A pronounced shift to wetter local conditions is associated with the establishment of Sphagnum sect. Cuspidata and the deposition of an unhumified matrix. This 'wet' phase is rapidly replaced by a Sphagnum fuscum-S. capillifolium association more typical of drier site conditions. The absence of macrofossil components indicative of relatively wet local habitats points to reduced water levels. A return to a more humified matrix is not effected however, indicating that decomposition conditions remained unfavourable. Several workers (Overbeck and Happach, 1957; Pedersen, 1975; Clymo and Hayward, 1982; Proctor, 1982; Silvola and Aaltonen, 1984) have demonstrated that dense hummocks, or cushions, remain wet for longer periods than loose mats, even when they stand well above the surrounding water table. Proctor (1982) and Rydin (1985) suggest that this is attributable to the arrangement of the shoots and proximity of neighbouring plants. This mechanism alone appears an unsatisfactory explanation for the presence of unhumified Sphagnum sect. Acutifolia peat in the post-MHC matrix. Results from Lichtenmoor (figure 43) also indicate that the main shift in peat formation was not associated with a transition to markedly wetter conditions. This raises the possibility that a thermal component may have been more important than an increase in precipitation in initiating unhumified peat formation. Recent modelling by Dupont (1986), based on isotope and macrofossil data from the Meerstalblok, The Netherlands, has indicated that small differences in precipitation have a relatively large impact on surface evapotranspiration and that large differences in annual temperature cause a relatively small effect. An increased absolute range, perhaps manifest in a reduced effective vegetative season, may therefore have been involved.

Both Totes Moor (figure 44) and Gifhorn Moor (figure 45) display similar humidity curves. A pronounced dry phase characterises the pre-MHC peats, low values of % identifiable Sphagnum making recognition of wetter phases difficult. An oscillatory deterioration involving a series of sharp, wet-dry shifts is associated with the rise in % identifiable Sphagnum at each site. The shift to wetter local conditions at Gifhorn appears to have been particularly marked. Drier phases in the post-MHC matrix, not readily apparent from the macrofossil analyses, are clearly shown by the humidity curves.

The wet-dry curves derived from north eastern Poland (Machnacz figure 49 and Kurianska Bagno figure 50) reflect the tendency to drier vegetations throughout the Subboreal and Subatlantic. Minor 'wet' phases at 152cm, 118cm and 78cm may be identified in the Machnacz sequence. These coincide with expansions of Sphagnum sect. Cuspidata (cf S. recurvum). The shift at 78cm has been dated to 1120 +/- 50 B.P. (SRR-3175). The catotelm-acrotelm boundary and the lower fen peat transition are marked by sharp fluctuations in the moisture balance.

6.24 SUMMARY

The strength of the weighted averages ordination technique remains its simplicity in revealing the main community and environmental gradients present in a data set. However, subjective estimation of species indicator values, the existence of different ecads of major components and a disregard of species absences may potentially give misleading results (Grieg-Smith, 1983, p.130). In an attempt to obtain greater objectivity, additional ordinations using detrended correspondence analysis were performed. See Gauch et al. (1977), Gauch and Whittaker (1981), Gauch et al. (1981), Gauch (1982) and Minchin (1987) for reviews of this technique.

6.3 THE APPLICATION OF DETRENDED CORRESPONDENCE ANALYSIS TO THE IDENTIFICATION AND ANALYSIS OF ENVIRONMENTAL GRADIENTS

6.31 INTRODUCTION: A METHODOLOGICAL BACKGROUND TO DETRENDED CORRESPONDENCE ANALYSIS

Detrended correspondence analysis (DCA) is an eigenvector ordination technique which ordinates simultaneously both the species and the sites by a re-iterative weighting procedure (Hill, 1979). Essentially, what is done is to take a set of species scores, then to define sample scores such that each sample score is the mean score of the species that occur in it, and finally to calculate new species scores so that the score of each species is the mean of the scores of the samples in which that species occurs (Hill, 1979). Two forms of this analysis are available, the original reciprocal averaging technique or RA (Hill, 1973b) and a recently modified version, detrended correspondence analysis or DECORANA (Hill, 1979), used in the present study. Technical details are given by Hill (1979) and Hill and Gauch (1980). Related both to simple weighted averaging and to eigenvector ordinations, the technique is similar to that for principal components analysis (Gauch, 1982). However, several workers have shown it to be more powerful than principal components analysis for displaying environmental gradients in data sets where sample heterogeneity is high (see for example Hill, 1979; Kershaw and Looney, 1985). Reciprocal averaging has two main faults: the ends of the first reciprocal average axis are compressed relative to the middle and the second reciprocal average axis is often a spurious, quadratic (arch) distortion of the first axis. The arch distortion of reciprocal averaging arises because when second and higher axes are derived, they are only constrained to be orthogonal with lower axes. The orthogonality criteria for second and higher axes of reciprocal averaging is replaced in DECORANA with the more restrictive criterion that second and subsequent axes have no systematic relations of any kind to lower axes (Hill, 1979; Gauch, 1982). This is achieved by dividing the first axis into a series of segments, and within each segment, the axis 2 scores are adjusted to have an average score of zero. This procedure results in an eigenvector ordination of the species with no arch distortion and a corresponding series of sample scores, which are weighted averages of the species scores (Gauch, 1982).

Axis rescaling by expanding the local scaling in proportion to the reciprocal of the local mean square deviation removes axis compression problems inherent to reciprocal averaging. The intention of rescaling is to ensure that species turnover occurs at a uniform rate along the species ordination axis and, consequently, that equal distances in the ordination correspond to equal differences in species composition. The resulting unit of ordination length is referred to as an 'average standard deviation of species turnover', or SD. A species appears, rises to its mode, and then disappears over a span of circa 4.0 SD, and a full turnover in species composition of samples similarly occurs in about 4.0 SD (Hill 1979). DECORANA implicitly assumes a Gaussian species response curve along environmental gradients (Hill, 1979; Hill and Gauch, 1980; Gauch, 1982). Gauch and Whittaker (1972) have provided the most detailed statement of this model based on a subjective evaluation of species response curves from the direct gradient studies of Whittaker (1956, 1969, 1965). More complex response curves than the Gaussian are recognized as occurring (Whittaker, 1978) but where polymodal curves occur, the different optima are believed to represent different ecotypes and are not considered in their studies. Evidence for the shape of a species response curve is limited (Ellenberg, 1954; Ernst, 1978; Austin and Austin, 1980) and more observations of performance along environmental gradients are needed. Whilst Austin (1976, 1980), Clymo (1980) and Faith et al. (1987) have pointed out that in published accounts non-Gaussian curves appear more frequent, it is recognised that the shape of the curve is dependent upon the scaling of the environmental gradient. In the absence of firm evidence to the contrary, Gauch (1982, p.97) concludes that "...the Gaussian model is presented as, and should be received as, an approximation- a generality from a vast array of particulars. At its level of detail, however, no alternative model appears better". Similar conclusions have recently been drawn by ter Braak and Looman (1986) and ter Braak and Gremmen (1987). Hill and Gauch (1980) and Gauch (1982) believe that this intermediate stance, embracing the Gaussian model but not too rigorously, is the fundamental reason for the superior performance of this ordination technique; see also Kershaw and Looney (1985). Using simulated vegetation data to assess the relative robustness of DECORANA, Minchin (1987) has shown that the program still has imperfections with respect to variations in the response model and sampling pattern. Its performance remains, however, superior to competing techniques such as principal components analysis, principal co-ordinates analysis and Gaussian ordination.

Although Clymo (1965) has calculated slightly different decomposition rates between species of Sphagnum in the acrotelm of a valley mire in southern England, it has been assumed throughout that macrofossil components display unimodal response curves. Based on observed species distributions along hummock-hollow gradients in contemporary situations (see earlier) this seems tenable (I.C. Prentice, personal communication). In addition, the implicit distance metric scaling of DECORANA tends to minimize the statistical noise and thus maximise the signal present in palaeoecological data (Prentice, 1980).

6.32 RESULTS AND DISCUSSION

6.32.1 THE ANALYTICAL SEQUENCE

Five runs of the DECORANA program were performed. Run 1 involved a default analysis including both cover abundance and presence/absence macrofossil data. The eigenvalues for axes 1-4 are 0.572, 0.455, 0.224 and 0.104 respectively. As DECORANA calculates only the first four axes, the eigenvalues are relative, rather than absolute, measures of variance (or 'data structure') accounted for by each axis. Although axis 1 is the more important of the structures identified, the eigenvalues for axes 2, 3 and 4 are not so low as to be unimportant (Hill and Gauch, 1980). In an attempt to improve data interpretation, a second run excluding presence/absence data was undertaken. Eigenvalues of 0.743, 0.396, 0.225 and 0.105 were obtained for the first four axes. Downweighting for rare species according to the criterion of Hill (1979, p.15) involved Sphagnum papillosum and Sphagnum magellanicum, but failed to provide more weight to axis 1. The possibility that the presence of % U.O.M. or % U.O.M. together with % Monocotyledonous remains and % Ericaceae was distorting structure recognition (I.C. Prentice, personal communication) was explored in successive default analyses excluding these components. The omission of % U.O.M. failed to improve eigenvalues for the first four principal axes. Values of 0.706, 0.479, 0.265 and 0.138 were obtained respectively. The analysis of Sphagnum cover abundance data alone did, however, lead to an improvement in the eigenvalue scores. The eigenvalues for axes 1-4 were 0.794, 0.366, 0.135 and 0.118 respectively. This is not unexpected given the low number of species involved in the ordination. Since Run 2

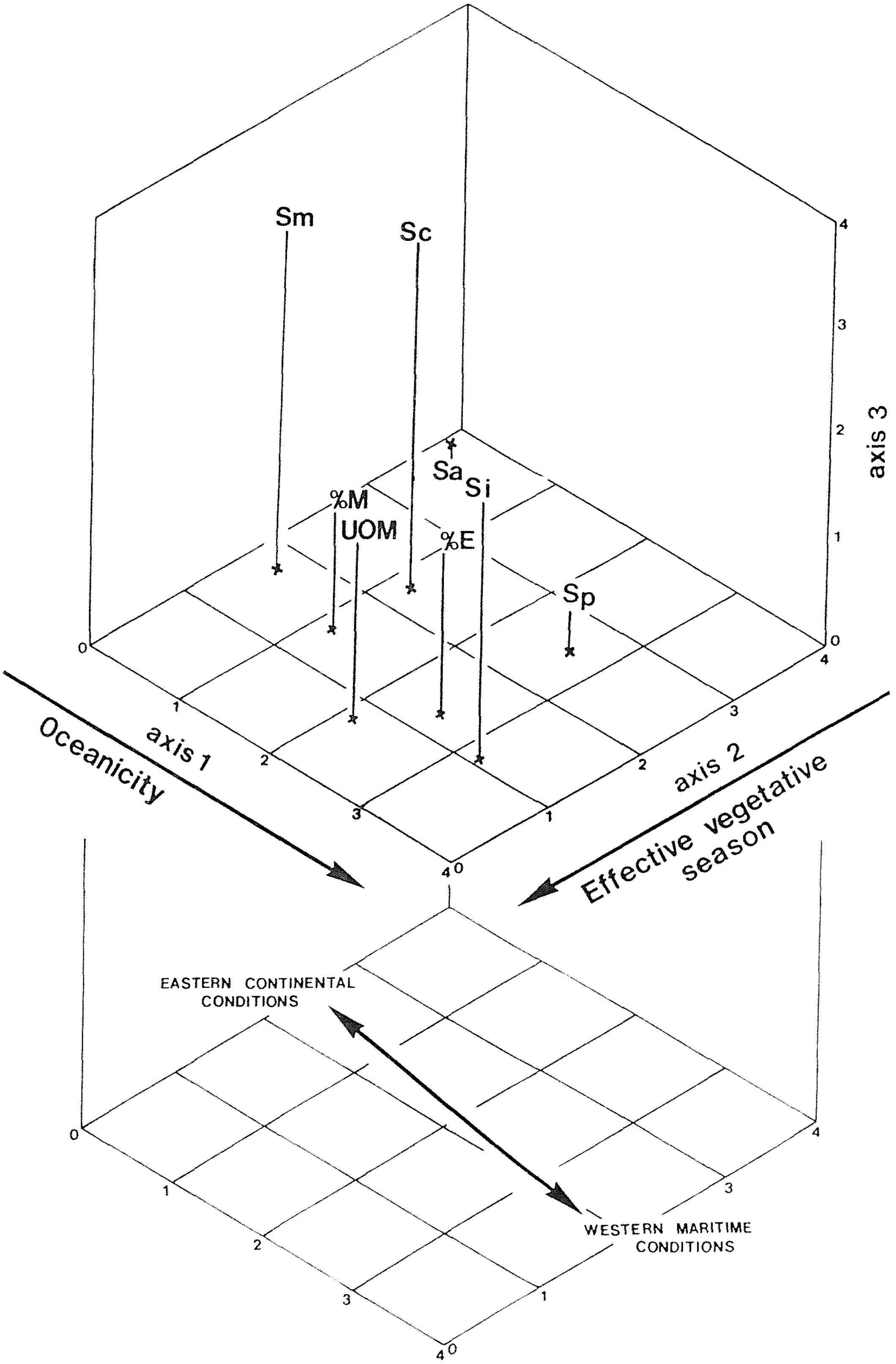


Figure 51. Three dimensional species ordination by DECORANA of macrofossil data from north western Europe. This figure shows axes 1, 2 and 3 of a default DECORANA ordination of macrofossil abundance data. Axes units represent 'average standard deviations of species turnover' (Hill, 1979), with a range 0-4 SD. Si, Sphagnum imbricatum; Sp, Sphagnum papillosum; Sm, Sphagnum magellanicum; Sc, Sphagnum sect. Cuspidata; Sa, Sphagnum sect. Acutifolia; UOM, Unidentifiable Organic Matter; %E, Ericaceae; %M, Monocotyledonous remains.

contained more 'indicator' species and had only marginally inferior eigenvalues than Run 5, it was decided to concentrate upon this analysis.

6.32.2 INTERPRETATION OF THE SPECIES ORDINATION

Inferences concerning the environmental meaning of DECORANA axes are made from consideration of the ecological preferences of species associated with the ends of each ordination axis. Figure 51 displays a three-dimensional DECORANA species ordination for the macrofossil "cover-abundance" data. The first-axis species ordination has a length of 3.24 SD, the second-axis 3.18 SD and the third-axis 2.86 SD. Short community gradients and the low number of species present in the analysis make axis interpretation difficult.

Sphagnum imbricatum, *S. papillosum* and % Ericaceae score high on the first axis while *S. magellanicum* and *Sphagnum* sect. *Acutifolia* score low values. Pearson correlation coefficients for *Sphagnum imbricatum* and *Sphagnum* sect. *Acutifolia* correlate significantly with the ends of this axis: *Sphagnum imbricatum* 0.7624 (P=0.001, n=645), *Sphagnum* sect. *Acutifolia* -0.6264 (P=0.001, n=645). The presence of *Sphagnum* sect. *Acutifolia* (cf. *S. capillifolium* and *S. fuscum*) and *S. magellanicum* in eastern and continental European raised mires, and the dominance of *S. imbricatum*, *S. papillosum* and *Erica tetralix* in western maritime sites (see Section 5) suggests the axis to represent a measure of oceanicity. Single factor interpretation is difficult given the presence of only 8 indicator species/components. The distribution of *Sphagnum* and higher plants along the principal moisture gradient in raised mire ecosystems, pool-lawn-hummock (see for example, Ratcliffe and Walker, 1958; Vitt and Slack, 1975; Clymo and Hayward, 1982; Boatman, 1983), is not reflected by the DECORANA ordination. Instead it seems that macroscale variations have been highlighted. No correlation was found between chemical determinations of humification and axis 1 scores.

A few anomalies to this interpretation were found, such as *Sphagnum* sect. *Cuspidata* and *Sphagnum magellanicum* which, at 0.79 SD and 0.32 SD respectively, were unexpectedly near the 'continental' end of this axis.

The occurrence of Sphagnum magellanicum in both oceanic wet lawn and continental low hummock situations has been noted earlier (see Section 5). It is postulated that the dominance of this species at Totes Moor and in north eastern Poland accounts for its axis 1 score. That it does not replace Sphagnum sect. Acutifolia as the axis extreme may be attributed to the low cover-abundances of this species in Polish sequences. Sphagnum sect. Cuspidata contains a series of Sphagna of varying ecological preference. Though Sphagnum cuspidatum is typically associated with wet pool environments other members identified include S. tenellum, S. balticum and S. recurvum, all more typical of drier habitats (Hill, 1978; Daniels and Eddy, 1984). Whilst sub-division to species level was not undertaken in the DECORANA analysis, high frequencies of S. tenellum, S. balticum and S. recurvum have been noted in eastern European profiles (see Section 5). It is believed that this may explain the slightly anomalous position of Sphagnum sect. Cuspidata. % U.O.M. occupies an intermediate position between continental and maritime extremes.

On the second axis, no hummock-hollow moisture gradient is apparent (figure 51). Pearson correlation coefficients show that Sphagnum sect. Acutifolia ($r=0.5992$, $P=0.001$, $n=645$), Sphagnum papillosum ($r=0.5024$, $P=0.001$, $n=645$) and Sphagnum sect. Cuspidata ($r=0.4728$, $P=0.001$, $n=645$) are positively correlated with axis 2 whilst % U.O.M. displays negative correlation ($r=-0.5495$, $P=0.001$, $n=645$). No correlation was found between axis 2 scores and chemical determinations of humification. Possible alternative interpretations of this axis include variations in the nutrient balance, cation exchange capacities and effective vegetative season for raised mire species.

Early studies on the nutrient status of Swedish ombrotrophic mires (Sjors, 1950, 1952) illustrated that the growth rate of Sphagnum was affected by the concentration of solutes. Comparable results were obtained by Gorham (1956) working with Sphagnum cuspidatum and S. auriculatum at Moor House, northern England and McVean (1959) who studied the growth of S. compactum, S. auriculatum, S. cuspidatum and S. tenellum in Scottish blanket peats. Clymo (1973), Sonesson et al. (1980) and Janssens and Glaser (1986) have shown that the rate of supply of solutes may be important. Aulio (1982) developing earlier work by Boatman and Lark (1971) on the growth of protonema of S. papillosum, S. cuspidatum and S. magellanicum, has determined the concentration of 8 elements in the tissues of Sphagnum capillifolium, S. fuscum, S. magellanicum and S. cuspidatum from the Finnish raised mire Kurjenrahka and the minerotrophic mire-fen complex Karevanrahna. The average concentrations of individual elements were higher in the minerotrophic water and moss samples than in the ombrotrophic material. Interspecific differences between hummock and hollow taxa remained small however, preventing accurate estimation of the mineral element contents of individual Sphagnum moss species. Clymo and Hayward (1982) conclude that at present there is insufficient information upon which to differentiate between the various Sphagna based upon variations in the nutrient balance. This proposition is supported by results from Cranesmoor, southern England, showing that Sphagnum papillosum occupies the more oligotrophic lawns and S. magellanicum the flushed areas (Newbould, 1960) whilst at the Akhult mire, southern Sweden, the reverse tends to be true (Malmer, 1962).

The cation exchange capabilities of Sphagnum are a function of pH and dissolved solutes. Each Sphagnum species creates an acidity within a certain range if the dissolved solutes fall within limits. Concentrations that are too high will overstress the exchange mechanism and plants will suffer, since elevated cation concentrations are known to kill or reduce growth in Sphagnum (Gordeeva, 1979). In Sphagnum, high cation exchange capacity is correlated with high polyuronic acid content (Clymo, 1963; Craigie and Mass, 1966; Spearing, 1972). There is a strong correlation between polyuronic acid content and optimum height above the water table for various species (Clymo, 1963; Spearing, 1972), with hummock species having higher amounts than lawn species. Clymo (1963), working with Sphagnum papillosum, also demonstrated that cation exchange capacity rises intraspecifically both with increasing pH values and increasing cation concentrations, thus allowing adaptation to chemically different aquatic environments. Insufficient information is available on the interrelationship of cation concentration, pH and flushing rates for different species to permit accurate use of Sphagna as site quality indicators however.

Although a number of investigations of Sphagnum growth and decomposition have been published (see for example Chapman, 1965; Clymo, 1965, 1973; Clymo and Reddaway, 1971, 1974; Pedersen, 1975; Boatman, 1977, 1983; Hayward and Clymo, 1983) little work has been done on the effects of growing season length. Working on the Silver Flowe National Nature Reserve, southern Scotland, Hulme and Blyth (1982) have attempted to measure the annual growing season in several Sphagnum species. The five most abundant Sphagnum species presently growing on the Silver Flowe were selected, these being Sphagnum cuspidatum, S. papillosum, S. magellanicum, S. capillifolium and S. auriculatum var. inundatum. Each species was grown in a naturally occurring community of the same species. Growth was measured monthly over a period of 14 months. A growth period between 5-7 months of the year was detectable for S. papillosum, S. magellanicum and S. capillifolium and approximately 10-12 months for S. auriculatum var. inundatum and S. cuspidatum. Hulme and Blyth (1982) attribute this to a difference in habitat, with wet hollow/pool species (S. cuspidatum and S. auriculatum var. inundatum) having a longer growing season than lawn/low hummock species (S. papillosum, S. magellanicum and S. capillifolium). It is postulated that lawn/low hummock species appear either to require sustained improvement in weather conditions to stimulate growth or have a relatively high temperature/daylength growth thresholds. Ambient water temperatures may also play an important role.

