UNIVERSITY OF SOUTHAMPTON

FACULTY OF SCIENCE

GEOGRAPHY

PAST AND PRESENT MIRE COMMUNITIES OF THE NEW FOREST AND THEIR CONSERVATION

by

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A thesis submitted in fulfillment of the regulations
for the degree of Doctor of Philosophy

UNIVERSITY OF SOUTHAMPTON

ABSTRACT

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The origin, development, present status and conservation of the New Forest valley mires are investigated. Existing hypotheses of peat inception are tested and methodological problems are examined. A null model for peat inception has logical primacy over other causal hypotheses of mire origins and provides a framework for investigation. The proximate cause of valley mire formation is related to the present water regime. The stratigraphic record may be much simpler than the real history of New Forest mire communities.

Methods of macrofossil analysis are critically reviewed and are developed for vegetative remains. Valley mire development is investigated from the Lateglacial. The direction of succession is differentiated within the mire system and most communities have a high probability of self-replacement. Discussion is extended to the theoretical basis of palaeoecology.

Mire vegetation composition and the heathland transition are studied using ordination and classification techniques. The community types obtained are compared with other classificatory schemes. Although composition is closely related to environment, internal features of the vegetation are also important in determining the main gradients of floristic variation.

The nature conservation significance of the valley mires is discussed, and the ecological characteristics used in evaluation are reviewed. Past and present management impacts are assessed. Grazing is important in maintaining the diversity of open mire communities, especially where *Molinia* is potentially dominant. The constraints on the grazing system are reviewed and it is concluded, from ecological and behavioural evidence, that the mires play an important role during limiting periods of the year. Drainage continues to damage the nature conservation interest of the mires - yet may be counter-productive or neutral in benefits.

ACKNOWLEDGEMENTS

First, and foremost, I wish to thank my wife, Nim, for living with my thesis, for her loving support and not least for her appreciation of bogs as special, wild places. I also wish to express my gratitude to my supervisors, Dr Keith Barber and Colin Tubbs, for their encouragement, advice and understanding.

This research was carried out under a Natural Environment Research Council C.A.S.E award with the Nature Conservancy Council, and I would like to acknowledge the support of both organisations, financial or otherwise. I am also grateful to Professors K J Gregory and R J Small for the support of Southampton University Geography Department, particularly in assisting my visits to The Netherlands and Czechoslovakia. My research was linked to the survey of the New Forest mires by the England Field Unit of the NCC. I would like to thank Dr T Bines and other past or present members of the unit for their co-operation and interest, especially Drs Martin Alcock and Dave Sheppard.

My work benefited from a period of study at the Hugo de Vries - Laboratorium, Universiteit van Amsterdam. I am very grateful to Dr Bas van Geel for sharing his knowledge of macrofossil analysis and for increasing my awareness of the macrofossil literature of continental Europe. Dr Colin Prentice (now at the University of Uppsala) and Professor Viktor Masing (Tartu State University) both helped to shape my thoughts on the processes of mire succession and its investigation, during a number of useful discussions. I also thank both Honor and Colin Prentice for the hospitality they showed me at Utrecht. Professor Galen and Rose Smith helped to provide references from North America, and in addition I thank them for introducing me to the prairie fens and bogs of Wisconsin.

I am grateful to Ron Allen, and several other members of the Soil Survey of England and Wales during the period of the Hive Garn Bottom joint-project. Noelle and Tony Welstead kindly showed me how to observe dragonflies properly. I also acknowledge the permission of the Forestry Commission to carry out my research in the Forest.

I was greatly assisted in the latter stages of thesis preparation by the ever efficient typing and expertise of Mrs R Flint, and Mr Alan Burn and the staff of the Cartographic Unit helped with some of the figures. Finally, I would like to thank all those friends, and colleagues both at the University and in the NCC, who have helped me from fieldwork to discussion, especially Dave Anderson, Chris Hill and Drs Nige Arnell, Tony Brown and Dave Watson.

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CHAPTER ONE : INTRODUCTION

1.1 Background and objectives

The valley mires of the New Forest occur within a biogeographical region which encompasses the lowland parts of southern England and northwest France. The mires are closely associated with heathlands, and even in the days of Thomas Hardy these habitats still covered extensive tracts of the southern English countryside. Today, the New Forest contains the largest series of valley mires which survive, and it is regarded as the "*locus classicus*" for this mire type (Ratcliffe, 1977a). The mire, wet heath and other wetland and riparian communities of the New Forest are of great importance to nature conservation, because of the international rarity of these habitats and the species they support. The vegetation-environment relationships of the New Forest mires were the subject of now classic research by mire ecologists (Rose, 1953; Newbould and Gorham, 1956; Newbould, 1960), and the mires remain of great scientific interest, especially because there is a series or suite of sites. However, subsequently, there has been relatively little research carried out on the New Forest mires, compared to the development of mire ecology in upland and northern regions of Britain.

This research project was conceived as a study of the origin, development and present status of the New Forest valley mires, leading to a consideration of their conservation. "Status" may be regarded as the factors which tend to maintain an ecosystem in its present state and those which promote most rapidly its change (Harley, 1977). The start of this project was co-ordinated with the surveys of the England Field Unit (EFU) of the Nature Conservancy Council (NCC), which provided baseline data and site dossiers for the vegetation (Alcock, 1985) and invertebrate communities (Sheppard, 1987) from a range of New Forest mires.

The organisation of this thesis falls naturally into three parts, the aims of which may be stated as follows:

1) To develop and test hypotheses concerning the origin of the valley mire communities.

2) To determine the successional pathways which have operated in the

valley mires over time, and to draw conclusions concerning the processes of valley mire plant succession.

3) To investigate the important physical, biological and management factors affecting the composition and structure of the present-day communities. From this, to identify implications for the evaluation and maintenance of the nature conservation interest of the valley mires.

Nature conservation tends to deal, inevitably, with vegetation at the community level. The aims of this thesis also require a multidisciplinary approach to be taken. This involves a variety of approaches to the problems under study. As a result, it is felt necessary to discuss the methodological basis and techniques of investigation in some detail - not only to ensure that they are brought together within a single framework in this thesis, but also, it is hoped, to help in the cross-fertilisation of ideas between different areas of research.

1.2 Description of the study area

The following is a brief review of the environment, history and administration of the New Forest. For further details, readers are directed to the accounts of Monkhouse (1964), Tubbs (1968, 1986) and Pasmore (1977), as starting points, and also to the bibliography of New Forest publications and reports, compiled by the Nature Conservancy Council (Flower, 1979 and addenda).

1.2.1 Geology

The New Forest lies in the north-central part of the Hampshire Basin, a tectonic downwarping of the Chalk containing Tertiary and Quaternary sediments. The Forest comprises exposures of the following Eocene and Oligocene strata:

Oligocene:	Osborne Beds
	Headon Beds (Upper and Middle)
Eocene:	Headon Beds (Lower)
	Barton Sand
	Barton Clay
	Bracklesham Beds
	Bagshot Beds

The southerly dip of these strata (c 1-2°) is slightly greater than the descent in altitude in the Forest towards the coast in the south. As a

result, the Lower Tertiary beds tend to be exposed in the north, with the younger having greater exposure in the south.

The Tertiary succession is made up of fluviatile, lacustrine and littoral deposits, with marine beds indicating a series of marine incursions during the Eocene. The uppermost Eocene and Oligocene deposits are mainly lacustrine, estuarine or lagoonal, including brackish or freshwater clays (Melville and Freshney, 1982). The solid geology of the Forest is, therefore, principally one of soft sands, clayey sands, and sandy and silty clays. The sedimentary environments of the Tertiary sequence result in considerable facies variation which, together with drift deposits, often make field determination of near-surface geology difficult. The bipartite division of the Barton Beds is overly simple (Melville and Freshney, 1982), since both units are very variable (especially the Barton Sand which includes clays), and the division between the Bracklesham and Bagshot Beds is also currently under review (M.R.Clarke, pers. comm., 1987).

1.2.2 Geomorphology and drift deposits

The geomorphological evolution of the region has been discussed by Small (1964, 1980) and Jones (1980, 1981), and a number of more recent studies are given in Barber (1987). The New Forest is normally described as a series of dissected terraces, or plateaux, which gently slope and descend in altitude south towards the coast. The Pleistocene terrace deposits, or Plateau Gravels, are the dominant feature in western and southern parts of the Forest. Various environments of deposition have been postulated for these gravels, but there is now a consensus that they are fluvial, or glaciofluvial, in origin and represent a series of terraces of the eastward-flowing, former River Solent (Keen, 1980) and its tributary, the River Avon (Clarke, 1980; Kubala, 1980; Clarke and Green, 1987).

The terrace deposits and lithological discontinuities within the solid geology provide suitable conditions for the development of seepage steps (Tuckfield, 1973); which are often organised into crescentic hollows which Tuckfield (1986) has termed 'dells'. These landforms, and other

valley features, represent phases of considerable periglacial erosion, away from the disturbed, but stable, terrace surfaces. Modern spring-lines occur at most seepage steps and are related to mire development in many valleys.

Brickearth deposits are closely associated with the terrace gravels, especially in the southern terraces of the Solent River (Fisher, 1971; Keen, 1980; Reynolds, 1985), although they survive locally elsewhere. The brickearths are thought to be derived from loessic sediments, and aeolian drift is a frequent component of surface soil horizons in the Forest. The aeolian drift probably comprises a fine sand and silt component of local origin, as well as far-travelled silt. Further aspects of the deposits and geomorphological features described in this section are discussed in Chapter Three.

1.2.3 Soils

Early research on New Forest soils was closely linked to forestry and described work done mainly in the inclosures and unenclosed woodland (Dimbleby and Gill, 1955; Davies, 1959 - 1960; Pyatt, 1970). The combined study of archaeology, semi-natural vegetation and soils soon led to the publication of Dimbleby's (1962) classic paper on British heathlands and their soils, which was based heavily on the New Forest. More recently Eide (1982) has repeated this approach using a number of modern analytical techniques.