The DECORANA species ordination scores (figure 51) display some correlation with the findings of Hulme and Blyth (1982). In particular, Sphagnum sect. Acutifolia (3.82 SD) is associated with the end of the axis believed to correspond to a short effective vegetative season. This is in accordance with the demonstrated low/high hummock preference of this section (Isoviita, 1966; Hill, 1978; Daniels and Eddy, 1984). Both Sphagnum imbricatum and % U.O.M. are associated with a long effective vegetative season. Although the results of the current study indicate the association of Sphagnum imbricatum with low hummock situations, its western European distribution has been noted by several workers (King and Morrison, 1956; Tallis, 1961; Green, 1968; Hill, 1978; Daniels and Eddy, 1984). These areas are typically associated with a long effective vegetative season (Meteorological Office, 1972; Damman, 1979; Kalb and Noll, 1980). % U.O.M. occurs unexpectedly at the negative end of axis 2. Considered together with its intermediate position along axis 1, it is

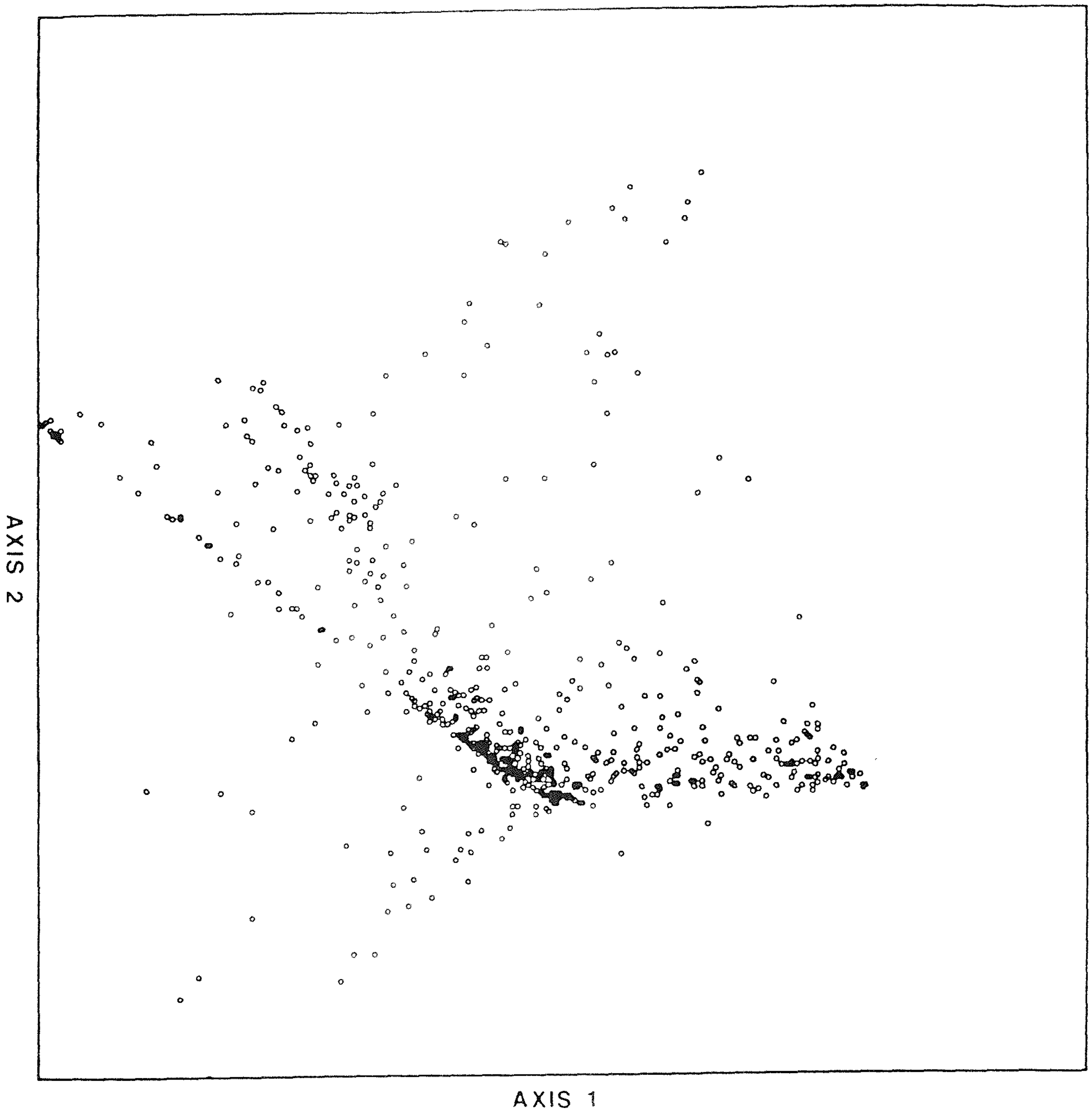


Figure 52. Samples ordination by DCA of macrofossil data from north western Europe. This figure shows axes 1 and 2 of a default DECORANA ordination of macrofossil abundance data. Each point represents a sample. Axes units represent 'average standard deviations of species turnover' (Hill, 1979), with a range 0-4 SD.

suggested that a combination of moist and/or mild conditions favour the formation of U.O.M. The anomalous position of Sphagnum sect. Cuspidata is explained by the presence of low hummock species such as S. tenellum, S. balticum and S. recurvum in more eastern continental profiles.

Despite extensive analyses, no obvious ecological or environmental explanation could be found for the third or fourth axes. That they have not been found to be intelligible may be regarded as an indication of internal data 'noise', and the effectiveness of axis 1 in displaying an east-west structure. A possible environmental gradient for the species ordination is suggested in the lower section of figure 51. The correlation between the index of oceanicity on axis 1 and the effective vegetative season index on axis 2 is apparent. According to Hill and Gauch (1980), Gauch et al. (1981) and Gauch (1982) second and higher axes have no systematic relations of any kind to lower axes. It seems however that in the current study where only 8 species have been ordinated, the orthogonality criterion may become stressed. Similar observations have recently been made by Lahti and Vaisanen (1987) in relation to ecological gradients present in ordinated data from Finnish boreal forests. Reservations about the possible effects of the empirical adjustments in DECORANA have been expressed by some authors (Fewster and Orloci, 1983; Minchin, 1987). Minchin (1987) argues that interpretation of DECORANA ordinations should take into account the possibility of artificial distortions, due to properties of the implied dissimilarity measure or the activities of detrending or rescaling. Nevertheless, DECORANA has become probably the most widely-used ordination technique for community data (Gauch, 1982; Whittaker, 1987).

6.32.3 SAMPLE ORDINATION OF MACROFOSSIL DATA

Sample ordination scores are presented in figure 52 (n=645). The distribution of sample scores along axes 1 and 2 is unusual. A central 'core' in the lower section of the diagram is characterised by several apparent 'internal' axes of variation. The constrained nature of these

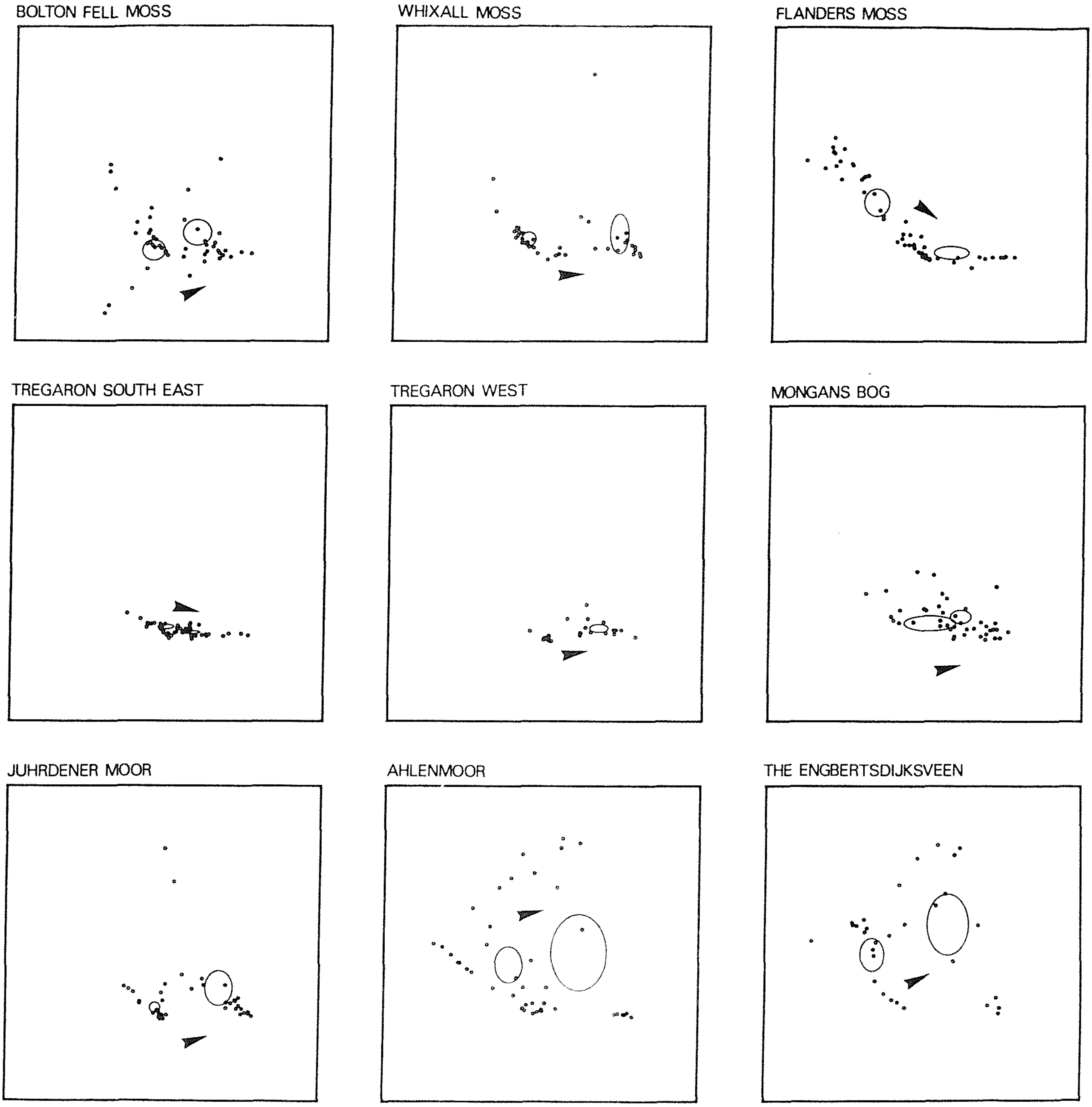
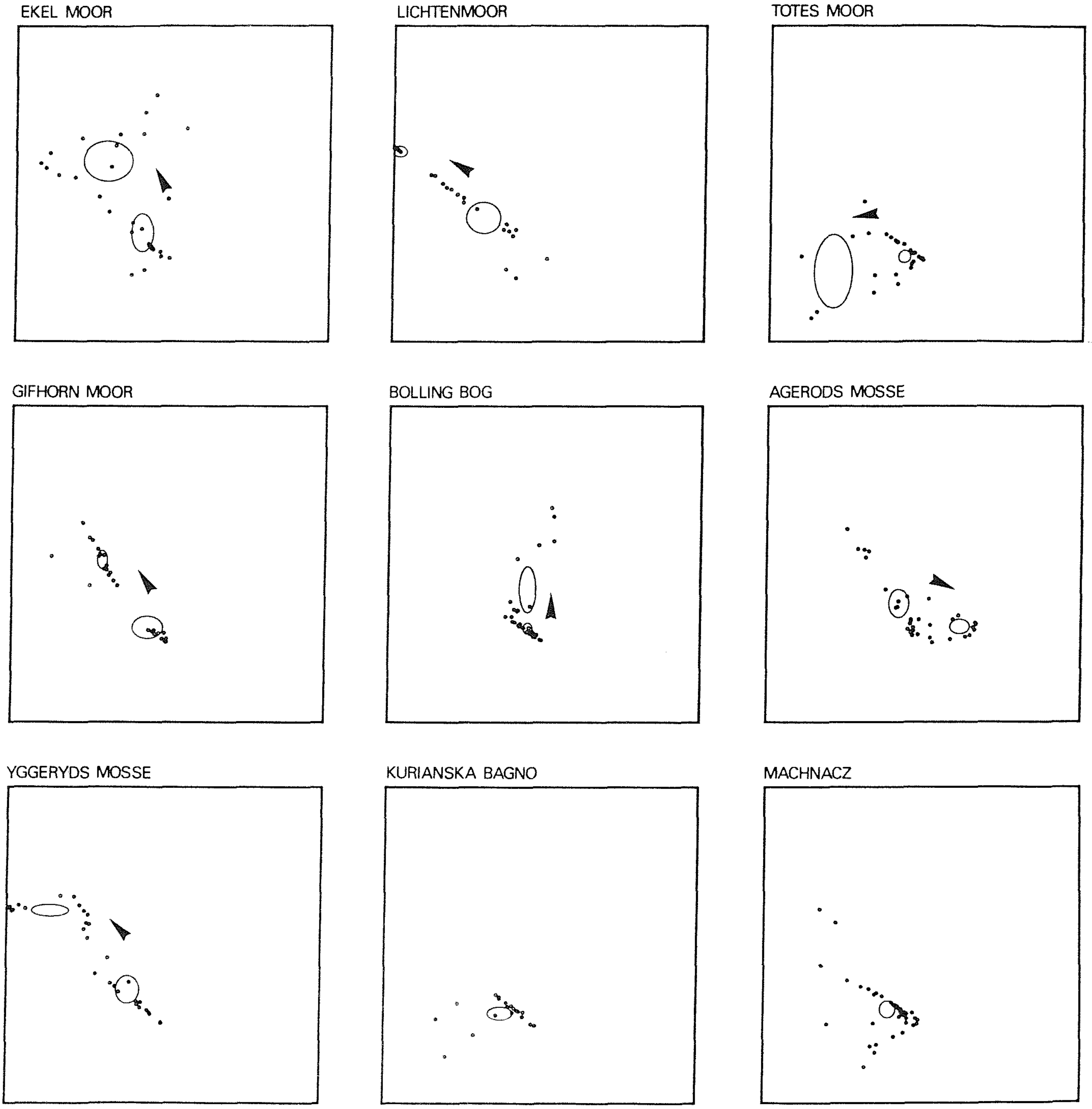


Figure 53. Samples ordination by DECORANA of macrofossil data from north western Europe. This figure shows axes 1 and 2 of a default DECORANA ordination of macrofossil abundance data for individual sample sites. Each point represents a sample. Axes units represent 'average standard deviations of species turnover' (Hill, 1979), with a range 0-4 SD. 95% confidence level ellipses plotted surrounding mean pre- and post-MHC scores. Arrow denotes direction of ecological change.



EKEL MOOR

LICHTENMOOR

TOTES MOOR

GIFHORN MOOR

BOLLING BOG

AGERODS MOSSE

YGGERYDS MOSSE

KURIANSKA BAGNO

MACHNACZ

Figure 53 . Samples ordination by DECORANA of macrofossil data from north western Europe. This figure shows axes 1 and 2 of a default DECORANA ordination of macrofossil abundance data for individual sample sites. Each point represents a sample. Axes units represent 'average standard deviations of species turnover' (Hill, 1979), with a range 0-4 SD. 95% confidence level ellipses plotted surrounding mean pre- and post-MHC scores. Arrow denotes direction of ecological change.

2 1	SITE MEAN (all samples)		PRE-MHC PEATS		POST-MHC PEATS		AMOUNT AND DIRECTION OF ECOLOGICAL CHANGE		IMMEDIATE PRE-MHC PEATS		IMMEDIATE POST-MHC PEATS		AMOUNT AND DIRECTION OF ECOLOGICAL CHANGE	
Axis Site	1	2	1	2	1	2			1	2	1	2		
Mongans Bog	2.35	1.31	2.07	1.25	2.46	1.33	0.40	↗	2.03	1.22	2.85	1.09	0.83	→
Tregaron (South East)	2.16	1.16	1.99	1.20	2.30	1.13	0.32	→	2.23	1.18	2.28	1.17	0.05	→
Tregaron (West)	2.42	1.13	2.01	1.06	2.68	1.18	0.68	→	2.05	1.06	2.68	1.17	0.64	→
Whixall Moss	2.20	1.33	1.73	1.30	2.88	1.37	1.16	→	1.54	1.50	2.60	1.35	1.07	→
Bolton Fell Moss	2.04	1.27	1.77	1.15	2.32	1.38	0.59	↗	1.76	1.32	1.66	1.76	0.44	↑
East Flanders Moss	1.70	1.53	1.35	1.77	2.30	1.13	1.15	↘	1.10	2.14	1.74	1.35	1.02	↘
Engbertsdijksveen	1.85	2.04	1.37	1.85	2.32	2.24	1.02	→	1.33	2.24	2.14	3.08	1.16	→
Juhrdener Moor	2.35	1.32	1.91	1.18	2.72	1.43	0.85	→	1.82	1.32	2.60	1.29	0.79	→
Ahlenmoor	1.87	1.42	1.59	1.73	2.48	1.89	0.90	→	1.39	1.76	1.85	2.91	1.24	→
Bolling Bog	1.79	1.42	1.79	1.19	1.79	1.68	0.49	↑	1.71	1.34	1.78	1.45	0.13	↑
Lichtenmoor	0.66	1.96	1.17	1.57	0.09	2.40	1.36	↖	1.20	1.38	0.17	2.35	1.42	↖
Totes Moor	1.51	1.03	1.72	1.07	0.81	0.89	0.92	↙	1.65	0.98	0.93	1.03	0.72	↖
Ekel Moor	1.40	1.81	1.61	1.38	1.17	2.29	1.01	↖	1.41	1.90	1.28	2.64	0.75	↖
Gifhorn Moor	1.47	1.60	1.74	1.20	1.16	2.06	1.03	↖	1.83	1.15	1.21	1.97	1.02	↖
Agerods Mosse	1.95	1.41	1.68	1.50	2.47	1.21	0.84	↘	1.92	1.34	2.41	1.12	0.54	↘
Yggeryds Mosse	1.11	1.87	1.54	1.44	0.55	2.44	1.41	↖	1.47	1.60	0.98	2.37	0.91	↖
Kurianska Bagno	1.50	1.14	1.50	1.14	1.50	1.14	0.00		1.50	1.14	1.50	1.14	0.00	
Machnacz	1.57	1.18	1.57	1.18	1.57	1.18	0.00		1.57	1.18	1.57	1.18	0.00	
Mean	1.77 (0.23)	1.44 (0.15)	1.67 (0.12)	1.34 (0.12)	1.86 (0.41)	1.58 (0.25)	0.78 (0.21)		1.64 (0.15)	1.43 (0.18)	1.79 (0.35)	1.69 (0.34)	0.71 (0.22)	

Table 3 .Summary table showing mean sample DECORANA ordination scores on axes 1 and 2, and the amount and direction of ecological change associated with the formation of the Main Humification Change in 18 north west European raised mires. Ecological change and axis scales are in units of 'average standard deviations of species turnover' (Hill, 1979), with a range 0-4 SD. 95% confidence limits given in parentheses.

points provides additional evidence for the supposition that axes 1 and 2 may be correlated. Figure 52 provides little information on the internal dynamics of each site. Accordingly, separate sample ordination diagrams were plotted for each profile (figure 53) The mean sample scores for pre- and post-MHC peats and the corresponding 95% confidence level ellipses of the estimates have been added. The distance between the two means represents the amount of 'ecological change', or beta diversity, associated with MHC formation: greater distance represents greater change. Arrows denote direction of change. Beta diversity can be defined as the "extent of species replacement or biotic change along environmental gradients" (Whittaker, 1972). Accurate measurement of beta diversity is important since it indicates the degree to which habitats have been partitioned by species and values may be used to compare the habitat diversity of different study sites. Wilson and Mohler (1983) and Wilson and Shmida (1984) have discussed guidelines for measuring beta diversity with quantitative and presence/absence data. More recently, Jacobson and Grimm (1986) have applied the technique, in conjunction with DECORANA, to five-sample running averages of fossil pollen assemblages from central Minnesota.

With the exception of Polish sequences, differences in the amount and direction of ecological change may be identified in the macrofossil ordinations. Western maritime sites are characterised by an axis 1 shift whilst variation in eastern continental sites occurs principally along axis 2. Table 3 summarizes the mean sample DECORANA ordination scores on axes 1 and 2, and the amount and direction of ecological change associated with MHC formation.

Macrofossil results and weighted average ordinations, suggesting little ecological change at Mongans Bog, Tregaron South East and West Bogs, are supported by the DCA results. Low beta diversities of 0.40 SD, 0.32 SD and 0.68 SD were obtained respectively. More oceanic conditions with little change in the effective vegetative season is suggested. At Bolling Bog (0.49 SD) a change in the effective vegetative season appears more important. A beta diversity of 1.16 SD is recorded for the Whixall Moss sequence. This particularly large value reflects the intermediate position of northern Shropshire, with similarities to the milder oceanic winters

IMMEDIATE PRE- AND POST-MHC PEATS

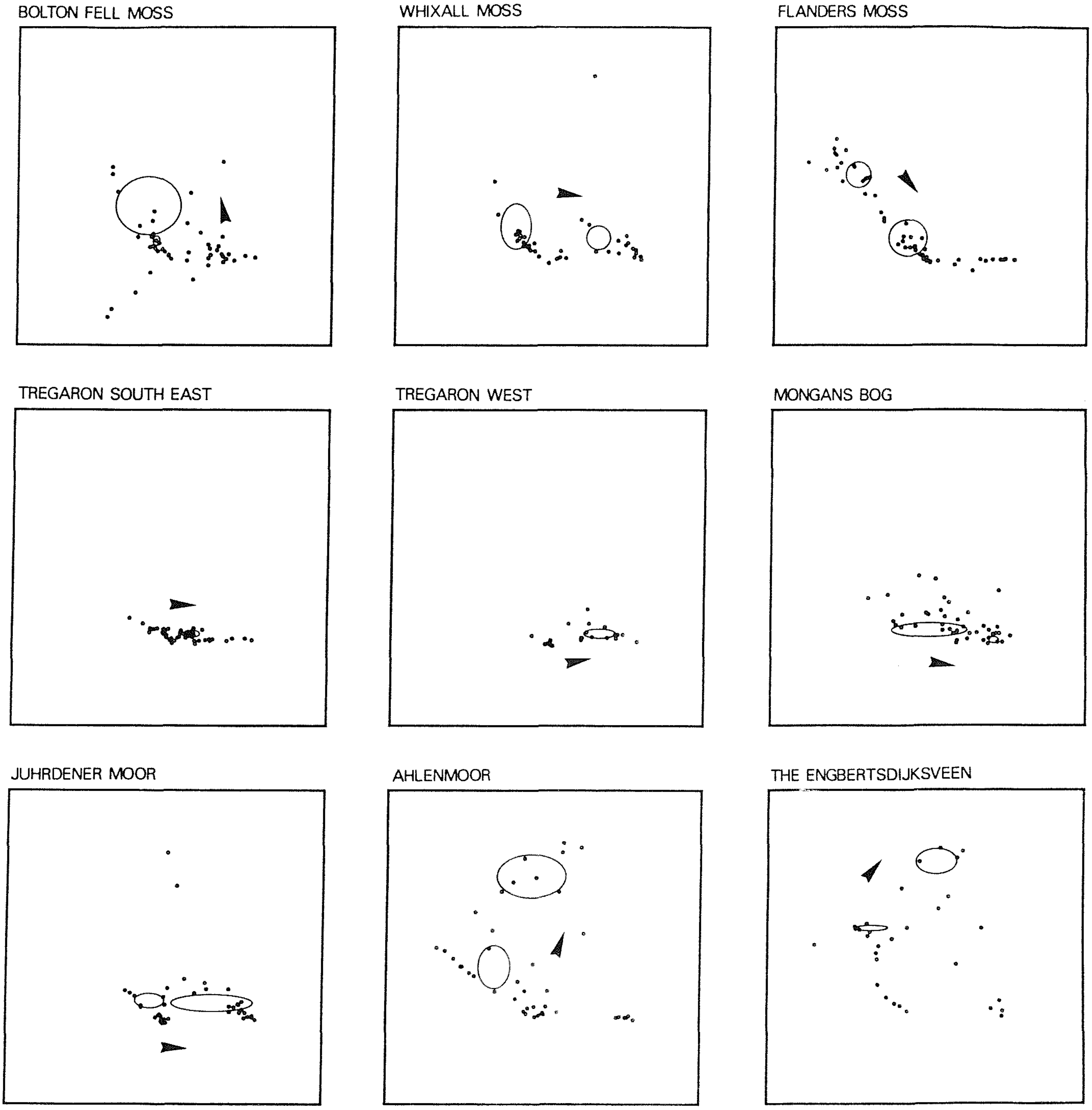


Figure 54 . Samples ordination by DECORANA of macrofossil data from north western Europe. This figure shows axes 1 and 2 of a default DECORANA ordination of macrofossil abundance data for individual sample sites. Each point represents a sample. Axes units represent 'average standard deviations of species turnover' (Hill, 1979), with a range 0-4 SD. 95% confidence level ellipses plotted surrounding mean immediate pre- and post-MHC scores. Arrow denotes direction of ecological change.

IMMEDIATE PRE- AND POST-MHC PEATS

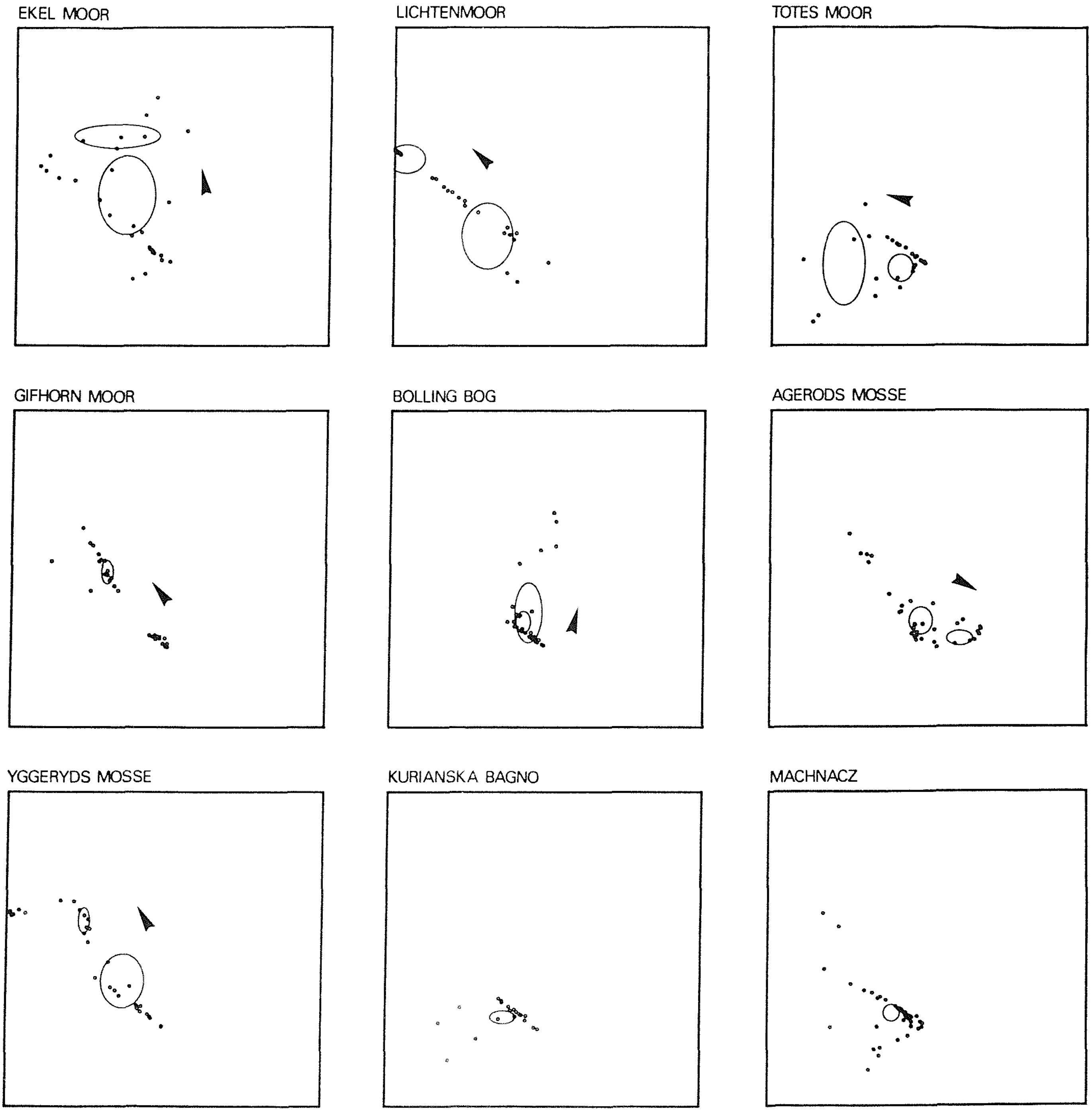


Figure 54 . Samples ordination by DECORANA of macrofossil data from north western Europe. This figure shows axes 1 and 2 of a default DECORANA ordination of macrofossil abundance data for individual sample sites. Each point represents a sample. Axes units represent 'average standard deviations of species turnover' (Hill, 1979), with a range 0-4 SD. 95% confidence level ellipses plotted surrounding mean immediate pre- and post-MHC scores. Arrow denotes direcion of ecological change.

experienced in western Britain and warm continental summers of eastern areas. An increase in oceanicity, sufficient to negate the rainshadow effects of the Welsh Mountains, facilitated the establishment of Sphagnum imbricatum. A shift towards increased oceanicity with a marginally shorter effective vegetative season characterises the coastal sites of Niedersachsens and The Netherlands. Beta diversities of 0.90 SD, 0.85 SD and 1.02 SD were measured at Juhrdener Moor, Ahlenmoor and The Engbertsdijksveen respectively. Anomalous responses are recorded at Flanders Moss and Agerods Mosse where a change from Sphagnum sect. Cuspidata (cf. S. cuspidatum) to S. imbricatum occurs. Whilst the oceanicity component remains the dominant variant, an increase in the effective vegetative season is indicated. In part, this may reflect the position of Sphagnum sect. Cuspidata in the species ordination (figure 51), a position which is considered unsatisfactory given the varying ecological preferences of species contained within this section.

Excepting Totes Moor, where a marginally longer vegetative season is suggested, a shift to more continental conditions with shorter effective vegetative period occurs at Ekel Moor, Lichtenmoor, Gifhorn Moor and Yggeryds Mosse. High beta diversities, ranging between 1.01 SD and and 1.41 SD, were recorded.

A second series of plots showing the means and 95% confidence ellipses of 5 immediate pre- and post-MHC samples were considered in an attempt to identify the precise factors involved in MHC formation. These are presented in figure 54. Whilst confidence limits are less satisfactory due to the small sample size, trends in the amount and direction of ecological change are comparable with those presented in figure 53. Exceptions include Bolton Fell Moss, Ahlenmoor and The Engbertsdijksveen, where a reduced effective vegetative season appears equally as important as any increase in oceanicity. At Ahlenmoor and The Engbertsdijksveen this may be attributed to the presence of Sphagnum papillosum in the immediate post-MHC matrix. The Bolton Fell Moss response is however questionable, since macrofossil analyses indicate the presence of S. cuspidatum pool muds at this level. Results from Totes Moor are now in accordance with those identified in other eastern European sections.

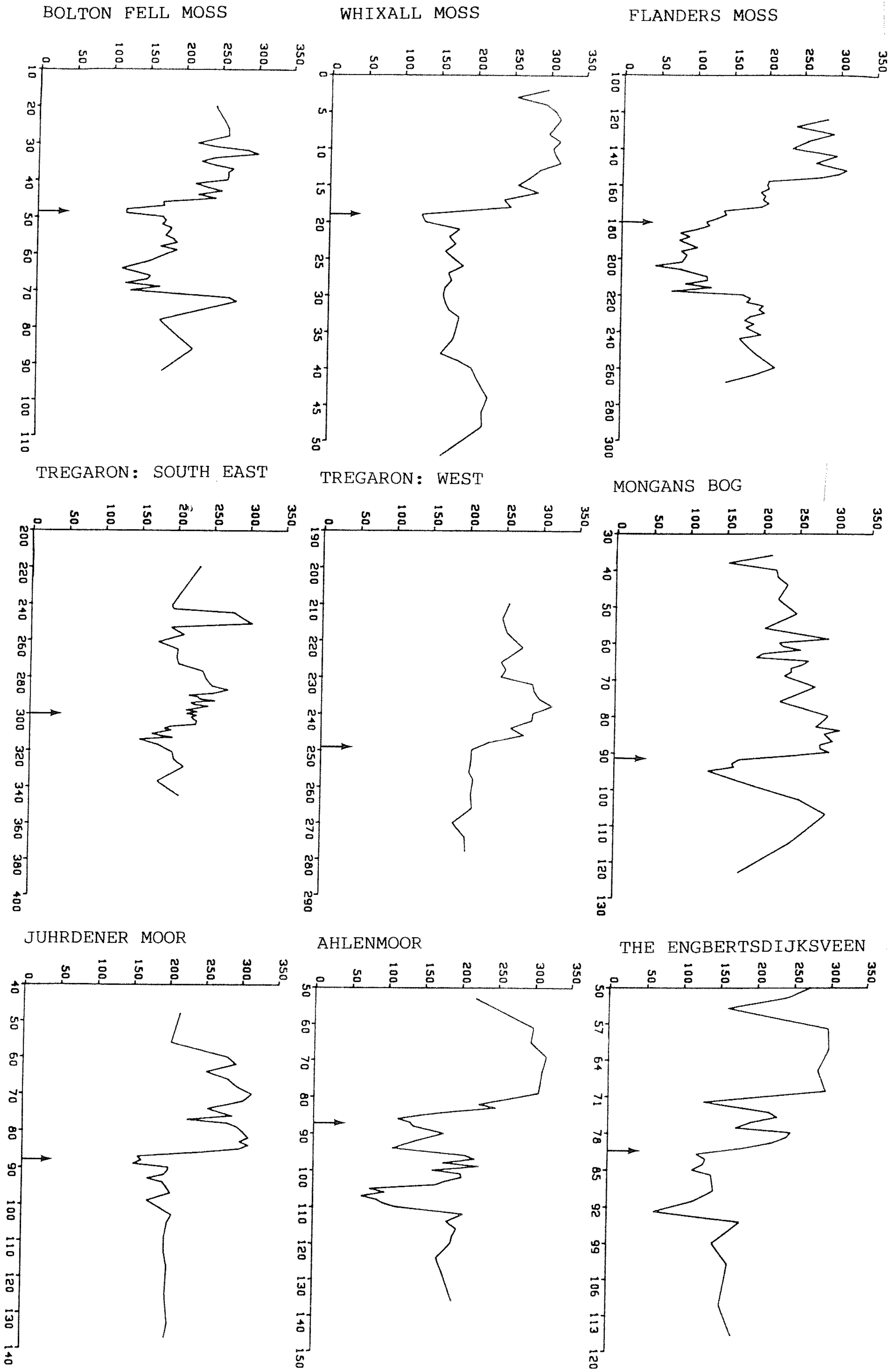


Figure 55 . Individual sample site axis 1 scores plotted against depth below present surface (cms) for a default DECORANA ordination of macrofossil data from north western Europe. Axes units represent 'average standard deviations of species turnover' (Hill, 1979), with a range 0-3.5 SD. Arrow denotes position of the Main Humification Change.

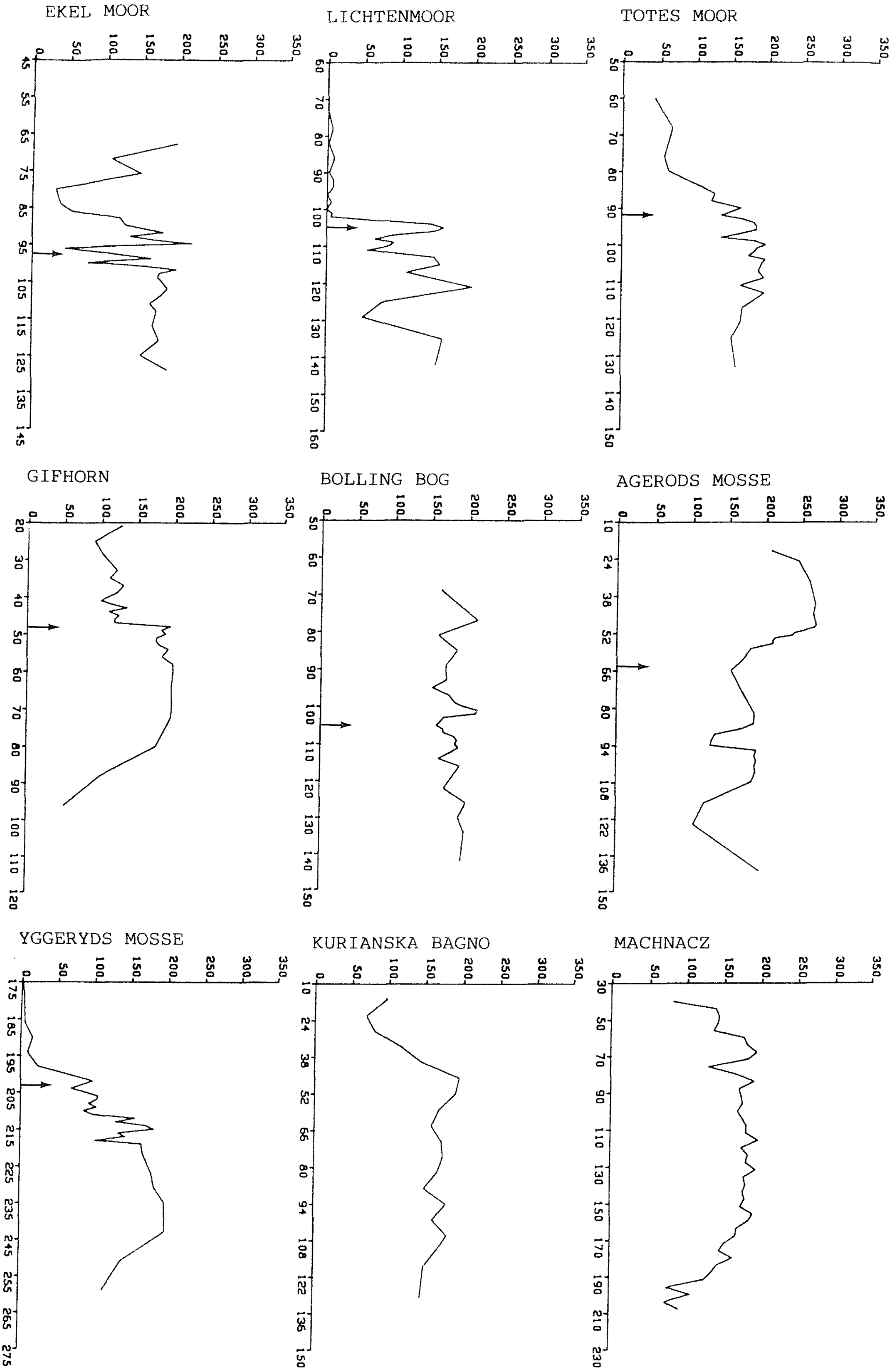
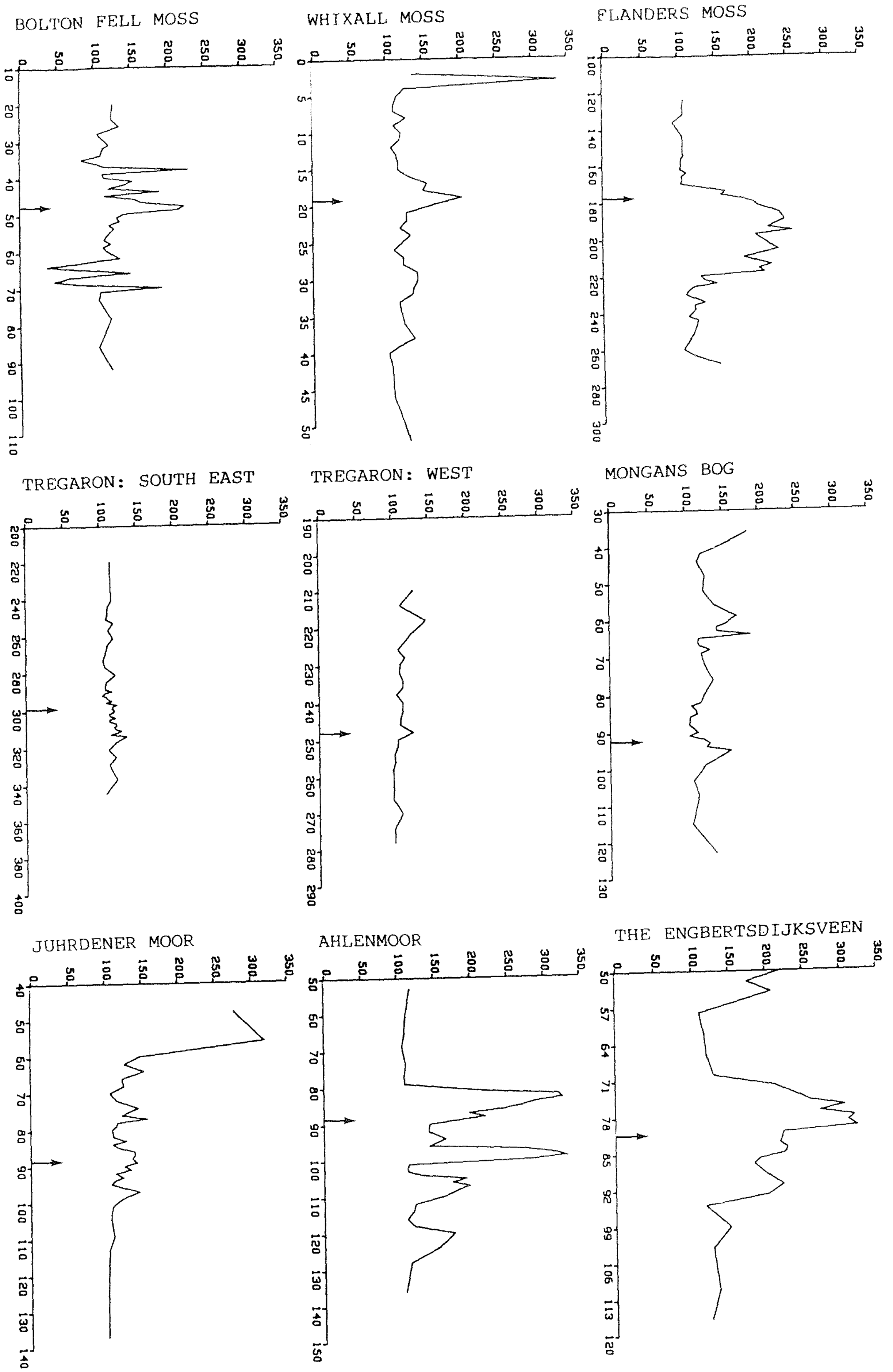


Figure 55 . Individual sample site axis 1 scores plotted against depth below present surface (cms) for a default DECORANA ordination of macrofossil data from north western Europe. Axes units represent 'average standard deviations of species turnover' (Hill, 1979), with a range 0-3.5 SD. Arrow denotes position of the Main Humification Change.