The New Forest soils were described in general terms by Birch (1964) and there have been a number of unpublished surveys (notably by Manchester University Department of Geography). However, with the exception of Fisher (1971, 1975a, b), there was little detailed research or comprehensive survey of New Forest soils until 1979. Fisher (1975a, b) sampled soils and vegetation, on a systematic basis, from 60 sites. He described five main soil types: (i) stagnogley and stagnohumic gley soils, (ii) gley podzols (iii) podzols (iv) brown podzolic soils, and (v) argillic brown earths associated mainly with brickearth (see Avery, 1980, for definition of terms). In 1979, the Soil Survey of England and Wales commenced a national mapping exercise at a scale of 1:250000, which led

to the description of the New Forest soils in a regional context of south-east (Jarvis *et al*, 1984) and south-west England (Findlay *et al*, 1984). This confirmed that New Forest soils are typically very acid, have impermeable or slowly-permeable layers and are seasonally water-logged. Further work was carried out by the Soil Survey linked to this project and in association with the British Society of Soil Science annual meeting in 1984 (Allen and Staines, 1984; Clarke and Allen, 1986). This research was terminated by cuts in the staff and resources of the Soil Survey of England and Wales, following a review in 1984. The main soil associations and soil development in the New Forest are discussed in detail in Chapter Three.

The soils are quite clearly an important component of the semi-natural habitats of the Forest, yet their significance to nature conservation is not widely recognised - even though they are one of the main determinants of the vegetation patterns which are of such interest. The soils of the New Forest are of great, and largely untapped, potential to soil science; primarily because there is an extensive representation of soils which have escaped the degree of agricultural disturbance which has occurred elsewhere in southern England, but also because of the intimate relationship between semi-natural soils, vegetation and archaeology.

1.2.4 Climate

The climate of the New Forest is transitional between that of south-west England and the more continental climate of eastern counties and E.Anglia. The southern parts of the Forest, at least, occur within the coastal strip of central southern England (Barry, 1964; Jarvis *et al*, 1984) which is characterised by an early start to the growing season and a long frost-free period (June - September, with occasional ground frosts only in May and October). The main gradient in climate reflects distance from the sea and elevation. Frost frequency and precipitation increase and temperature decreases inland towards the north of the Forest. In general, the Forest has a mean annual precipitation (mainly as rainfall) of about 800mm, but exceeding 880mm (1916 - 1950) in the north-west (Barry, 1964). As a result, the north-west tends to have more days (over 175 days/yr) when the soils are at field capacity

(Jarvis *et al*, 1984). The Forest experiences a little over 120 'wet days' a year, compared to well over 160 wet days for Wales, NW England, most of Scotland and parts of SW England (NCC, 1986). A 'wet day' is defined as a period of 24 hours in which precipitation exceeded 1mm, and is a useful ecological index of wetness. The accumulated temperature above $0^{o}C$ for the first half of the year is now the preferred index of heat available for plant growth and is correlated with the length of the growing season (see Jarvis, *et al*, 1984). Between 1959 - 1978, southern parts of the Forest had a median accumulated temperature above $0^{o}C$ of 1550 - 1600 (day-degrees), compared to 1500 - 1550 for the north-west sector (Jarvis, *et al*, 1984).

1.2.5 Vegetation

General accounts of the vegetation are given by Lambert and Manners (1964) and Tubbs (1968, 1986). The literature on valley mires is reviewed in Chapter Six. The vegetation history of the New Forest has been investigated by a number of palynological studies of the valley mires (Seagrief, 1960; Barber, 1975, 1981a; Barber and Clarke, 1987; Clarke and Barber, 1987).

TABLE 1.1 The number of valley mires in the New Forest and their distribution according to catchment (see text).

Forest catchment	Catchment area (ha)	Approx. No. of mires
River Avon	4455	33
Lymington River	5670	37
Avon Water	1620	5
Beaulieu River	3040	11
Cadnam River and Blackwater	1015	5
Dark Water	610	6
Crockford Stream	1015	8
	Total	105

The valley mires in the New Forest were first described from an ecological viewpoint by Moss, Rankin and Tansley (1910) and Rankin (1911), although there are brief references to them in the earlier natural history literature. Rankin (1911) distinguished four main vegetation associations of the "valley moors" as well as recognising an intermediate zone between the "moor" and the "heath". He also made a distinction

between spring-line mires on the valley-side and more extensive valley-bottom mires which show greater floristic variability. Together, valley mire and wet heath occupies some 2894ha in the New Forest (based on a survey by C.R.Tubbs in 1967; see Tubbs, 1986). The mosaic of valley-bottom mire, seepages and wet heath makes it difficult to define discrete mire systems in many cases. Table 1.1 gives the approximate number of mires occurring in the main catchments of the Forest, which yields a total of 105 sites, within about 20 major valley systems. A minimum figure would be no less than about 90 well-defined mires, and an upper value would be much larger if all the small flushes and soakways were included (probably nearer 200). Mussett (1964) and Atkinson (1978) describe these catchments in detail. A list of sites described in this study is given in Appendix One, with O.S. map grid references.

The other main habitats of the 'open' (unenclosed) Forest are lowland heath (8121ha), acid and neutral grassland (4874ha) and ancient pasture woodland (3671ha). The silvicultural inclosures (8379ha) include about 40% native broadleaved trees. Most of the mires occur in close association with the Anglo - Norman heath, which is dominated by *Calluna vulgaris*, *Erica tetralix*, *E.cinerea* and *Molinia caerulea*, with *Agrostis curtisii*, *Ulex europaeus* and *U.minor* as frequent, and diagnostic, species (see Harrison, 1970; Gimingham, 1972; Bridgewater, 1980). There are a number of mires (c 7%) within the unenclosed woodland, which is dominated mainly by *Quercus* (*robur* and *petraea*) and *Fagus sylvatica* with a shrub layer of *Ilex aquifolium*. Several lines of evidence suggest that some sites may have had continuity of woodland cover throughout the post-glacial (Rose and James, 1974; Barber, 1975; Flower, 1980; Clarke and Barber, 1987). Woodland regeneration is closely related to historical fluctuations in the populations of large herbivores over the last few centuries (Peterken and Tubbs, 1965; Tubbs, 1986; see also Morgan, 1977). Stands of self-sown *Pinus sylvestris* occur locally on the open Forest, sometimes covering extensive areas, and are the subject of active management. Pine is thought to have been re-introduced into the New Forest from Scottish seed between about 1770 and 1776, and it is thought to have colonised the open Forest rapidly in the following half century (Pasmore and Lavender, 1974).

1.2.5 History and administration

There is little direct archaeological evidence for the occupation of the Forest by Man before the Bronze Age. Pollen data indicate anthropogenic forest disturbance may have occurred around the transition from the Mesolithic to Neolithic, with events dated to 5750 $\pm$ 60 (Barber and Clarke, 1987) and 5170 $\pm$ 50 (Clarke and Barber, 1987). There are abundant remains from the Bronze Age, but the status of Man before this period remains inconclusive. Over 200 round barrows survive in the Forest, which are attributable to mainly the Middle and Late Bronze Age (see Tubbs, 1986). Subsequently, there is relatively little evidence of Iron Age settlement, although there are small hill forts on most of the main watersheds of the Forest. However, pollen analysis of soils and peat deposits indicates considerable activity in the Late Bronze Age and Early Iron Age (see Tubbs, 1968, 1986; Eide, 1982 and Chapters 2, 3, and 5). Indeed, other than the barrows, the main evidence of Bronze Age settlement is in the form of boiling mounds (Tubbs, 1986) which would have no longer been necessary once heat-resistant vessels were available. There are fragmentary remains indicating occupation of parts of the Forest through the Iron Age and into the Romano - British era (Tubbs, 1986), including the well-known New Forest Roman pottery industry.

Information continues to be scanty until the Domesday survey (1086). However, since the Norman conquest and the establishment of a royal forest, the administration and management of the New Forest has had a long and complex recorded history (for an introduction see Stagg, 1979, 1983; Tubbs, 1968, 1986; Pasmore, 1977). In this context, 'forest' is a legal term referring to an area of land subject to Forest Law. This was intended to conserve, principally, deer (the venison) and its habitat (the vert). Forest Law was imposed on a Saxon settlement pattern, and it operated by controlling the exploitation of natural resources and the enclosure of afforested land. The extent to which the creation of the New Forest caused depopulation and peasant suffering is now uncertain. There was a degree of compensation for inhabitants affected by afforestation, in the form of tax relief and rights to depasture domestic animals on the unenclosed land, as well as other practices, which eventually became legal rights of common.

Initially, the Crown's interest in the New Forest lay in the deer and revenue raised through fines for infringements of Forest Law. However, from the late 15th and early 16th centuries it increasingly turned to the woodland resources, for sale of timber and naval shipbuilding. This led to a series of Acts, and unsuccessful Bills, which provided for the enclosure of land for silvicultural purposes free of commoners' stock. By the early 19th century, most forests had been successfully disafforested by the Crown but the number of commoners and the value of their rights probably made this an unprofitable course of action in the case of the New Forest.

The survival of the semi-natural vegetation in the Forest owes much to the creation of a royal forest, between 1066 and 1086, which restricted settlement expansion and produced a vigorous pastoral economy linked to common rights. This has resulted in an unbroken history of land use for almost a thousand years (possibly extending back in similar form for another two millenia) and has limited recent change, especially since about 1750 when the capability to agriculturally improve the Forest began to be possible.

As an alternative avenue to direct disafforestation, the Crown sought to increase the area of land enclosed for timber production, thereby reducing the value of commoners' rights on eventual disafforestation. This led, first, to the New Forest Deer Removal Act, 1851, and then to the New Forest Act, 1877. The Deer Removal Act provided for further enclosure of 10000 acres in supposed compensation for the virtual eradication of the deer population which, it was claimed, would benefit the commoners' animals. It also confirmed 'rolling powers' to enclose the Forest, and concentrated the administration of the Forest into the Office of Woods. The Act of 1877 was the product of intense opposition to the ambitions of the Crown and, essentially, laid out the framework for the present administration of the Forest (see especially Pasmore, 1977).