BOLTON FELL MOSS

WHIXALL MOSS

FLANDERS MOSS

TREGARON: SOUTH EAST

TREGARON: WEST

MONGANS BOG

JUHRDENER MOOR

AHLENMOOR

THE ENGBERTSDIJKSVEEN

Figure 56 . Individual sample site axis 2 scores plotted against depth below present surface (cms) for a default DECORANA ordination of macrofossil data from north western Europe. Axes units represent 'average standard deviations of species turnover' (Hill, 1979), with a range 0-3.5 SD. Arrow denotes position of the Main Humification Change.

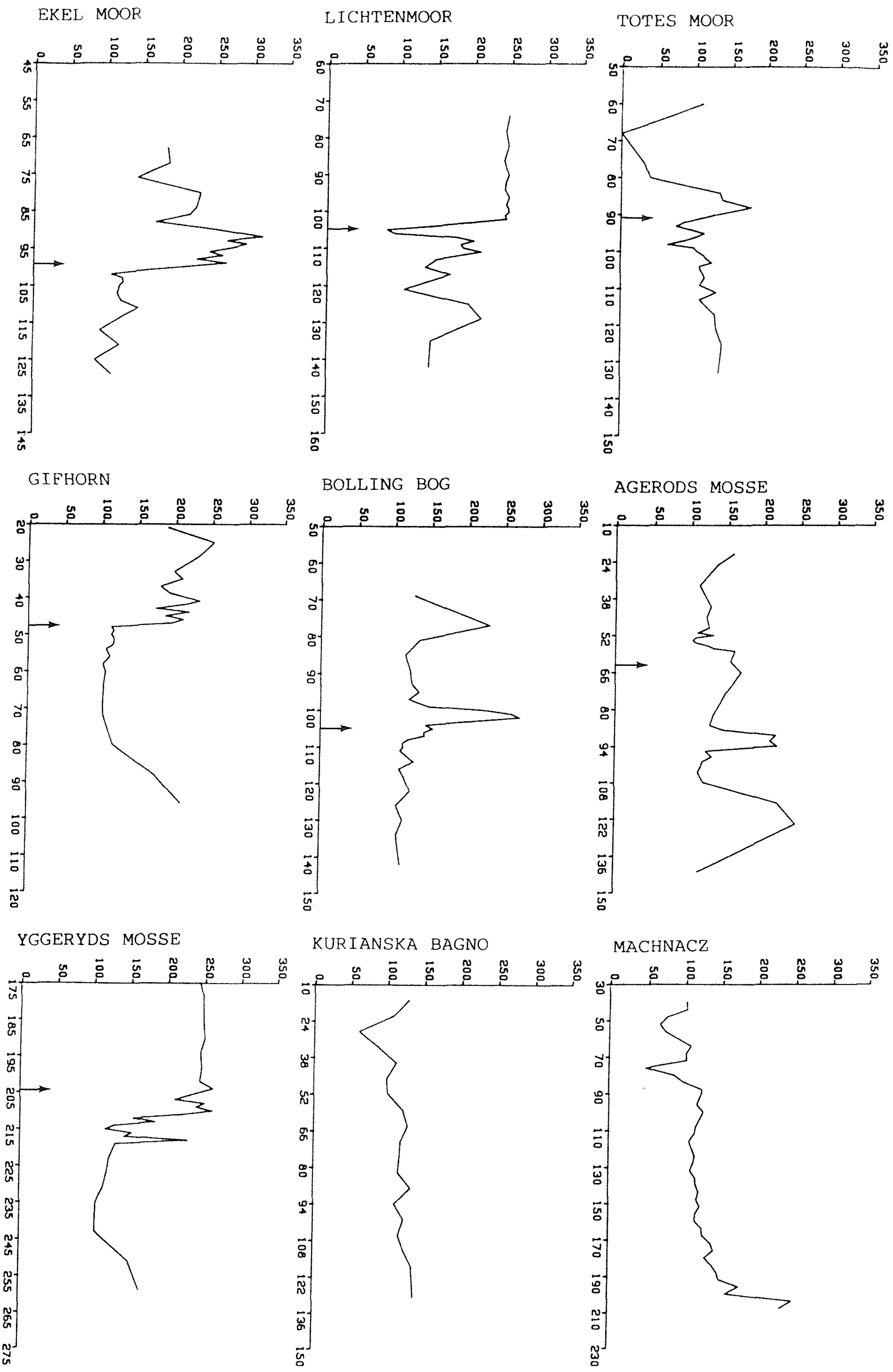


Figure 56 . Individual sample site axis 2 scores plotted against depth below present surface (cms) for a default DECORANA ordination of macrofossil data from north western Europe. Axes units represent 'average standard deviations of species turnover' (Hill, 1979), with a range 0-3.5 SD. Arrow denotes position of the Main Humification Change.

Analysis of the beta diversities shows that the amounts of ecological change associated with MHC formation are lowest towards the ends of the west-east transect. No ecological change was recorded in Poland. Highest values coincide with central Sweden and West Germany. The existence of a theoretical climatic 'hinge-line' separating western maritime and eastern continental sites has been postulated by Overbeck (1975) and Barber (1982) based upon contemporary and palaeoecological investigations of raised mire ecosystems. The origin of these ideas may be traced back to the study of climatic rhythms by Conway (1948). This work has been reviewed in Section 2.1. Developing the idea of mire 'threshold values', Conway (1948, p.236) hypothesises that "the reactions of a vegetation type to climatic fluctuations will be most marked in places near to the margin of the climatic region which is characterised by that vegetation type". This supposition is supported by the recorded values of ecological change associated with the boundary between the western European *Sphagnum imbricatum*-*S. papillosum* association and eastern continental *Sphagnum* sect. *Acutifolia*-*S. magellanicum* association during the period coinciding with MHC formation.

6.32.4 AXES 1 AND 2 DEPTH RESPONSE CURVES

Yet more detailed information may be derived from an examination of individual axes 1 and 2 depth response curves. These are presented in figures 55 and 56. An increase in oceanicity associated with MHC formation is indicated in western sites belonging to the *Sphagnum imbricatum*-*Sphagnum papillosum* association (figure 55). A corresponding decrease in the effective vegetative season also occurs (figure 56). As noted earlier, this secondary component appears to have been less important at Mongans Bog, Tregaron South East and West Bogs and Juhrdener Moor. This contrasts with Flanders Moss, Ahlenmoor, The Engbertsdijksveen and, to a lesser extent, Bolton Fell Moss, where a complex shift involving oceanic phases with long effective vegetative season and less-oceanic periods with short effective vegetative period is indicated. Oceanic phases in the pre-MHC matrix coincide with expansions of the *Sphagnum cuspidatum*-*S. papillosum* association and less-oceanic phases with increased frequencies of Sphagnum sect. Acutifolia (cf. S. capillifolium). Though less marked, a similar interaction may be identified at Whixall Moss where the S. cuspidatum-Sphagnum sect. Acutifolia (-S. papillosum) assemblage has also been noted.

A more direct shift in peat formation, involving greater continentality and shorter effective vegetative period occurs in eastern sites belonging to the Sphagnum magellanicum-Sphagnum sect. Acutifolia association. The reaction is particularly marked at Lichtenmoor. An oscillatory transition, similar to that isolated at Ahlenmoor and The Engbertsdijksveen, characterises the Ekel Moor response curves. The shift to more continental conditions at 86cm favoured the replacement of the Sphagnum sect. Cuspidata-S. papillosum association by Sphagnum sect. Acutifolia, rather than by S. imbricatum as occurred at both Ahlenmoor and The Engbertsdijksveen.

Response curves for Machnacz and Kurianska Bagno reflect their eastern European location: strong continentality with short effective vegetative season. The Sphagnum magellanicum expansion noted at 78 cm in the Machnacz sequence coincides with a shift to greater continentality and shorter effective vegetative period. This is at variance with the results obtained by weighted averages ordination indicating wetter local conditions. This may be attributable to the application of an indicator value for Sphagnum magellanicum more in common with its western European lawn habitat (see earlier in Section 6.22).

6.33 SUMMARY

Environmental interpretation of DECORANA axes remains to an extent provisional, since experimental verification of the interpretation is not feasible. Ordinations of several random subsets of the macrofossil data sensu Wilson (1981) retained the basic pattern and thus increases confidence in the environmental interpretations. Low species numbers prevented single factor interpretation. Nevertheless, the technique provided an important means by which community structure could be analysed, and has revealed trends not readily apparent in the macrofossil

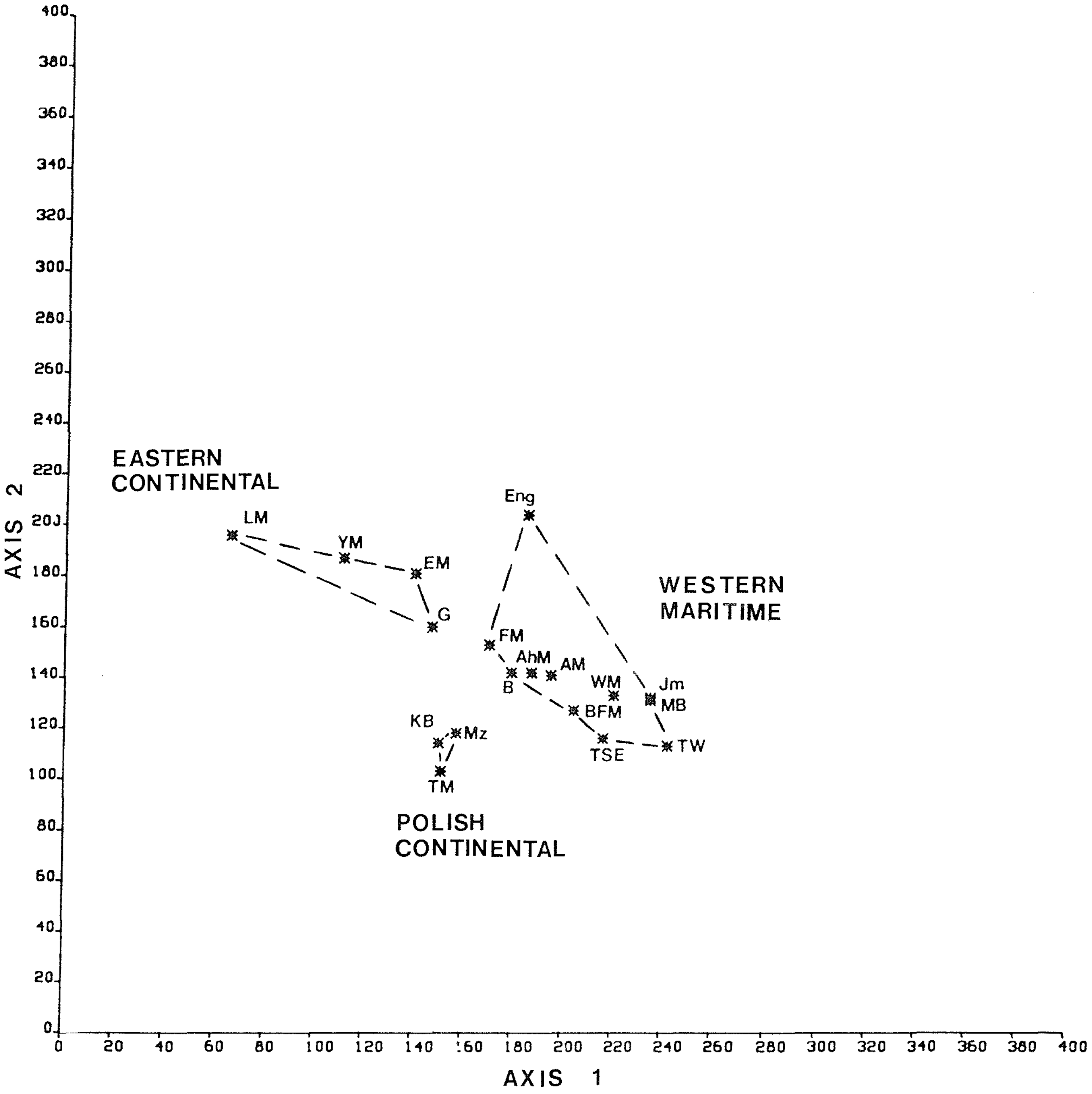


Figure 57 . Summary diagram showing mean sample DECORANA ordination scores on axes 1 and 2 of a default ordination of macrofossil abundance data from north western Europe. Axes units represent 'average standard deviations of species turnover' (Hill, 1979), with a range 0-4 SD. WM, Whixall Moss; TW, Tregaron West Bog; TSE, Tregaron South East Bog; BFM, Bolton Fell Moss; MB, Mongans Bog; FM, Flanders Moss; Eng, The Engbertsdijksveen; Jm, Juhrdener Moor; AhM, Ahlenmoor; B, Bolling Bog; E, Ekel Moor; LM, Lichtenmoor; G, Gifhorn; TM, Totes Moor; YM, Yggeryds Mosse; AM, Agerods Mosse; Mz, Machnacz; KB, Kurianska Bagno.

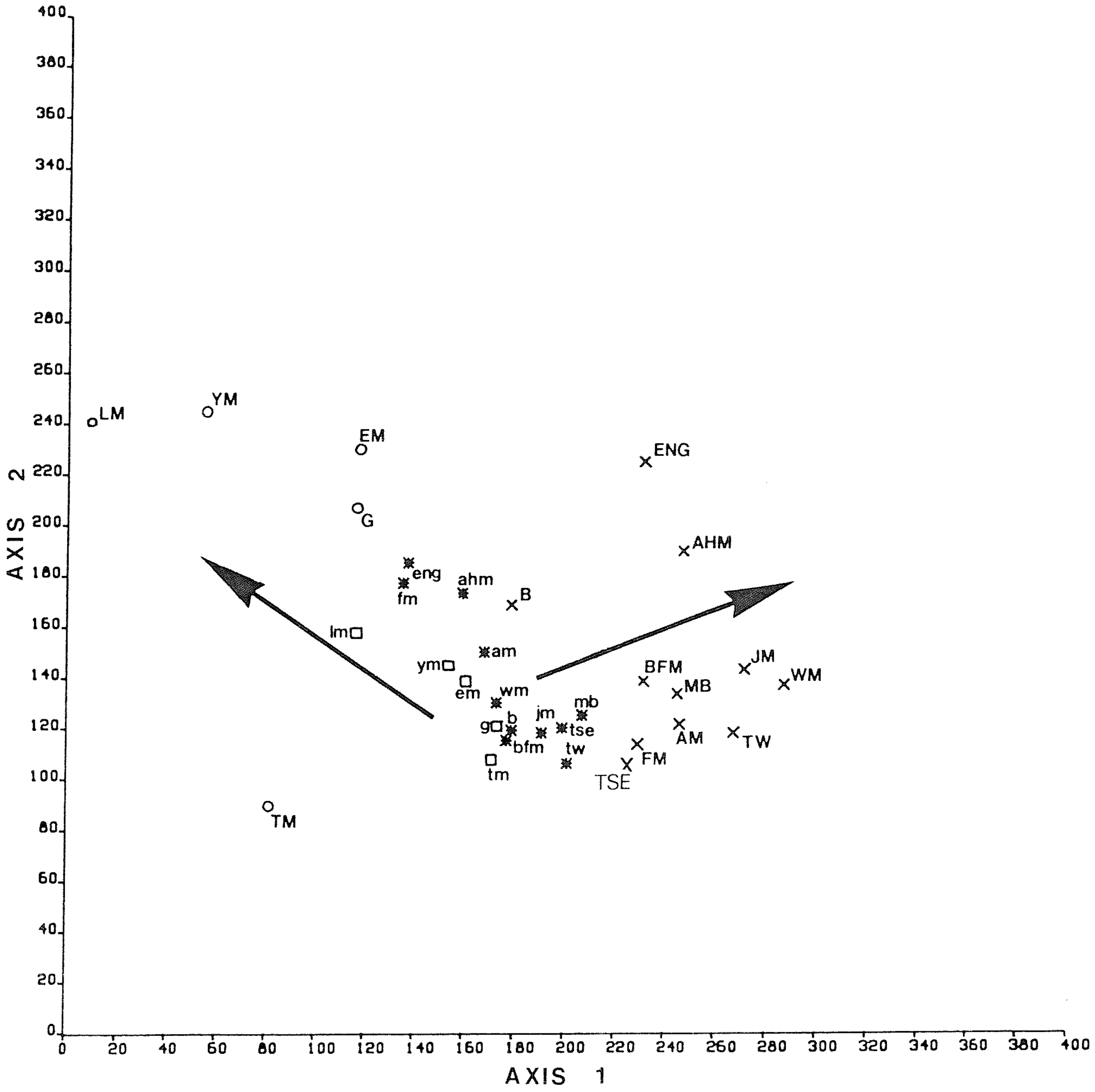
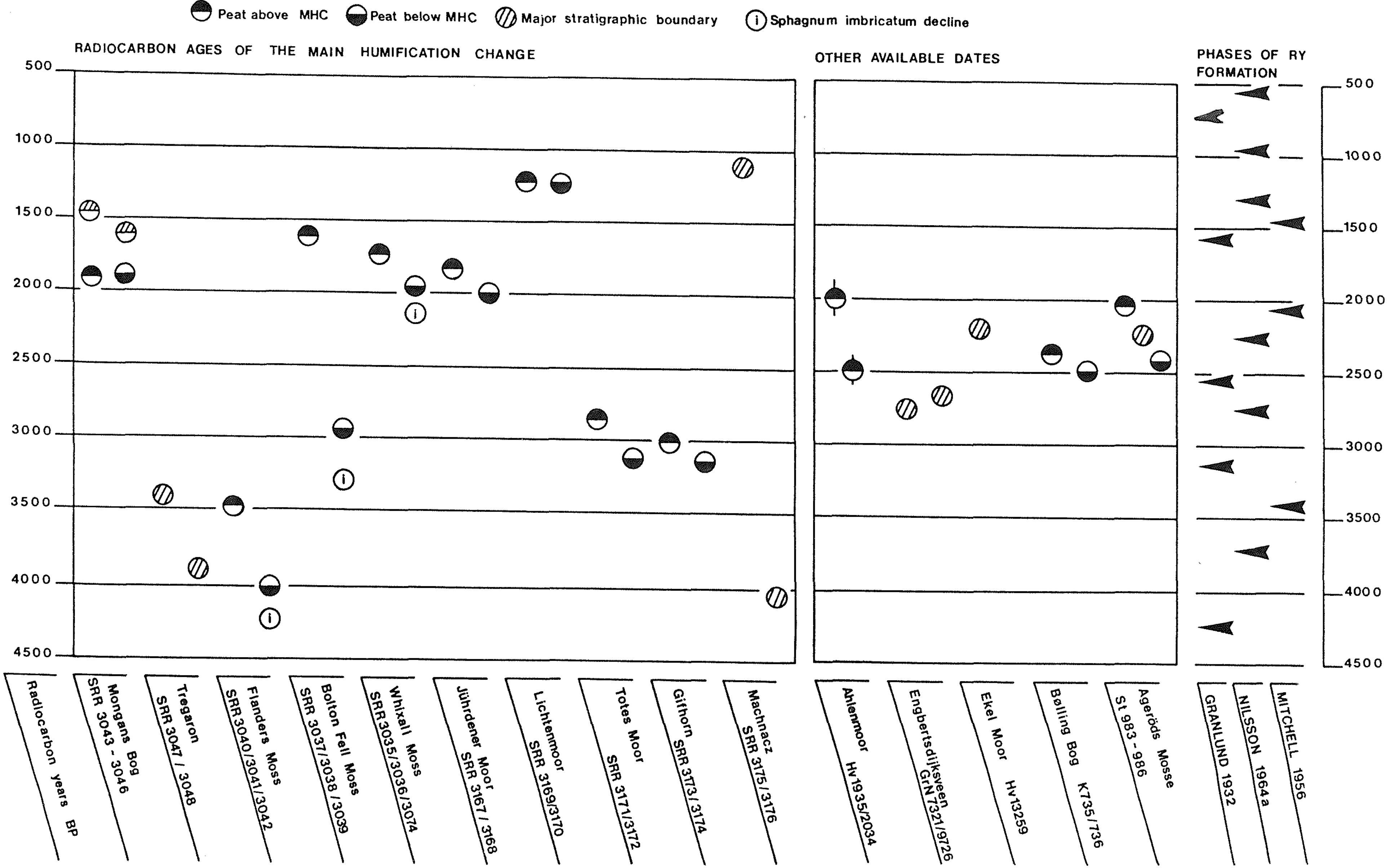


Figure 58. Summary diagram showing mean pre- and post-MHC sample DECORANA ordination scores on axes 1 and 2 of a default ordination of macrofossil abundance data from north western Europe. Axes units represent 'average standard deviations of species turnover' (Hill, 1979), with a range 0-4 SD. Lower case lettering denotes pre-MHC position and upper case lettering post-MHC location. Arrows denote direction of ecological change associated with western maritime and eastern continental sites. WM, Whixall Moss; BFM, Bolton Fell Moss; TW, Tregaron West Bog; TSE, Tregaron South East Bog; FM, Flanders Moss; MB, Mongans Bog; ENG, The Engbertsdijksveen; JM, Juhrdener Moor; AHM, Ahlenmmor; AM, Agerods Mosse; B, Bolling Bog; EM, Ekel Moor; G, Gifhorn Moor; LM, Lichtenmoor; TM, Totes Moor; YM, Yggeryds Mosse.