The New Forest Act, 1877 restricted the amount of enclosure, thus ensuring a minimum amount of Crown common land (45000 acres) which would remain permanently unenclosed. It also reconstituted the mediaeval Court of Verderers, which formerly had been part of the judicial system administer-

ing Forest Law. The Verderers no longer owed their allegiance to the Crown, instead they were to protect the interests of the commoners (by whom they were mainly elected) and to carry out the administration of common rights. The 1877 Act established a dual system of administration of the Forest. First, between the Verderers and the Office of Woods, and then the Forestry Commission following the Forestry (Transfer of Woods) Act 1923. Today, the Crown land (27153ha) is vested in the Ministry of Agriculture by Section 4(5) of the Forestry Act, 1945 and is managed by the Forestry Commission in accordance with the Forestry Acts and New Forest Acts 1877 - 1970.

Following the Report of the New Forest Committee, 1947, the New Forest Act 1949 made a number of important provisions for the management of the Forest. It broadened the powers of the Verderers, allowing them to give consent to the Forestry Commission to enclose parts of the unenclosed woodland to assist regeneration. It also allowed them to authorize temporary enclosures for improvement of grazing and the enclosure of more open Forest for forestry plantations. The latter became known as the Verderers Inclosures (812ha) and were created in the late 1950's. It was claimed that some were to be a barrier to urban/industrial expansion into the Forest from Southampton Water (due to the capital value of the timber), and others were supposed to be a buffer between roads and the stock on the open Forest. Section 11 of the same Act provides the basis for the present management of the open Forest. This requires the Forestry Commission

> "to carry out such works as appears to them after consultation with the Verderers, and with due regard to the interests of amenity, reasonably necessary, or as the Minister may direct, for securing that the Forest will be properly drained, that culverts and bridges crossing drains and streams in the Forest... will be properly maintained, and that the grazing will be kept sufficiently clear of coarse herbage, scrub or self-sown trees."

This duty is "balanced" by Section 15 of the subsequent New Forest Act, 1964 which requires both the Forestry Commission and the Verderers

> "to have regard to the desirability of conserving flora, fauna and geological or physiographical features of special interest"

in the exercise of their powers and duties. The relicts of Forest Law were abolished in 1971 (Wild Creatures and Forest Laws Act) so that now, strictly speaking, the New Forest is no longer a 'Forest' and is

rather a state-owned area of common land.

In addition to laying the foundations of the present administration, the 1877 Act marks the beginning of nature conservation or environmental concern, in a broad sense, in the New Forest (see Pasmore, 1977). The New Forest Association was founded in 1866 to oppose what was seen as the unreasonable administration of the Forest by the Office of Woods. It was led principally by affluent individuals, motivated mainly by aesthetic concern over blanket afforestation by the Office of Woods. The New Forest Association harnessed the growing public opinion against enclosure of common land and the recognition of the Forest's landscape value, during the Select Committee of 1875 and 1877, and the passage of the 1877 Act through Parliament.

By the first part of the 20th century, the importance of the New Forest was well-recognised by naturalists. There was increasing concern over the management of the Forest, particularly the incompatibility of the floristic and invertebrate interest of the valley mires and artificial drainage (Haines, 1929; see Pasmore, 1977). In 1943, the British Ecological Society committee on 'Nature Conservation and Nature Reserves' recommended that Matley Bog should be made a National Habitat Reserve because it was an outstanding example of an unspoilt valley bog. This area was extended in 1945 to include Denny Bog and the Longwater Lawn series of mires in the recommendations of the Nature Reserves Investigation Committee (Society for the Promotion of Nature Reserves, 1945). The Government report on "Conservation of Nature in England and Wales, 1947" (Command 7122) proposed that the whole of the New Forest should be designated a Scientific Area, and it drew attention to the outstanding scientific interest of the valley mires. The report also recommended the Matley and Denny area as a National Nature Reserve (Nature Reserve 30). A small part of this area had already been set aside by the Forestry Commission for the observation of natural woodland processes.

Soon after the creation of the Nature Conservancy and the passage of the National Parks and Access to the Countryside Act in 1949, the NC organised an ecological survey of the proposed Nature Reserve 30

(Chadwick, 1954), and in 1950 V.M.Conway (with W.H.Pearsall) carried out surveys of Cranes Moor/Vales Moor, Church Moor/Barrow Moor, Digden Bottom/ Linwood Bog and Wilverley Bog/Avon Water which all lay within proposed Forest Nature Reserves (FNR) or Sites of Special Scientific Interest (SSSI). Under an agreement with the Forestry Commission in 1959, the Nature Conservancy notified large areas of the Forest as FNR or SSSI. These early agreements were succeeded in 1971 when the whole of the New Forest was notified as a SSSI. An important step occurred in 1969, in terms of management, when a Minute of Intent was signed by the Forestry Commission and Nature Conservancy (strictly speaking, between government departments), which recognised that the status of the New Forest was equivalent to a National Nature Reserve. This is a formal consultation agreement which may be regarded as an instrument for implementing Section 15 of the New Forest Act, 1964. It was followed by a Mandate from the Minister of Agriculture to the Forestry Commission in 1971 which directed that

> "the New Forest must be regarded as a national heritage and priority given to the conservation of its traditional character."