FIGURE 59.


Peat above MHC
Peat below MHC
Major stratigraphic boundary
Sphagnum imbricatum decline
RADIOCARBON AGES OF THE MAIN HUMIFICATION CHANGE
OTHER AVAILABLE DATES
PHASES OF RY FORMATION
500
1000
1500
2000
2500
3000
3500
4000
4500
Radiocarbon years BP
Mongans Bog SRR 3043 - 3046
Tregaron SRR 3047 / 3048
Flanders Moss SRR 3040/3041/3042
Bolton Fell Moss SRR 3037/3038/3039
Whixall Moss SRR 3035/3036/3074
Jührdener Moor SRR 3167 / 3168
Lichtenmoor SRR 3169/3170
Totes Moor SRR 3171/3172
Gifhorn SRR 3173/3174
Machnacz SRR 3175/3176
Ahlenmoor Hv 1935/2034
Engbertsdijksveen GrN 7321/9726
Ekel Moor Hv 13259
Bølling Bog K735/736
Agerõds Mosse St 983 - 986
GRANLUND 1932
NILSSON 1964a
MITCHELL 1956

diagrams and the indices of relative hydrological conditions. Mean sample scores on axes 1 and 2 for pre- and post-MHC peats (figure 57 and table 3) show the existence of three distinct palaeoecological associations: western maritime sites (Mongans Bog, Tregaron South East and West Bogs, Flanders Moss, Bolton Fell Moss, Whixall Moss, Juhrdener Moor, Ahlenmoor, The Engbertsdijksveen, Bolling Bog and Agerods Mosse), eastern continental sites (Ekel Moor, Gifhorn Moor, Lichtenmoor and Yggeryds Mosse) and Polish continental sites (Machnacz, Kurianska Bagno and Totes Moor). Similarities between the Totes Moor section and Polish sequences have been discussed earlier (Section 5.32.5).

A summary diagram displaying the direction and amount of ecological change associated with MHC formation is presented in figure 58. A central 'core' characterised by high values of % U.O.M., is correlated with the mean sample scores for pre-MHC peats. The contrasting response of western maritime and eastern continental sites in the post-MHC matrix, where community information is at a premium, is apparent.

6.4 TEMPORAL VARIATION ASSOCIATED WITH THE FORMATION OF THE MHC

6.41 THE DISTRIBUTION OF DATES IN NORTH WESTERN EUROPE

In total, 25 samples underwent radiocarbon assay at the N.E.R.C. Radiocarbon Laboratory, East Kilbride, Scotland. These have been summarized in table 1 and are presented graphically in figure 59. At each profile, samples directly below and above the main humification change present in the stratigraphy were dated. Variations with previously published dates are discussed as appropriate in Section 5. Unfortunately, financial constraints prevented age determinations at Tregaron West Bog, The Engbertsdijksveen, Ahlenmoor, Ekel Moor, Bolling Bog, Agerods Mosse, Yggeryds Mosse and Kurianska Bagno. Where available, alternative dates for these sites are also depicted on figure 59. Results from Gifhorn

Moor (Schneekloth, 1965), which display a range of 945 radiocarbon years for the same phenomenon, have been omitted.

The determinations obtained by the current study demonstrate greater temporal variability in the formation of the MHC than was formerly assumed. The initiation of unhumified peat formation occurs between 4050 +/- 60 B.P. (SRR-3041, Flanders Moss) and 1230 +/- 50 B.P. (SRR-3170, Lichtenmoor), a range of 2820 radiocarbon years. The onset of climatic deterioration is first noted at Flanders Moss, where the replacement of Sphagnum imbricatum by Sphagnum sect. Cuspidata (cf. S. cuspidatum) pool peats has been dated to 4200 +/- 60 B.P. (SRR-3042). A protracted and oscillatory climatic deterioration is indicated between 4500 B.P.and 500 B.P.. Recent reviews (see for example Frenzel, 1977; Smith, 1981; Tinsley, 1981; Lamb, 1982; Flohn and Fantechi, 1984) corroborate this view. The available dates for The Engbertsdijksveen, Ahlenmoor, Ekel Moor, Bolling Bog and Agerods Mosse are more consistent with the archaeological observations of Weber (1900), who postulated that the MHC or 'Grenzhorizont' dated from circa 500 BC (2450 B.P.).

Several additional features are worthy of note. Excepting Bolton Fell Moss, where a hiatus in peat accumulation between the lower humified and upper unhumified matrix of 1340 radiocarbon years is suggested (SRR-3037, 1640 +/- 50; SRR-3038, 2980 +/- 50), the shift at the remaining sites appears direct. In this respect, it must be remembered that quoted dates refer to samples spanning several centimetres either side of the transition, and not the horizons immediately below and above the MHC. The possibility that the determination SRR-3037 may be erroneous has been discussed more fully in Section 5.24. A possible hiatus of 570 radiocarbon years at Flanders Moss may be attributable to pool formation in the immediate pre-MHC matrix. Godwin (1960) and Turner (1964) discuss surface erosion and reworking of older sediments in pool environments, and conclude that age determinations beneath recurrence surfaces, may, in such circumstances, be distorted. That the response to changes in local hydrological conditions was direct, supports the views expressed by Aaby (1976, 1978), Barber (1981, 1982, 1985) and Barber and Coope (1987), amongst others, that raised mire habitats are sensitive recorders of changes in the environmental milieu.

Dates for the *Sphagnum imbricatum* decline at Flanders Moss (SRR-3042, 4200 +/- 60 B.P.), Bolton Fell Moss (SRR-3039, 3270 +/- 50 B.P.) and Whixall Moss (SRR-3074, 2180 +/- 50 B.P.) permit calculation of average peat accumulation rates in the pre-MHC matrix at these sites. Values of 4.3y/cm, 14.5 y/cm and 13.1 y/cm were obtained respectively, higher than many average accumulation rates reported for post-MHC peats by Walker (1970) and Barber (1982). Based on the isolation of a *Sphagnum* sect. *Acutifolia* (cf. *S. capillifolium*)-*Sphagnum* sect. *Cuspidata* (cf. *S. cuspidatum*) association at these levels, it is postulated that an active peat accumulating environment, involving 'wet' and 'dry' phases, preceded the transition to *Sphagnum imbricatum* and more stable local hydrological conditions in the post-MHC matrix. The water absorption capacity of the Cymbifolia peat prevented sharp dry-wet fluctuations (see Casparie, 1972, p.240).

Previously published radiocarbon dates for Tregaron South East bog (Turner, 1964; Hibbert and Switsur, 1976), Flanders Moss (Turner, 1965) and Gifhorn (Overbeck et al., 1957; Schneekloth, 1965; Overbeck, 1975) are at variance with those obtained by the current study. The possibility that local edaphic and hydrological factors may have influenced the date of 'fresh' *Sphagnum* peat initiation obtained by these workers has been discussed in Sections 2.1, 5.2.2, 5.2.3 and 5.32.6.

Finally, brief mention should be made of the radiocarbon dates obtained for Machnacz. They confirm that whilst changes in peat formation were being initiated in western maritime and western continental areas during the Subboreal-Subatlantic transition, the climatic shift was of insufficient magnitude to trigger unhumified peat formation in north eastern Poland. It is noteworthy that a trend towards more continental conditions, dated to 1120 +/- 50 B.P. (SRR-3175), coincides with MHC formation at Lichtenmoor. A phase shift identified at Bolton Fell Moss (Barber, 1981: Section HI9) also dates from this period.

6.42 PERIODS OF RECURRENCE SURFACE FORMATION

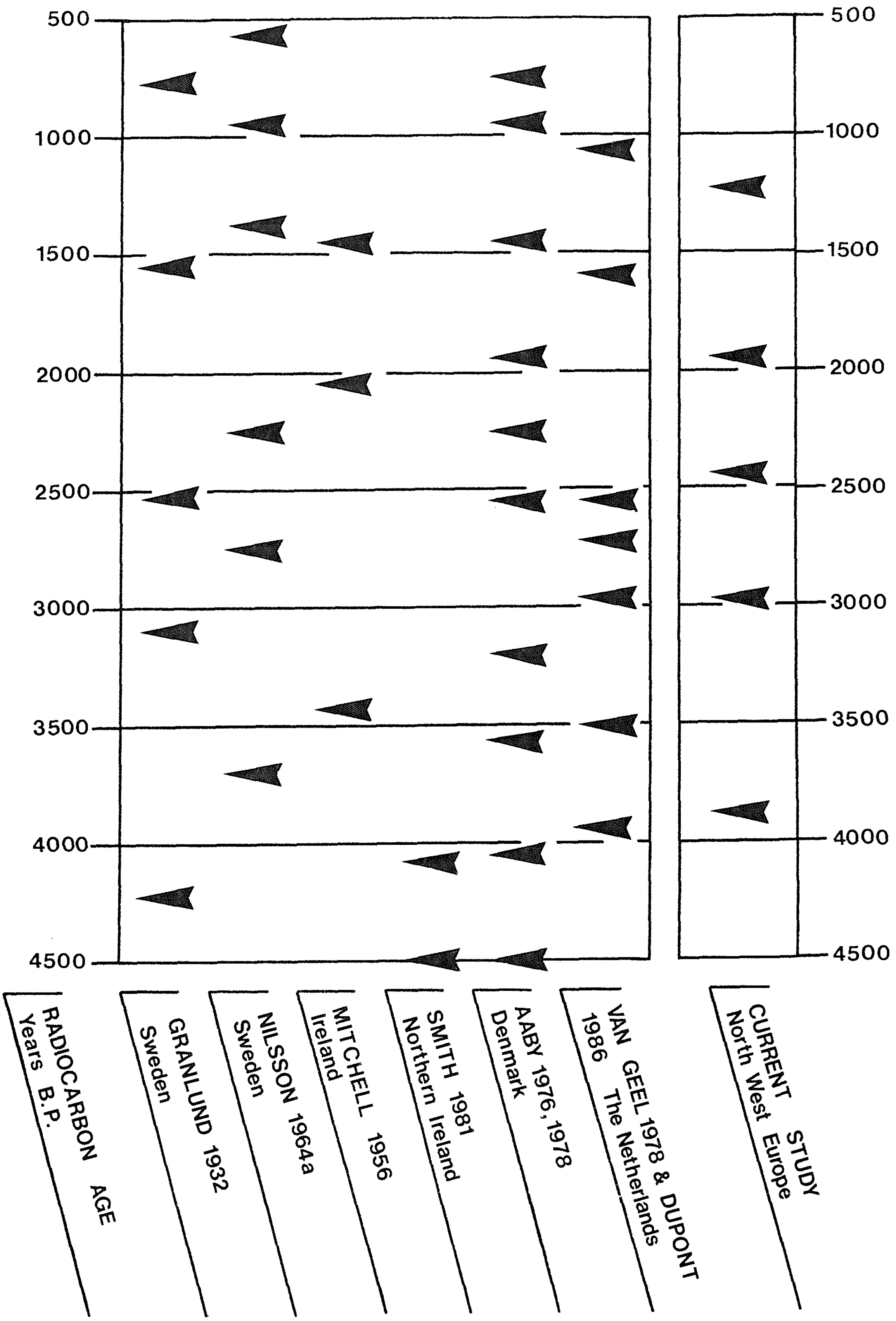


Figure 60. Periods favouring recurrence surface formation

Granlund (1932) identified five periods favouring recurrence surface formation from Swedish raised mires. These were dated on archaeological grounds as: RYI A.D. 1200 (750 B.P.); RYII A.D. 400 (1550 B.P.); RYIII 600 B.C. (2550 B.P.); RYIV 1200 B.C. (3150 B.P.); RYV 2300 B.C. (4250 B.P.). The most distinct of these surfaces was RYIII, the 'Grenzhorizont' of Weber (1900). Subsequent studies by Nilsson (1964a) recorded seven shifts from humified to unhumified peat; A.D. 1400 (550 B.P.), A.D. 1000 (950 B.P.), A.D. 650 (1300 B.P.), 300 B.C. (2250 B.P.), 800 B.C. (2750 B.P.), 1700 B.C. (3700 B.P.) and 2700 B.C. (4650 B.P.). Working in Ireland, Mitchell (1956) recognised three periods; A.D. 500 (1450 B.P.), 100 B.C. (2050 B.P.) and 1450 B.C. (3400 B.P.). These 'classic' shifts in peat formation have been indicated in figure 59. More recently, evidence for cooler and/or wetter periods has been recorded at A.D. 1500 (450 B.P.), A.D. 1250 (750 B.P.), A.D. 1000 (950 B.P.), A.D. 500 (1450 B.P.), 0B.C./A.D. (1950 B.P.), 300 B.C. (2250 B.P.), 600 B.C. (2550 B.P.), 1250 B.C. (3200 B.P.), 1650 B.C. (3600 B.P.), 2150 B.C. (4100 B.P.), 2550 B.C. (4500 B.P.) and 2750 B.C. (4700 B.P.) in Denmark (Aaby, 1976, 1978); A.D. 850 (100 B.P.), A.D. 300 (1650 B.P.), 600 B.C. (2550 B.P.), 780 B.C. (2730 B.P.), 950 B.C. (2900 B.P.), 1600 B.C. (3500 B.P.) and 1950 B.C. (3900 B.P.) in The Netherlands (Van Geel, 1978; Dupont, 1986); and at 2155 B.C. (4105 B.P.) and 2550 B.C. (4500 B.P.) in Northern Ireland (Smith, 1981). Any consistent trend remains unclear (figure 60). In a cogent review of Subboreal and Subatlantic climates, Barber and Coope (1987) demonstrate however, that in the case of Danish data (Aaby, 1976) not all shifts were shown in all of the five mires studied. Local site factors are considered responsible for this variation (Barber, 1985).

Based on radiocarbon ages of the MHC obtained by the current study and previously published dates, five periods favouring recurrence surface formation are suggested for the period 4500 B.P.-500 B.P. in north western Europe; around 3800 B.P. (1850 B.C.), 2900 B.P. (950 B.C.), 2450 B.P. (500 B.C.), 1900 B.P. (A.D. 50) and 1200 B.P. (A.D. 750). These are shown on figure 60. Correspondence with several 'wet' shifts identified in The Netherlands (Van Geel, 1978; Dupont, 1986) and Denmark (Aaby, 1976, 1978) is indicated (figure 60). The correlation is less clear in the British Isles, though Smith (1985) and Wimble (1986) have identified a major phase shift at 3100-3200 B.P. in Humberside and Cumberland respectively, and

Barber (1981) demonstrates 'wet' shifts at c.2800 B.P. and 1200 B.P. at Bolton Fell Moss. A less distinct upper recurrence surface at Mongans Bog (SRR-3043, 1480 +/- 50 B.P.; SRR-3044, 1650 +/- 50 B.P.) coincides with shifts in peat formation noted elsewhere (Granlund, 1932; Mitchell, 1956; Nilsson, 1964a; Aaby, 1976, 1978; Van Geel, 1978; Barber, 1981; Dupont, 1986), and most likely reflects a less marked transition to cooler and/or wetter conditions.

Several radiocarbon dates have been presented for the initiation and spread of blanket mire in the European uplands. Smith et al. (1971) identify two periods of peat inception in Ireland: between 3610 +/- 75 B.P. (UB-376 F) and 3955 +/- 75 B.P. (UB-380)(1660 B.C.-2005 B.C.) and 2520 +/- 70 B.P. (UB-347) and 2900 +/- 70 B.P. (UB-337 F) (570 B.C.-950 B.C.). In the Welsh uplands a suite of radiocarbon dates have been obtained, ranging from 4830 +/- 55 B.P. (UB-821)(2880 B.C.) (Moore et al., 1984) to 1310 +/- 70 B.P. (CAR-48 F)(A.D. 640) (Chambers, 1981). No clustering of dates is apparent. Recent computer modelling by Maguire (personal communication) has, however, demonstrated a bimodal peak in dates for the British Isles. It is hypothesised that the periods 2750-2250 B.P. (800 B.C.-300 B.C.) and 1750-1250 B.P. (A.D. 200-A.D. 700) were particularly conducive to blanket mire inception. Some correspondence with the phases of recurrence surface formation identified by the current study is suggested.

Evidence based on ages of blanket peat inception remains unsatisfactory. Moore (1975) identified three major factors believed to influence blanket peat initiation: climatic change, soil maturation, and the influence of human activity (in prehistory). This last was considered by Moore to have been a more important factor than previously thought. Taylor and Smith (1981) also questioned the climatic origins of blanket peat and instead advanced a model of peat development which incorporated a basal 'pedogenic' peat. Recently, Edwards and Hirons (1982) drew attention to a number of factors which may influence the date of peat initiation, notably the topography of the pre-peat landscape. More importantly, Smith and Taylor (1969, p.86) have shown that where bog vegetation remains are preceded by an accumulation of mor humus, this basal raw humus layer may be equivalent to up to 1000 years of deposition. A single radiocarbon determination could therefore provide only an approximation of the peat initiation date. As Barber and Twigger (1987) note, more detailed work involving accurate dating is needed on this problem.

6.43 MECHANISMS OF PEAT FORMATION

6.43.1 THRESHOLD THEORY

As early as 1935 Jonas had noted that the formation of recurrence surfaces could vary temporally both on an intra- and inter-site basis. Subsequent studies (see for example Overbeck et al., 1957; Lundqvist, 1962; Schneekloth, 1968) supported this proposition. More recently, several workers have convincingly demonstrated broadly contemporaneous recurrence surface formation within individual mire systems (see for example Dickinson, 1975; Wimble, 1986; Svensson, 1987). Barber (1982) has also questioned early interpretations of dated sequences. These and other works have been reviewed more fully in Section 2.1.

The problem of inter-site variability remains unsolved. Barber (1985) postulates that the main humification change varies in date between mires due to differences in altitude and latitude and local climatological, hydrological and vegetational characteristics of each mire. This theme was first taken up by Conway (1948) in a speculative paper dealing with vegetational response to climatic fluctuation. Although examined in Section 2.1, brief reconsideration is appropriate. Developing earlier work by Von Post, Conways' thesis postulated that fluctuations of climate could be analysed into a series of rhythmic variations of one or more "master factors" in the climatic system. Each rhythm displayed a simple harmonic form. Whilst there was no instantaneous attainment of equilibrium in response to a changing climate, a shift in vegetation occurred once a theoretical value for change had been crossed. In mire habitats it was suggested that the precipitation/evaporation ratio, or "moisture factor", was of importance in controlling Sphagnum growth. Conway indicated that moisture factor curves for different localities should be roughly parallel in behaviour but not necessarily coincident due to local site characteristics. Additionally, only climatic shifts of sufficient magnitude to cause the moisture factor to cross a threshold line at a given locality would be expressed by the vegetation.

Conway (1948) examined this theory in the light of stratigraphic information obtained from Bettisfield Moss, Shropshire, Tregaron, Dyfed, and Ringinglow and Kinder Scout blanket mires in the southern Pennines. Although pollen-analytical dating techniques were applied, it was demonstrated (figure 2, p.228) that the main humification change could occur at different periods. Conway (1948) remains vague in specifying the precise local site factors involved, and makes no attempt to define system threshold values or climatic "master factors". Nevertheless, the theory provides a possible mechanism by which temporal variation in the MHC may be explained, and has been invoked by Aaby (1976) and Barber (1982). Little subsequent work has been undertaken to establish the precise local hydrological factors involved.

6.43.2 MIRE HYDROLOGY

The hydrological aspects of mire ecology have been examined by several workers. Cogent reviews are presented by Ivanov (1975) and Ingram (1983). According to Ivanov (1975) the water balance in a mire (dW/dt) may be expressed in terms of horizontal water exchange:

$$dW/dt = Q1-Q2+Pp+Pgr+Pe$$

where,
Q1 the total recharge of water across the front of influx and
Q2 the total discharge of water across the front of efflux (Both belong to the external water exchange)
Pp, Pgr and Pe form the internal water exchange, where
Pp denotes total precipitation,
Pe total amount of evaporation from the mire massif and
Pgr the net transfer resulting from exchange of water between peat deposits and subjacent soils.

All the water which enters the system must eventually leave it. In an ombrotrophic mire Ql=0, because the mire is only supplied by precipitation. At the boundaries of the system, inequalities of influx and efflux cause variation with time in the quantities of water stored (Ivanov, 1975). Inputs by precipitation and ground-water recharge vary according to location and underlying geology. After the peat deposits have become thick enough, seepage to the underlying soil will become negligible, this means that Pgr=0. A large proportion of the water received by mires is subsequently discharged by evapotranspiration. Evaluations by Sokolov and Chapman (1974) suggest that evapotranspiration is more consistent, so that the wettest mires generate the densest flux.

It seems that the water content of the catotelm remains sensibly constant over long time periods. Thus, most of the variations in water storage in mires accompany water-table movements in the acrotelm (Ingram, 1978). The acrotelm of an intact mire is generally thin (25-50cm) (Malmer and Holm, 1984), and according to Eggelsmann (1971), storage changes associated with the movement of water-tables generally amount to no more than 3 to 10% by volume. Limited storage capacities have also been reported by Boelter and Verry (1977). Any shift in mire hydrodynamics leading to increased water storage, will, through a reduced acrotelm, favour moisture retention and retard vegetal decomposition. In climatological terms, increased precipitation and/or reduced temperatures will decrease the precipitation/evapotranspiration ratio. Conditions experienced during the spring and summer months are likely to be most important to Sphagnum growth, though the autumn and winter situation may also be critical (Clymo and Hayward, 1982). Cold winters, contributing significant volumes of water from snowmelt, are an important but little quantified factor (Eggelsmann and Schuch, 1976; Barber, 1981).

Several workers have explored the effects of size, shape, effective rainfall and local vegetation on mire hydrology. Studies by Ingram (1982) and Dupont (1985, 1986) deserve mention. Turning to soil physics and hydrology, mathematical modelling by Ingram (1982) has demonstrated that the maximum height a raised mire may attain can be given by:

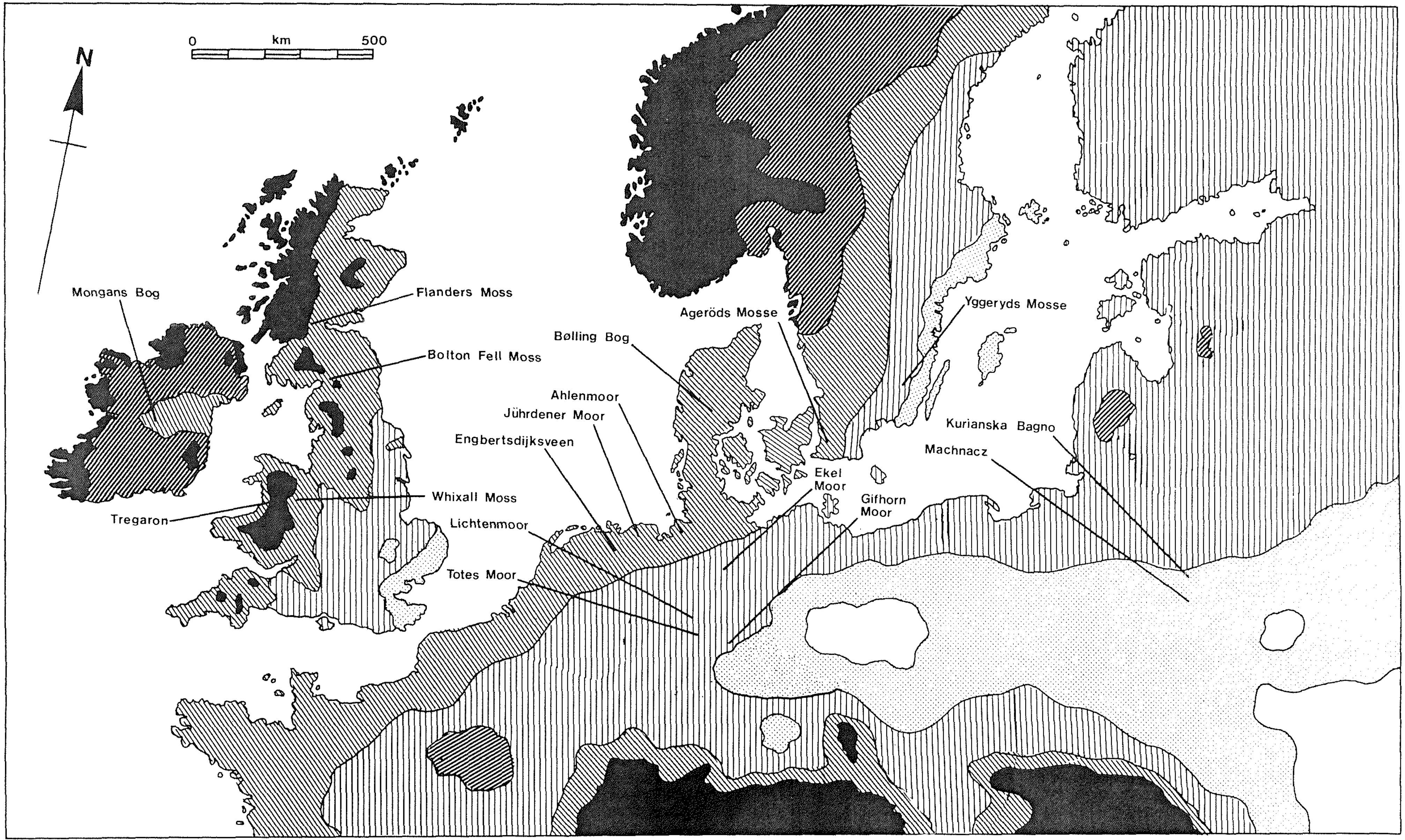


FIGURE 61. THE ANNUAL AVERAGE POTENTIAL WATER DEFICIT (SOIL MOISTURE DEFICIT IN mm) IN NORTH WESTERN EUROPE. ADAPTED FROM GREEN, 1964; BAUMGARTNER & REICHEL, 1975; GURNELL, 1981.

$$\frac{U}{K} = \frac{Hm^2}{L^2}$$

where,

U is the lateral discharge by seepage towards the lagg,

K is the hydraulic conductivity of the peat

Hm^2 denotes the height of the mire and

L^2 is the mire diameter.

This equation predicts that damper climates will support raised mires of more pronounced convexity. Substitution of water balance data for Dun Moss, Scotland (Mott, 1973; Rycroft et al., 1975) into this groundwater mound hypothesis enabled computation of mean hollow altitudes on the mire surface. Profiles obtained from 'wet' and 'dry' years produced conflicting results, suggesting that convexity was actually greater in 'dry' years. Dissatisfaction with estimates of U and the possibility that seepage was neither rectilinear nor parallel to the valley axis throughout the ground water mound, were considered responsible for the anomalous findings. Higher Hm:L ratios during wet periods have been reported for Sweden (Granlund, 1932) and West Germany (Eggelsmann and Schuch, 1976), contrasting with Finland where little difference was found (Aartolahti, 1965). More pronounced convexity would, on theoretical grounds, increase net efflux due to lateral seepage, and a negative feedback mechanism would ultimately operate. This was expressed by Granlund (1932) as the 'limiting height' hypothesis (see Section 2.1).

Inter-site differences in the initial Hm:L ratio may be involved in the observed diachroneity of MHC formation. The concept predicts however, that sites of less pronounced convexity will exhibit greater potential for water storage before a change in mire height and rate of peat accumulation is effected. It follows therefore that unhumified peat formation would be expected to occur initially in western maritime Europe. This is not supported by the radiocarbon dates for the MHC. In the absence of accurate water balance or mean annual evapotranspiration data for each site, annual potential water deficits in north western Europe have been calculated (figure 61). These confirm that potential deficits increase along a west-east transect. Thus, whilst the hypothesis holds true for the wettest sites examined in the current study (Tregaron, Flanders Moss, Bolton Fell Moss), MHC formation at c.3000 B.P. in Totes Moor and Gifhorn Moor remains contradictory. No correlation was found between the approximate former mire diameter, L, and the date of unhumified peat inception. Alternative causal mechanisms must be explored.

Dupont (1985) notes that for an ombrotrophic mire with a stable water balance ($dW/dt=0$), the total discharge of water across the front of efflux equals the total internal water exchange. This has been modelled by Ivanov (1975):

$$qnL_2 = (Pp-Pe)w$$

where,
L_2 is the boundary of the mire in km; qn is the average natural component of the seepage in the direction of the boundary in $dm^3/s/km$; Pp is the rainfall in mm/y; Pe is the mean evapotranspiration in mm/y; w is the area of the mire in km^2. A shift in the effective rainfall (Pp-Pe) will cause a change in average seepage (qn), whereby the mire is able to maintain its stability. Thus, if precipitation increases and/or temperature decreases, the mean water-table will rise, the percentage of 'wet' vegetation will increase and the average seepage (qn) will become greater, so that the total discharge of water also increases. If average seepage is impeded, then further disequilibrium will be effected.

Hydrological consequences of variations in the front of efflux (L_2) and effective precipitation (Pp-Pe) have been studied by Dupont (1985, 1986) in relation to the Bourtangerveen, The Netherlands. The establishment of a major rivulet, The Runde, following a mire burst at c.2500 B.P. is well documented (Casparie, 1972; Dupont, 1986), and led to a larger front of efflux and reduced surface area. Analysing recent records of precipitation and evapotranspiration, Dupont (1986) demonstrated that small differences in precipitation had a relatively large impact on effective precipitation, whilst large differences in annual temperature elicited a comparatively small effect. Applying this data to the period immediately predating the mire burst, it was shown that given contemporary values of effective

Average Seepage (qn)	Effective Rainfall (Pp-Pe)			
$dm^3/s/km$	Whixall Moss	Tregaron	Totes Moor	Machnacz
1	46.6	71.3	22.3	130.6
2	93.3	142.7	44.6	261.1
3	139.9	214.0	66.9	391.7
4	186.5	285.4	89.3	522.3
5	233.2	356.7	111.6	652.8
6	279.8	428.1	133.9	783.4
7	326.4	499.4	156.2	914.0
8	373.1	570.8	178.5	1044.6
9	419.7	642.1	200.8	1175.1
10	466.3	713.5	223.1	1305.7
11	513.0	784.8	245.5	1436.3
12	559.6	856.2	267.8	1566.8
13	606.2	927.5	290.1	1697.4
14	652.8	998.9	312.4	1828.0
15	699.5	1070.2	334.7	1958.5
16	746.1	1141.6	357.0	2089.1
17	792.7	1212.9	379.3	2219.7
18	839.4	1284.2	401.7	2350.3
19	886.0	1355.6	424.0	2480.8
20	932.6	1426.9	446.3	2611.4

	Whixall Moss	Tregaron	Totes Moor	Machnacz
Area (km^2)	8.5	8.0	27.0	0.85
Boundary (km)	12.5	18.0	19.0	3.5
Effective Rainfall (Pp-Pe)	204.0	868.0	194.0	106.0

Table 4. Computed values of effective rainfall (Pp-Pe) belonging to stable situations, according to the water balance of four raised mires with different ratios of boundary (L_2) and area (w), and twenty different values of average seepage (qn).

precipitation, an unstable water balance existed at c.2500 B.P. The excess of water may therefore have initiated the mire burst and the development of a better natural drainage via the rivulet Runde. Palaeoecologically, the tendency to wetter vegetation dominated by Sphagnum cuspidatum and S. papillosum between 3500-2500 B.P. is replaced at c.2500 B.P. by a drier facies with Sphagnum sect. Acutifolia and S. imbricatum

Unfortunately, the absence of reliable evapotranspiration, radiation and soil heat flux data prevented an evaluation of the effects of changes in effective precipitation and liquid discharge on the hydrodynamics of individual study sites. In addition, human interference made the evaluation of former fronts of efflux and surface areas difficult. However, using geological maps, values of the front of effective efflux (L_2) and area (w) of the former Whixall Moss, Tregaron, Totes Moor and Machnacz were estimated. In table 4 the computed effective rainfall (Pp-Pe) at each site is given for twenty values of average annual seepage (qn). Values of qn vary according to the surface biotope. No information is available for European mires, but Ivanov (1975, p.93) provides average values for western Siberia. Intermediate values of 2, 4 and 10 dm^3/km/s belong to kinds of biotopes with 80%, 50% and 20% of hummocks (and 20%, 50% and 80% of hollows) respectively. Seepage rates are generally lower on treed mires. In this way, table 4 provides a range of possible effective rainfall quantities belonging to stable raised mires of the given extensions.

These values have been compared with recent records of rainfall and evaporation. Evapotranspiration from a raised mire is considered to approximate that of an extensive wet surface, on which short vegetation (less than 1m high) is growing (Ivanov, 1975). Evapotranspiration equals the potential evaporation (Eggelsmann, 1975; Neuhausl, 1975), which probably holds true for treeless Sphagnum mires (Ingram, 1983). Mean annual potential evaporation data is available for Fenns Bank (Gorham, 1957; 500mm at 10+/-0.5°C), the Welsh Plant Breeding Station (Meteorological Office, 1984; 430mm at 10+/-0.5°C), Neustadt (Kalb and Noll, 1980; 450mm at 10+/-0.5°C) and Bialystok (Pioro, 1971; 445mm at 10+/-0.5°C). Altitudinal complications at Tregaron and tree cover at Machnacz distort potential evaporation. True values are likely to be marginally

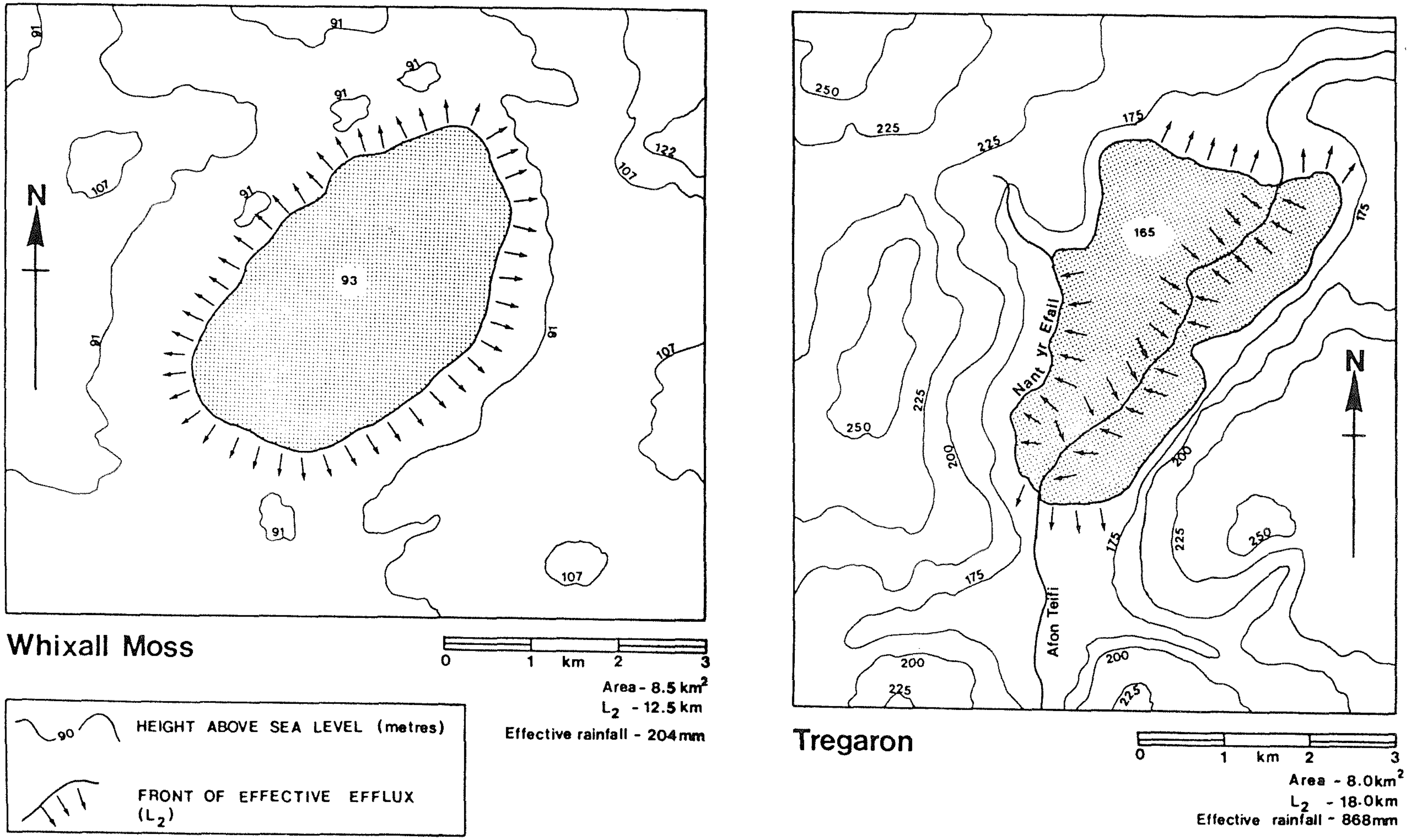
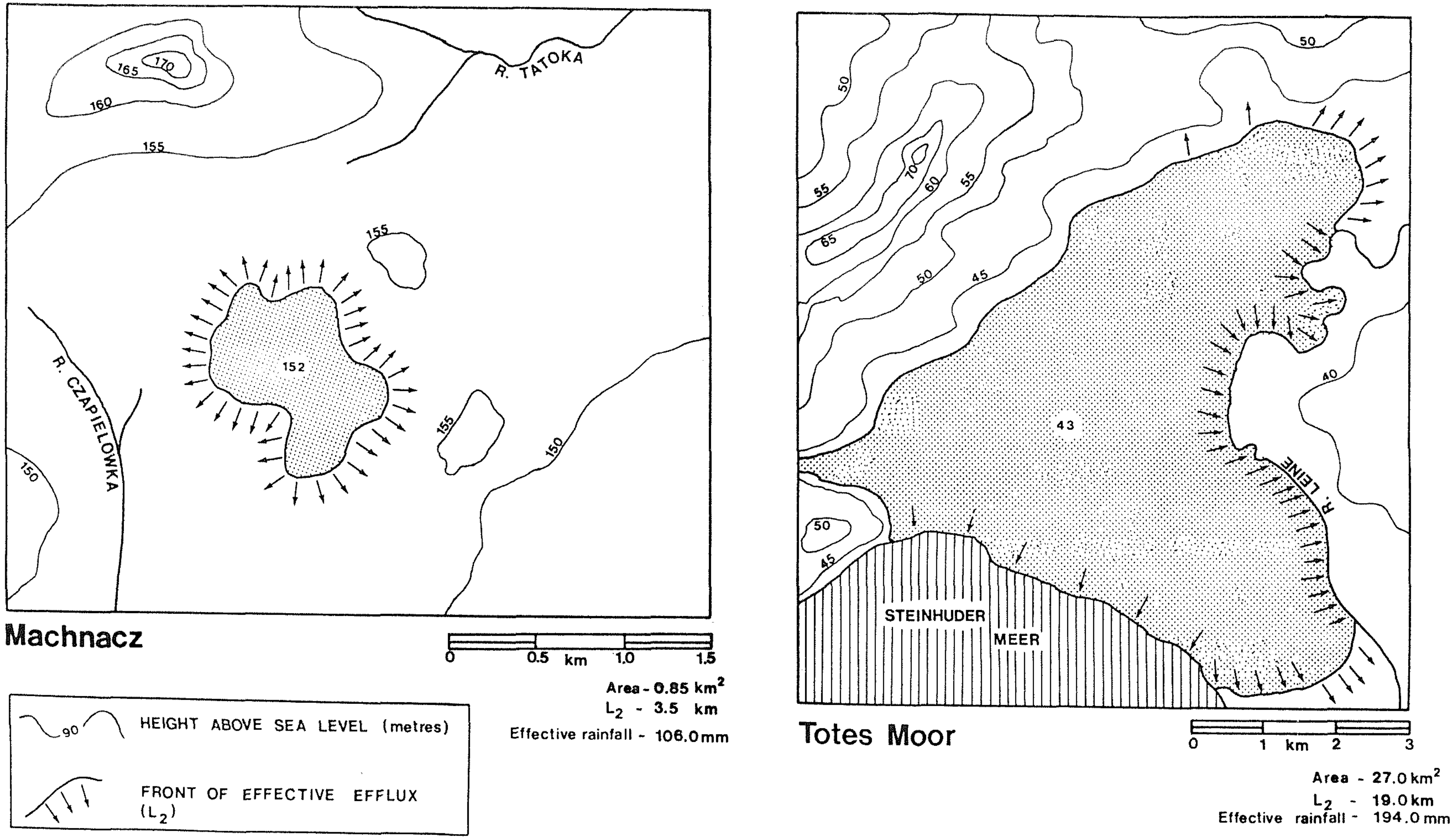


Figure 62. The topographic situation of Whixall Moss and Tregaron


Machnacz

Totes Moor

Figure 63. The topographic situation of Machnacz and Totes Moor

higher.

Contemporary effective rainfall values for Whixall Moss, Tregaron, Totes Moor and Machnacz of 204, 868, 194 and 106mm have been calculated respectively. From table 4, it is seen that to maintain hydrological stability minimum average seepage rates of 4.5, 12.0, 9.0 and 1.0 $dm^3/km/s$ must operate at Whixall Moss, Tregaron, Totes Moor and Machnacz. Any increase in effective rainfall would necessitate greater average seepage. At Tregaron topographic analysis indicates a limited effective front of efflux (figure 62). Both the river Teifi, which bisects the site, and the Nant yr Efail to the west act as natural drainage channels. Marginal efflux to the east is constrained by steep slopes which abut directly onto the mire. Similar observations have been made by Johnston (1970). Given an already large value of qn, it is suggested therefore, that unstable conditions would develop following a relatively small increase in effective precipitation. Increased runoff from the valley slopes would magnify the problem. Gentle slopes to the north and west and the Steinhuder Meer to the south generate similar impediments to marginal efflux at Totes Moor (figure 63). Despite its continental situation, limited buffering capacity is postulated. In contrast, a more open situation pertains at Whixall Moss (figure 62). Low rates of average seepage and a largely unimpeded front of effective efflux indicate that a substantial increase in effective precipitation would be required to initiate instability. A similar argument may be advanced for Machnacz, where an even more pronounced increase is necessary (figure 63).