It also went on to lay down that the unenclosed woodlands be conserved without regard to timber production.

The New Forest SSSI was re-notified under the Wildlife and Countryside Act, 1981 by the Nature Conservancy Council on 7 May 1987. This requires owners and occupiers to give the NCC four months notice of intention to carry out any operation which might potentially damage the scientific interest of the Forest. It should be noted, however, that Section 29 of the Act (which provides special protection for SSSI) does not apply to Crown land (Section 67(2)).

The NCC has become, therefore, increasingly part of the formal administrative framework in the Forest. However, there are conflicting requirements built into the web of legislation affecting management of the Forest. Section 11 of the New Forest Act 1949 is countered by Section 15 of the 1964 Act, but the balance achieved has not always prevented losses to the nature conservation interest. The 1949 Act, or its interpretation, is not always

compatible with the spirit of the Wildlife and Countryside Act, 1981. The trend, however, has been for greater emphasis on nature conservation on Crown land, with more positive conservation responsibilities being imposed on the Forestry Commission by the Wildlife and Countryside (Amendment) Act, 1985. Section 4 requires the Forestry Commission "to achieve a reasonable balance between commercial forestry and nature conservation."

The final element in the administration and management of the New Forest which needs to be described is the commoning system (see Pasmore, 1969, 1977; Countryside Commission, 1984; Tubbs, 1986). The rights of common in the New Forest are of "pasture" (ponies, cattle, donkeys and, in the past, sheep), "mast" (the right to put pigs on the mast in the pannage season), "turbary" (cutting of turves), "estovers" (the right to fuel wood) and "marl" (removal from particular sites for agricultural and possibly building purposes). The rights of common are attached either to buildings or land, rather than to people.

The commoning system has been vigorous all the while it has been economic to carry out a pastoral and low intensity system of agriculture. Since the 1950's, however, there have been many social and economic changes which have put pressure on the commoning system. In recent years, the number of ponies depastured on the Forest peaked at 3200 in 1978, and cattle at 3000 in 1961. Although there have always been fluctuations, the period covered by this study has been one of decline in the commoning system. During the period 1975 - 1986, the number of practising commoners (mainly pasture, mast, estovers) has declined by 22%, pony numbers have dropped by 17% and cattle 58%. In 1985 there were about 360 practising commoners and there were 2900 ponies and 1500 cattle depastured on the Forest (compared with a roughly constant and controlled deer population of about 1000).

1.3 Definition of some terms

1.3.1 Peatland classification and terminology

Over time peatland classification has become labyrinthine, with many differing schools of thought. There are two general reasons for this

complexity. First, mire communities exert a great influence on their physical surroundings through the accumulation of peat. This results in a wide variety of parameters on which classification may be based, including floristics, the structure of the vegetation, the structure of the mire, hydrology, peat stratigraphy (or other physical characteristics of peat), and chemistry (either of mire water or peat). Second, as research on these factors has increased so classification schemes have been modified, often in an unsystematic fashion. Differences in approach and interpretation have increased the complexity, which has been compounded by barriers in communication, especially language.

In many respects, the best single account of peatland classification is the posthumous review article by Gore (1983). Moore (1984) provides a review in relation to European mire classification (see other chapters in the same work). The published proceedings of the field symposium on classification of mire vegetation 1983 (Aquilo Ser. Bot. volume 21) also gather together a number of recent approaches to the problem, mainly in relation to Europe. Cowardin *et al* (1979) provide one of the few attempts to integrate peatlands within a classificatory framework for all wetland and aquatic habitats, though at a coarse scale. It is not intended to review peatland classification here, but it is necessary to explain and discuss a number of terms which are relevant to the mires of the New Forest.

The term mire is internationally accepted as encompassing all types of peatland. Beyond this point the problems start. In the past, peat was simply defined by a certain depth of organic deposits formed under more or less waterlogged conditions. One suspects that this is often used in an *ad hoc* fashion in the study of mire vegetation and in Britain, for example, the depth was often defined at twelve inches (i.e. a foot) which has since become 30cm with the use of metric units. Recent definitions of peat have been integrated within soil classifications (e.g. Avery, 1980) and a useful review is given by Clymo (1983). From a strict floristic viewpoint, there is some difficulty in this definition of mire vegetation. For example, what is the plant community (and indeed the ecosystem) called before the required depth of organic material has

accumulated for it to qualify as peat? Production and decomposition may be at equilibrium in some mire communities, for example the inferred 'stillstands' in the development of some raised bogs (see Barber, 1981b; see also Clymo, 1984). In the New Forest, similar plant communities may occur over differing depths (often very shallow) of accumulated organic material, particularly at the mire margins or in valleyside seepage areas.