Demonstrated inter-site variations in average seepage rates and hydrological stability provides a possible mechanism by which diachroneity of MHC formation may be explained. 'Wet' sites, such as Tregaron and Totes Moor, display limited ability to absorb any increase in effective precipitation and would initiate unhumified peat formation in the early stages of a climatic deterioration. Conversely, 'dry' sites, such as Whixall Moss and Machnacz, have larger storage capacities and more efficient fronts of efflux. These would cross threshold levels much later (if at all) in the deterioration. This interpretation is supported by the available radiocarbon dates for these sites.

Analysis of the topographic situation of the remaining study sites confirms that a relationship may exist between the date of unhumified peat inception and local site characteristics. For example, both Flanders Moss and Gifhorn occupy basin situations where impeded marginal efflux would be expected to occur. MHC formation has been dated to between 4000-3000 B.P. at these sites. Situations analogous to that identified at Whixall Moss are found at Juhrdener Moor, Lichtenmoor and, to a lesser extent, Mongans Bog. Unhumified peat formation at these sites occurs between 2000-1200 B.P. The relationship is less clear at The Engbertsdijksveen and Bolton Fell Moss, where the MHC dates from c.2800 B.P. Both mires occupy shallow hollow situations where evidence for an impeded front of efflux remains unclear. Alternative mechanisms may have therefore been involved.

6.32.3 ANTHROPOGENIC INFLUENCES

Human occupation of north west Europe during the late Holocene is well documented (Behre, 1987). Several workers have discussed the possible influences of these peoples on mire growth (see for example Frenzel, 1977, 1983; Schwaar, 1977; Taylor and Smith, 1980; Behre, 1987 and references therein). These works have been more fully reviewed in Section 2.1. Large-scale deforestation could create contrasting responses: increased runoff would promote poorer marginal efflux and a wetter mire surface, whilst longer wind fetches would increase potential evapotranspiration and effect a shorter effective vegetative season. Particularly in continental situations, a drier surface during the summer months would promote rather than retard decomposition.

Whilst anthropogenic interference did undoubtedly occur, the scale of these modifications remain unquantified. The demonstrated response of mires to changes in humidity and rate of precipitation (Aaby, 1976; Barber, 1981) points to a dominant climatic growth control.

6.44 SUMMARY

The main humification change present in the stratigraphy of nine north west European raised mires has been radiocarbon dated. Results indicate greater diachroneity than was formerly assumed. Based upon these dates and previously published age determinations for the remaining study sites, five periods favouring recurrence surface formation have been identified over the period 4500-500 B.P. Some correspondence with phase shifts recorded elsewhere in Europe is suggested.

Antecedent moisture conditions determined by local climatological, hydrological and topographic characteristics appear to play a significant role in modifying the growth response of mire systems to climatic perturbation. Sites with restricted fronts of effective efflux demand high rates of average seepage in the direction of the mire boundary in order to maintain hydrological stability. Small increases in the effective rainfall, brought about by increased precipitation and/or lower temperatures, will initiate instability and a shift to wetter surface communities during the early stages of a climatic deterioration. The reverse holds true for sites with more efficient fronts of efflux.

This hypothesis has been modelled using hydrological data obtained from four contrasting study sites: Whixall Moss, Tregaron Bog, Totes Moor and Machnacz. Results support the theory and provide a possible mechanism by which mires experiencing high potential annual water deficits (see for example Totes Moor and Gifhorn, figure 61) may exhibit 'early' dates for the MHC.

SECTION 7 CONCLUSIONS

7.1 INTRODUCTION

In attempting to specify the nature and causal mechanisms responsible for the formation of the Main Humification Change (MHC) in north west European raised mires, this study has focused directly on the measurement, analysis and interpretation of close-interval macrofossil data. Moving away from a site-specific approach, the investigation has involved consideration of a suite of sites along a transect from western maritime to eastern continental Europe and has been data-intensive.

From the outset, however, the project was designed to contribute more than raw data and processed results. This section highlights the various substantive points that have been made and advances recommendations for future research.

7.2 SUMMARY OF RESULTS

Summarizing the peat stratigraphic evidence of climatic change during the Subboreal-Subatlantic transition, Barber (1982, p.110) noted:

> "(1) There was probably a climatic deterioration c.3950-3850 B.P. (2000-1900 B.C.) even if it was only of a minor nature.
> (2) A more pronounced decline followed c.3450-3350 B.P. (1500-1400 B.C.)
> (3) A catastrophic decline to a cooler and/or wetter climate around 2850-2550 B.P. (600-900 B.C.)
> (4) Some evidence for a further decline around 2050 B.P. (100 B.C.)."

The data derived from the current study has maintained and strengthened Barber's conclusions. Sample scores obtained by DECORANA ordination give

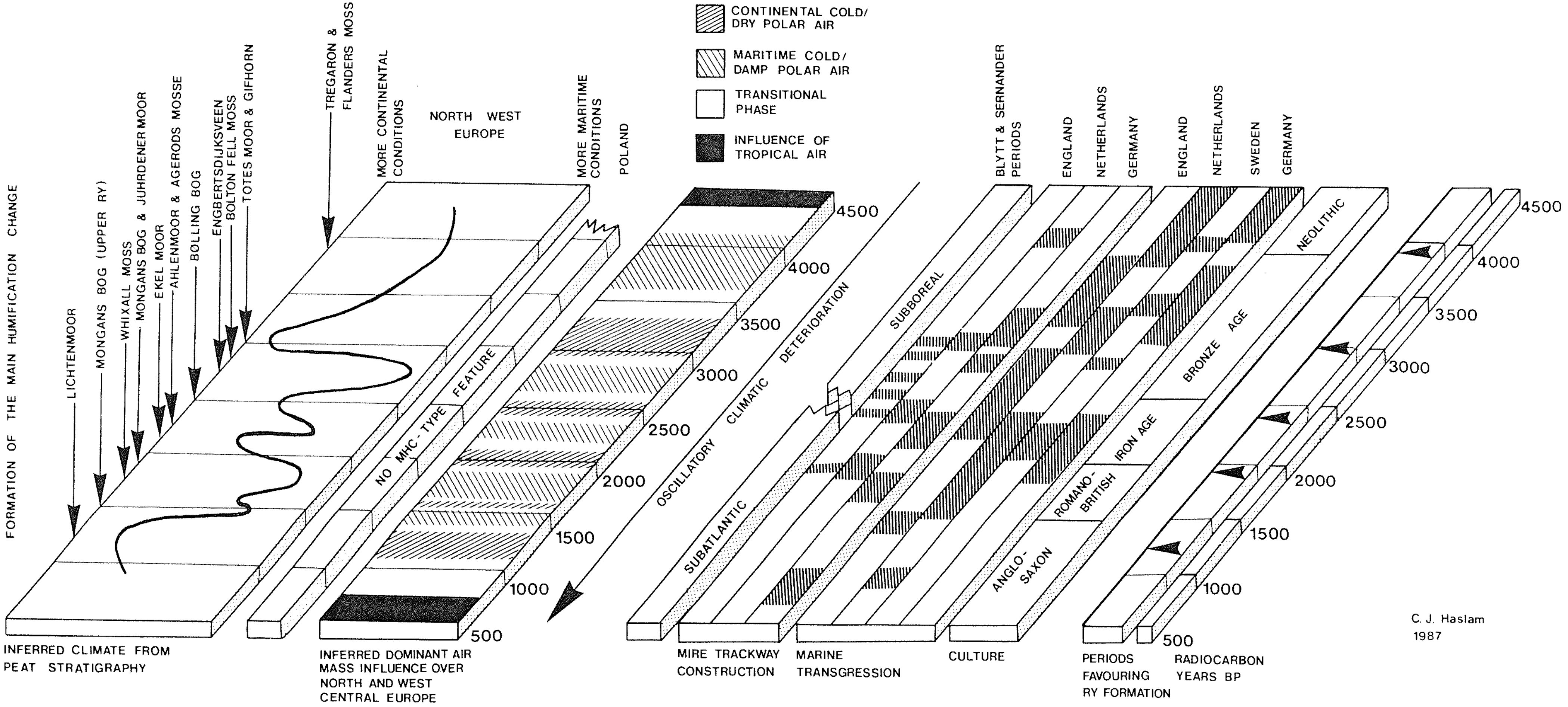


Figure 64. Regional Summary Diagram

an opportunity to discriminate between wetter and cooler conditions, which was hitherto much more difficult to do using vegetational data alone. Based on mean axis 1 and 2 DECORANA scores (Section 6.3) and available radiocarbon dates for the MHC (Section 6.4), a proxy climatic curve has been constructed for the period 4500 B.P.-500 B.P. in north western Europe (figure 64). 'Continental' (cool winters/warm summers/dry) and 'maritime' (wet/mild) shifts are indicated against a background of general climatic deterioration. This interpretation is supported by recent isotopic work in The Netherlands (Dupont, 1986) which has shown that the average annual temperature dropped from over 10°C to about 9°C between 4000 and 3000 B.P., rose shortly after 3000 B.P. to almost 11°C and fell off again to about 9°C after 2000 B.P. The absence of any humification change in north eastern Poland confirms that whilst changes in peat formation were being initiated in western maritime and western continental areas, the climatic shift was of insufficient magnitude to trigger unhumified peat formation in more continental regions.

Six distinct phases of climatic deterioration may be identified during the Subboreal-Subatlantic transition in north west Europe. These are:

(a) Gradual deterioration towards more maritime conditions c.3800 B.P. (1850 B.C.); MHC formation at Flanders Moss and Tregaron.

(b) Continued deterioration leading to marked continentality c.3000 B.P. (1050 B.C.); MHC formation at Gifhorn Moor and Totes Moor.

(c) Catastrophic shift to more maritime conditions c.2800 B.P. (850 B.C.); MHC formation at Bolton Fell Moss and The Engbertsdijksveen.

(d) A return to more continental conditions at c.2500 B.P. (550 B.C.); MHC formation at Bolling Bog.

(e) Less pronounced oscillatory deterioration between c.2500-1500 B.P. (550 B.C.-A.D. 450) involving maritime phases at c.2300 B.P. (350 B.C.)(MHC formation at Ahlenmoor and Agerods Mosse), 1900 B.P. (A.D. 50)(MHC formation at Juhrdener Moor, Mongans Bog and Whixall Moss) and c.1500 B.P. (A.D. 450)(upper recurrence surface at Mongans Bog) and continental phases at c. 2200 B.P. (250 B.C.)(MHC formation at Ekel Moor) and c.1600 B.P. (A.D. 350).

(f) A further decline to more continental conditions c.1200 B.P. (A.D. 750); MHC formation at Lichtenmoor and 'continental' phase in the Machnacz stratigraphy. Followed by amelioration to medieval warm epoch 800-650 B.P. (A.D. 1150-1300)

Based on this information, a series of periods favouring recurrence surface formation have been identified at c.3800 B.P. (1850 B.C.), 2900 B.P. (950 B.C.), 2450 B.P. (500 B.C.), 1900 B.P. (A.D. 50) and 1200 B.P. (A.D. 750). Some correspondence with phase shifts identified elsewhere in Europe (see for example Aaby, 1976, 1978; Van Geel, 1978; Barber, 1981; Smith, 1985; Dupont, 1986; Wimble, 1986) is suggested. Correlation of these phases with periods of mire trackway construction (Casparie, 1972; Overbeck, 1975; Turner, 1981) and marine transgression (Brand et al., 1965; Tooley, 1976) in north west Europe is also demonstrated in figure 64. The relationship is particularly clear at 2900 B.P. (950 B.C.), 2450 B.P. (500 B.C.) and 1900 B.P. (A.D. 50). Direct comparison with radiocarbon dates obtained for blanket peat inception in upland areas of north western Europe is problematic due to anthropogenic, topographic and pedogenic factors (Moore, 1975; Taylor and Smith, 1981).

Superimposed upon these general climatic trends were a series of short cycle wet-dry shifts. These are particularly marked in the pre-MHC matrix at Flanders Moss, Bolton Fell Moss, Whixall Moss, Juhrdener Moor, Ahlenmoor, Ekel Moor and The Engbertsdijksveen, where an unusual Sphagnum sect. Acutifolia (cf. S. capillifolium)-Sphagnum sect. Cuspidata (cf. S. cuspidatum) association has been identified. Van Geel (1978), Dupont and Brenninkmeijer (1984) and Dupont (1986) recognise a similar association in The Netherlands. Whilst it seems likely that each species was growing in sub-optimal conditions, periodic shifts to wetter and drier surface conditions maintained the association. The identification of wet-dry shifts in the post-MHC matrix is more problematic, especially where Cymbifolian species (mainly Sphagnum imbricatum) dominate. However, using a simple weighted averaging technique (Section 6.2) it has been possible to demonstrate the existence of wet-dry shifts in both pre- and post-MHC matrices. Extrapolations based on the available radiocarbon dates for the British Isles suggest cyclical wet-dry shifts of the order 30-120 radiocarbon years. The ability of Sphagnum imbricatum to mask variations in local hydrological conditions points to a wide tolerance of water level fluctuations. Macrofossil analyses indicate a low hummock preference for this species.

Additional evidence for short cycle wet-dry shifts has been provided by Brenninkmeijer (1983), Brenninkmeijer et al. (1982), Dupont and Brenninkmeijer (1984) and Dupont (1985, 1986) based on isotopic analyses of ombrotrophic peat. Brenninkmeijer (1983) and Dupont (1986) identify particularly wet conditions around 2600 B.P. (650 B.C.), a period shown by the current study to be associated with a shift to more maritime conditions in Europe.

Direct palaeoclimatic evidence from this period is poor. Magny (1982) proposes a southward displacement of the polar air mass and polar front during the Subboreal, effecting a cooler climate over the whole of Europe. Northern Europe became drier due to more marked influence of the continental cold and dry polar air. Increased dampness in central Europe is attributed to the southward tracking of depressions. In the Subatlantic cooling was accentuated, but involved increased influence of maritime cold and damp polar air in northern Europe. This led to pronounced dampness. DECORANA results indicate that alternative trigger mechanisms were involved in the initiation of unhumified peat in raised mire sequences: a shift to more maritime conditions in western coastal areas and increased continentality in west central Europe. When considered together with the observed diachroneity of MHC formation, a variable frequency of zonal and meridional circulation patterns, including blocking anticyclones, is suggested. High DECORANA beta diversities in central west Germany and Sweden (Section 6.32.3) provide evidence for a fluctuating 'border zone' between competing continental cold and dry polar air and maritime cold and damp polar air. A similar boundary has been postulated by Overbeck (1975) and Barber (1982). Inferred dominant air mass influences over north and west central Europe for the period 4500-500 B.P. are indicated on figure 64. Similarity with documentary evidence for 'continental' and 'maritime' shifts between c.1500-500 B.P. presented by Lamb (1982, p.148-177) is suggested.

Documentary information indicating short wet-dry shifts is available for the Little Ice Age Deterioration AD 1570-1860. During this period (Lamb, 1977, 1982; Pfister, 1983) several cold episodes lasting not more than a few decades led to a hemispheric advance of mountain glaciers to a level identical with the highest level ever reached during the Holocene. Longer warm periods separated cold phases. Lamb has published several weather anomaly maps for characteristic seasons (Lamb, 1977, 1979, 1982). The weather map series 1781-1786 (Kington, 1975) demonstrate an unusually high frequency of meridional circulation patterns with blocking anticyclones. The most striking event in the 1690's was the advance of polar water masses with seasonal ice blocking Iceland, reaching the Faroes and perhaps even western Norway, and sea surface temperatures 3-5°C lower than at present at the entrance to the North Sea (Lamb, 1979). All kinds of weather extremes were more intense and more frequent than at present.

Antecedent moisture conditions appear to play an important role in determining the date at which mire stability thresholds were transgressed. Hydrological modelling indicates that variations in surface area, the front of effective efflux, which in turn is controlled by the topographic situation, and effective precipitation modify the climatic 'sensitivity' (sensu Barber, 1981) of individual mire systems. Sites demanding high rates of average seepage in the direction of the massif boundary are more likely to initiate hydrological instability and unhumified peat formation in response to climatic deterioration than mires with lower seepage rates and greater storage potential.

This hypothesis has been explored using topographic and hydrological information derived from several study sites. Although further modelling will be required to establish the precise quantitative relations between evapotranspiration, precipitation, liquid discharge and water storage, as well as data on the response of surface vegetations to changes in these parameters, the theory provides a possible mechanism by which diachroneity of MHC formation may be explained.

7.3 RECOMMENDATIONS FOR FURTHER RESEARCH

It is inevitable that within a given research field it will prove impossible to pursue every avenue of potential interest, and so it has been with the current study. It is believed that several areas warrant additional research.

There is a real need for further detailed macrofossil and radiocarbon analysis of the Main Humification Change in raised mire sequences. In particular, suitable sites must be identified in the Fenlands of Great Britain, East Germany and Eastern Sweden. Time will play a crucial role in this investigation: the continued destruction of raised mire habitats may prevent such a study by the turn of the century. Allied to this, additional work must be undertaken on the usefulness of applying deuterium/hydrogen and O-16/O-18 ratios to palaeoclimatological problems. Thorough investigations should be made into the possible effects of interspecific differences in isotope metabolism.

Assessment of the Gaussian properties of subfossil macrofossil populations and the possible influence of differential decomposition rates between species of Sphagnum and vascular plants (Clymo, 1965), will permit the application of correction factors to palaeoecological reconstructions based on macrofossil analyses. The development of non-metric multidimensional scaling (NMDS) (Faith et al., 1987; Minchin, 1987), which does not make a direct assumption about the form of species response functions, may eventually supercede DECORANA as the most appropriate tool for analysing such data sets.

Chemical determination of decomposition degree using aqueous Sodium Hydroxide is a simple and direct approach, yielding valuable additional information for use in conjunction with macrofossil analyses. More work is needed however on the influence of individual species components on recorded atomic absorption and the mechanisms responsible for solution fading. Studies aimed at examining these problems are currently in progress at the University of Keele (F. Chambers, personal communication) and it would be premature to speculate as to the outcome of these investigations.

Finally, more evidence regarding the growth dynamics of individual mire systems is required. An important foundation has been laid by Clymo (1984), and upon which subsequent studies must build. Hydrological modelling (see for example Ivanov, 1975; Ingram, 1982, 1983; Dupont, 1986) will permit an evaluation of the importance of antecedent moisture conditions in modifying the growth response of raised mires to climatic change, and enable a more detailed examination of the threshold theory first expounded by Conway (1948).

Equipped with this type of information, more direct and universally applicable palaeoclimatological and palaeoecological models may be formulated for the Subboreal-Subatlantic transition. Ghazi (1983) and Hecht (1985) have demonstrated the considerable potential such models display. The ultimate goal of these studies must be the construction of a definitive climatic curve. The task is not inconsiderable. Nevertheless, the results of the current study are believed to represent a significant step along this pathway.