It is important to recognise the distinction between mires as plant communities (the living vegetation) and as physical peat-accumulating systems. The two are often, but not always, equivalent and the latter is more narrowly-defined. This study is concerned with the living assemblages of plant species as well as the peat deposits, and the term mire is taken to include those plant communities which are associated with peat deposits but are not necessarily restricted to them.

The peatlands in the New Forest have been referred to as, first, valley moor (Rankin, 1911), then valley bog (Tansley, 1939) and valley mire (e.g. Ratcliffe, 1977a). Recently, this type of mire has been referred to as valley fen or, simply, fen (e.g. Ingram, 1983; Wheeler, 1984). The term valley mire is preferred here. Tansley (1939) distinguished between bog, which was acidic and poor in minerals (i.e. oligotrophic), and fen which was mineral-rich and circumneutral or even alkaline (eutrophic). This usage has been popular with English workers and this principal division of mires remains valid (Gore 1983).

Early post-war research, particularly in Scandinavia, confirmed the link between floristics and the chemistry of mire waters, and the continuous nature of variation in these parameters (Sjors, 1948, 1950; Du Rietz, 1954). In this approach, any mire influenced by groundwater was classed as fen and much of the vegetation in the New Forest could be regarded as "poor fen" - the description "poor" referring to the low number of indicator species rather than overall species richness (Sjors, 1948). Research in the New Forest (Rose, 1953; Newbould and Gorham, 1956; Newbould, 1960) soon confirmed the close relationship between mire community composition and the chemical status of the water. The latter

was determined by the surrounding geology but also by hydrology (following Kulcynski, 1949). This research also established that there was a wide range of bog and fen elements (*sensu* Tansley) in the Forest mires, and that in some instances it was difficult to distinguish between fen developed in base-poor lithology and bog directly influenced by rain-water (*sensu* Du Rietz, 1954).

It was for these reasons that the term valley mire received wide acceptance for the peatlands of the New Forest. However, recent research has emphasised the hydrological status of mires (see Ingram, 1983), and Wheeler (1984, p.265) has classed the New Forest mires as "base-poor, valley fens". It is arguable that with the prefix "valley" the term fen is unnecessary compared to the neutral, and less confusing, "mire". Moreover, the hydrologic distinction between bog and fen is not always that clear-cut (see comment above). For example, the rates of throughflow or run-off in hyper-oceanic mires dependent solely on rainfall (ombrotrophic) may be comparable to those dependent on groundwater (minerotrophic) in more continental parts of Europe (Lindsay *et al*, 1985). Water-shedding and water-receiving areas in blanket mire also pose problems in what is essentially ombrotrophic bog (*sensu* Tansley). There is also the potential for groundwater exchange with the underlying substrate in some cases, but this is poorly understood (see introduction by Ingram in Ivanov, 1981). Another point is that the mires in the New Forest support invertebrate communities more typical of "bogs" than "fens" (see Chapter 7.2.3). Hydrology is important but is not the only underlying factor affecting variation in peatlands (e.g. Daniels, 1985; Malmer, 1986). It might also be pointed out that chemistry, another important factor, presents some difficulties in measurement for cross-site comparisons (Summerfield, 1974; Eurola and Holappa, 1985). "Valley mire" could invite confusion with, say, the more extensive flood-plain mire formations of Eastern Europe, but this is easily countered by the inclusion of "New Forest type", or something similar. An alternative might be "Anglo-Norman valley mires" since they are closely associated with this heathland type (see earlier). Finally, from a practical viewpoint, "valley mire" is becoming accepted by others than ecologists and a further change in nomenclature would be undesirable.

Other peatland terms referrable to the valley mires, and encountered in

the literature, are that they are geogenous, in that they depend on soil-derived water, and are either soligenous (flowing water) or topogenous (static). In a strict, etymological sense rheophilous is synonymous with soligenous and also applies to most of the valley mires. Finally, mesotrophic is sometimes used to indicate an intermediate chemical status.

1.3.2 Peat stratigraphy

The Troels-Smith (1955) system is used here to describe peat and other unconsolidated sediments (see also Barber, 1976; Aaby, 1979). This system describes sediments according to their physical features, humicity and components rather than making any assumption as to the sediments origin, or nature of the environment. Each characteristic is scored on a 0 - 4 scale. The following terms are those most frequently encountered in the stratigraphy of the valley mires (see Chapters 2 and 5)

Physical properties: Nigror = degree of darkness, Stratification = degree of stratification, Elasticitas = degree of elasticity.
Components: Substantia humosa = humous substance with a homogenous macroscopic structure. Detritus = various remains above the ground; D.lignosus = wood, D.herbosus = herbaceous material. Turfa = ground or below ground material (mainly roots and stems); herbacea and lignosa as before, T.bryophytica = moss. Argilla granosa = clay (0.002 - 0.06mm). Grana = mineral particles larger than 0.06mm; G.arenosa = silt, G.saburralia = sand, G.glareosa = gravel.
Humicity: each unit is equal to two units of the von Post scale.