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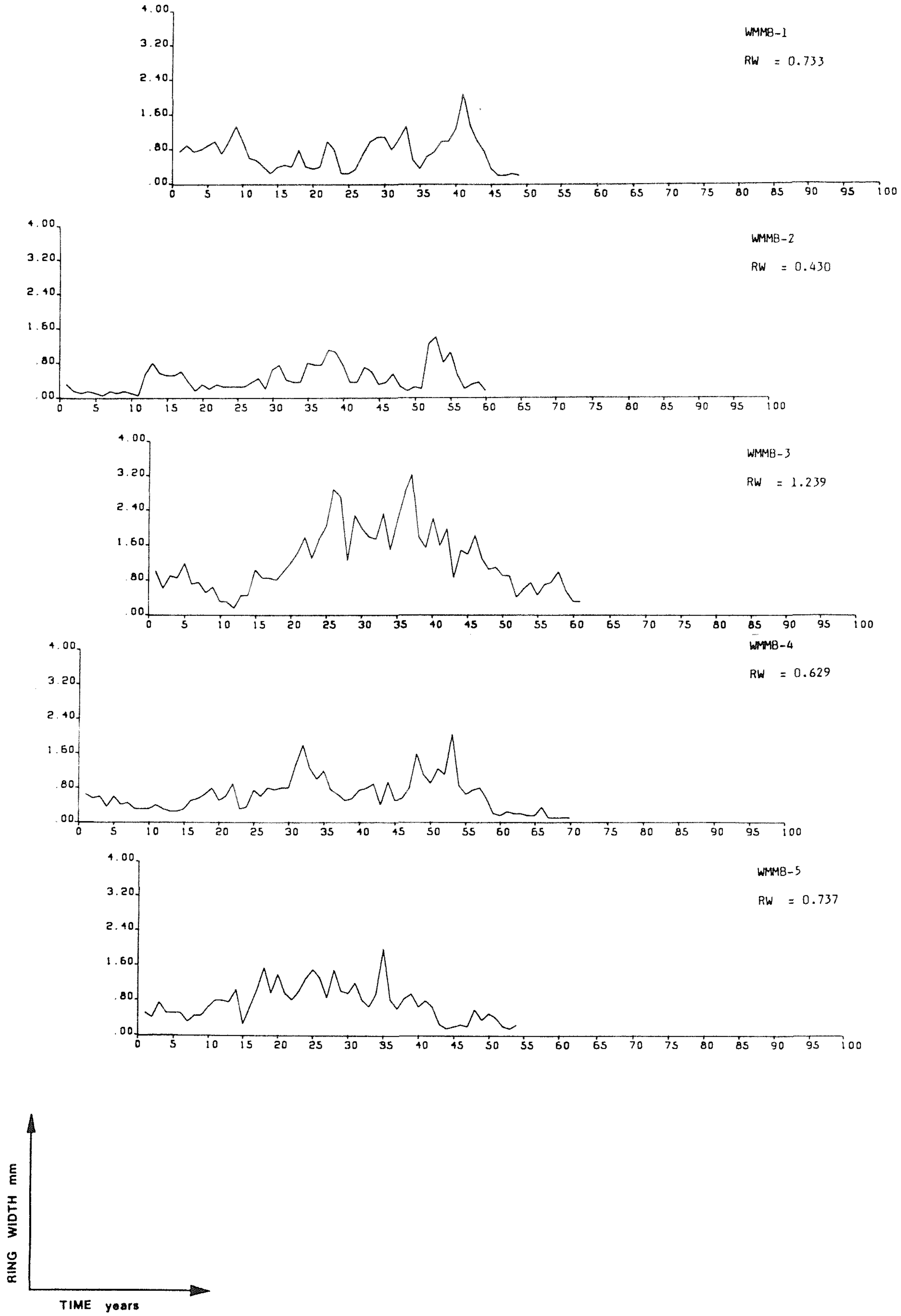
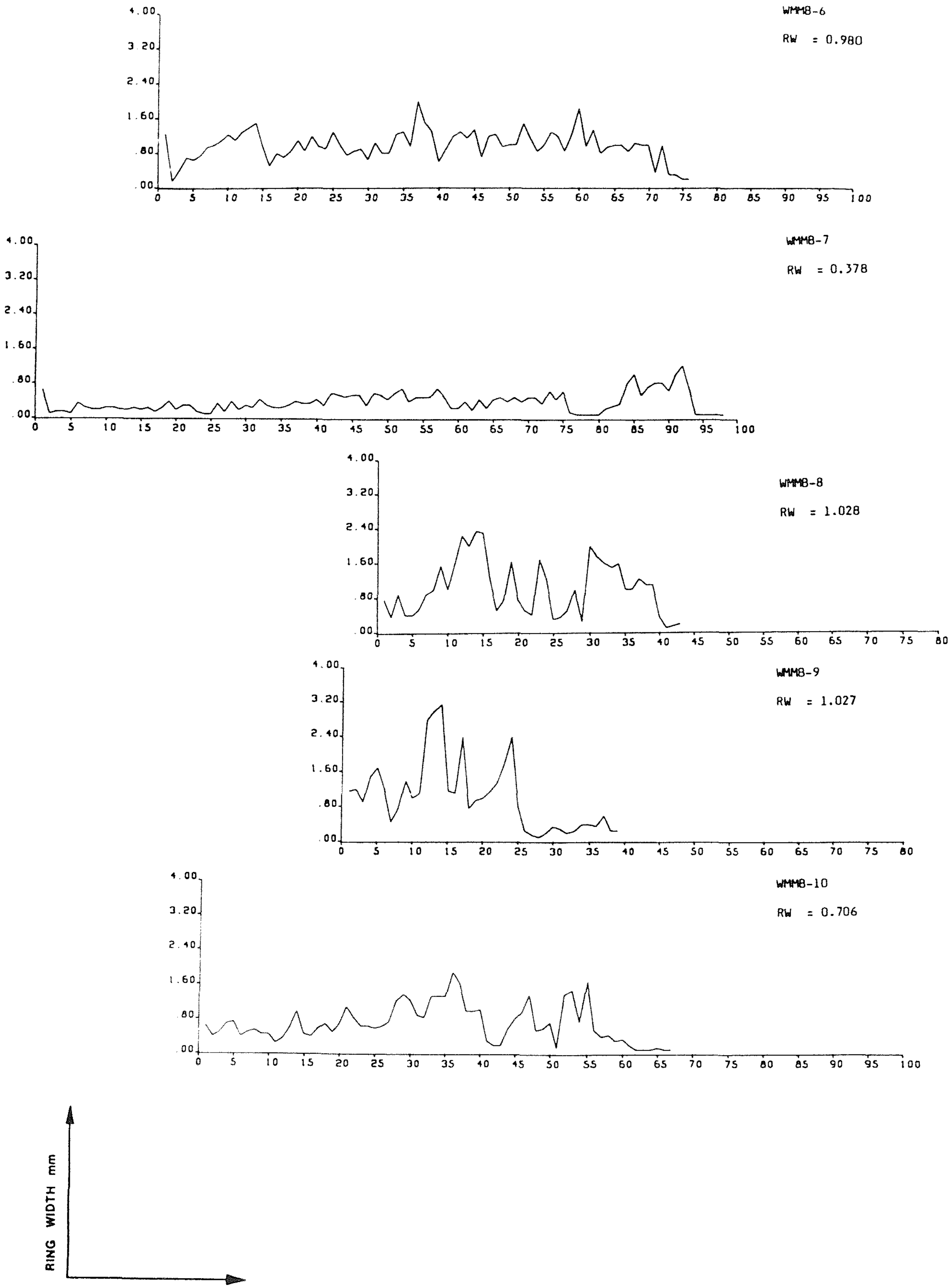
APPENDIX ONE

TIME SERIES OF RING WIDTHS FROM SCOTS PINE (*PINUS SYLVESTRIS*) STUMPS IN WHIXALL MOSS, SHROPSHIRE

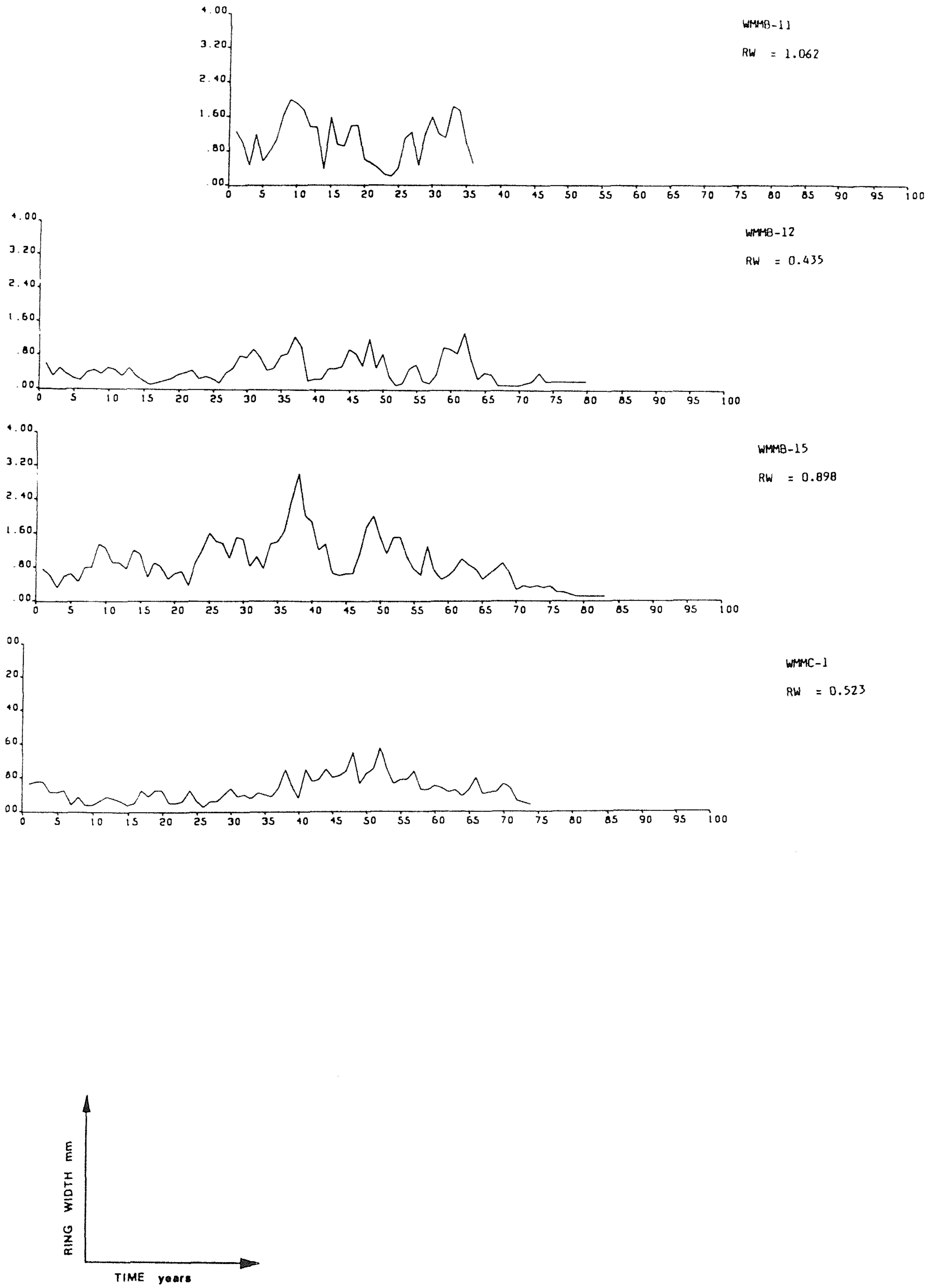
RW : Average Ring Width in millimetres for each series



TIME SERIES OF RING WIDTHS FROM SCOTS PINE (*Pinus sylvestris*) STUMPS IN WHIXALL MOSS, SHROPSHIRE, ENGLAND.



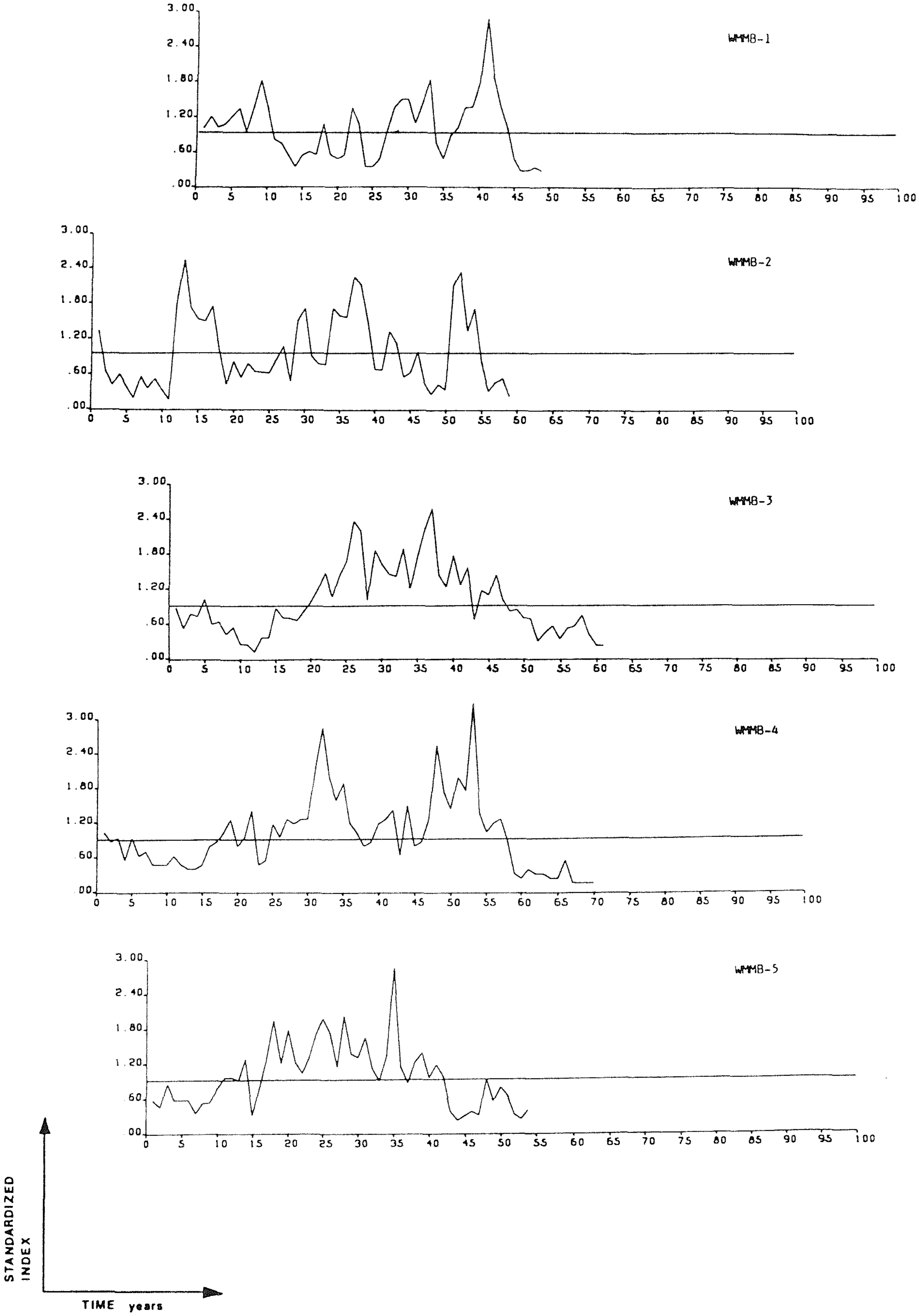
TIME SERIES OF RING WIDTHS FROM SCOTS PINE (Pinus sylvestris) STUMPS IN WHIXALL MOSS, SHROPSHIRE, ENGLAND.



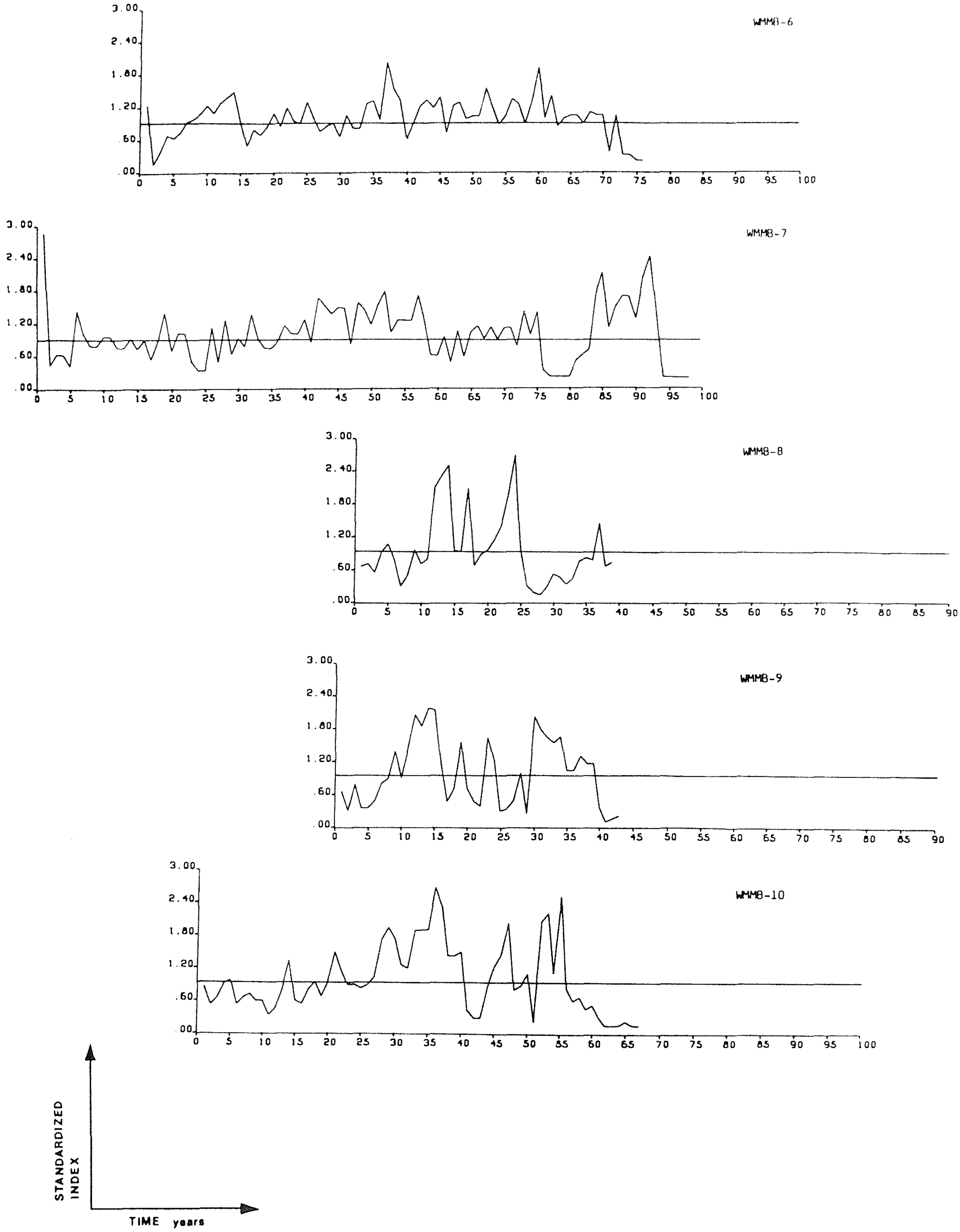
TIME SERIES OF RING WIDTHS FROM SCOTS PINE (*Pinus sylvestris*) STUMPS IN WHIXALL MOSS, SHROPSHIRE, ENGLAND.

APPENDIX TWO

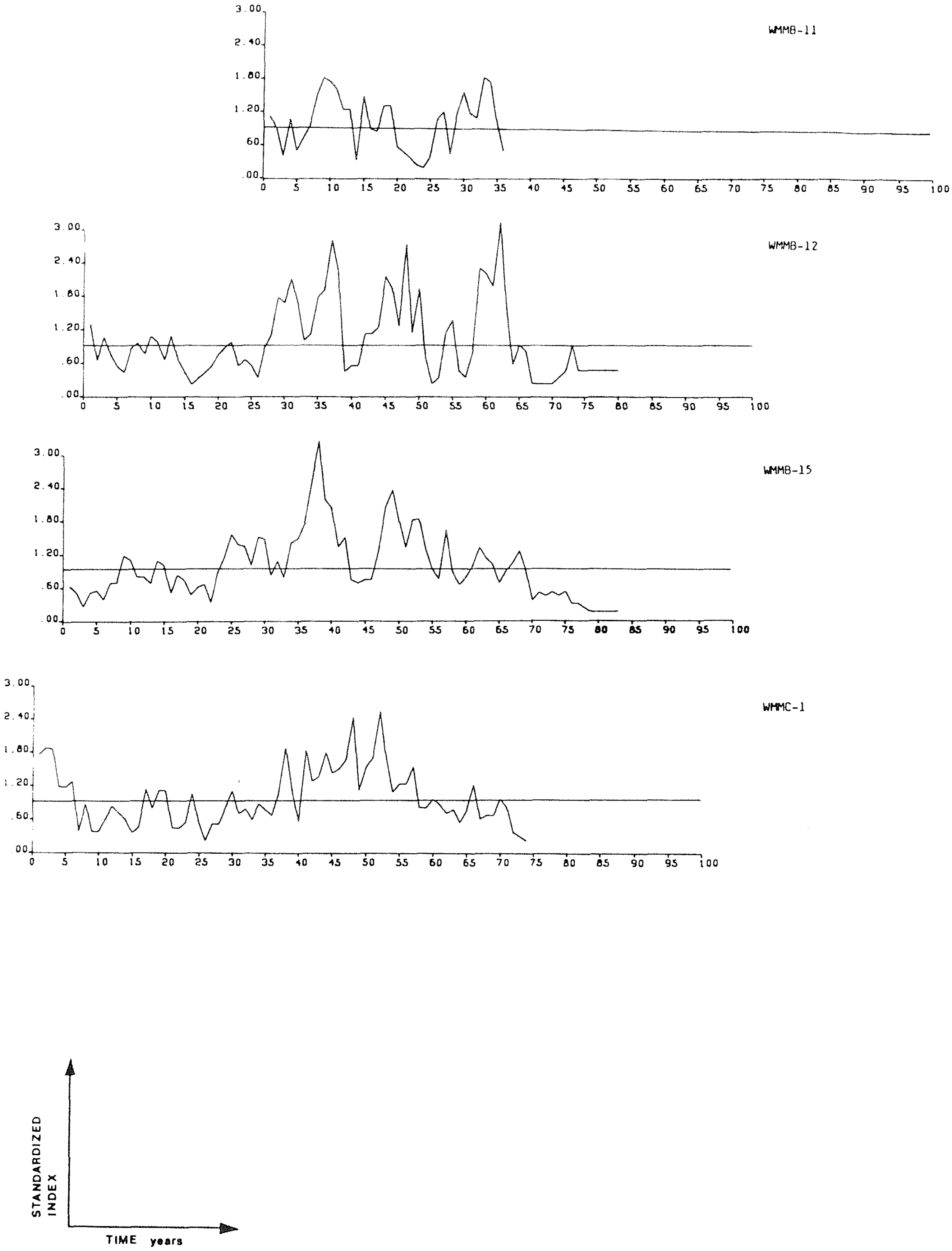
STANDARDIZED INDICES FROM SCOTS PINE (*PINUS SYLVESTRIS*) STUMPS IN WHIXALL MOSS, SHROPSHIRE



STANDARDIZED INDICES FROM SCOTS PINE (*Pinus sylvestris*) STUMPS IN WHIXALL MOSS, SHROPSHIRE, ENGLAND



STANDARDIZED INDICES FROM SCOTS PINE (*Pinus sylvestris*) STUMPS IN WHIXALL MOSS, SHROPSHIRE, ENGLAND.



STANDARDIZED INDICES FROM SCOTS PINE (*Pinus sylvestris*) STUMPS IN WHIXALL MOSS, SHROPSHIRE, ENGLAND.