1.3.3 Time periods

The cultural and geological (or biostratigraphical) periods used here are self-evident and are shown in Figure 1.1. The use of Flandrian for the postglacial is preferred here, as opposed to Holocene, for the following reason. There is no empirical or theoretical evidence to suggest that the present postglacial is more than the latest in a series of interglacials of the Pleistocene. Holocene elevates the postglacial to a geological period equivalent in rock to Pleistocene, and is arguably

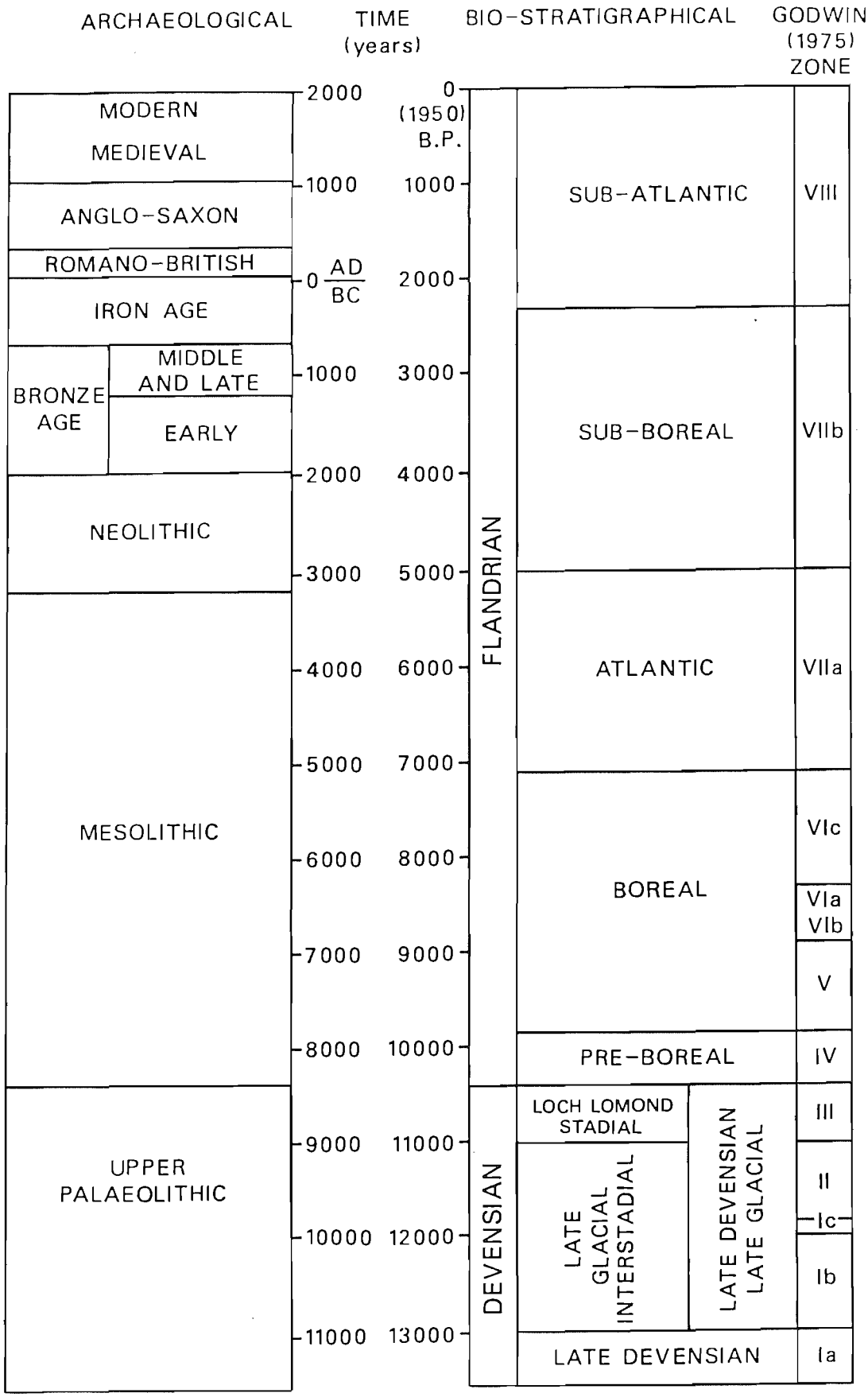


FIGURE 1.1 : Cultural and biostratigraphical periods referred to in text.

anthropocentric ("The Age of Man"). The counter argument, which is also valid, is that the names of the geological periods in the Cainozoic are derived from the present being "*holos*" = whole or complete, but there was a very different scientific view of the universe when these names were established.

A total of 22 radiocarbon age estimates are now available based on peat samples from the New Forest - details are given in Appendix 2 and are discussed within the text.

1.3.4 Biological nomenclature

The names of vascular plants follows Clapham, Tutin and Warburg (1981), in line with the Flora Europaea. Hill (in Smith, 1978) is used here for *Sphagnum*, rather than the more recent work of Daniels and Eddy (1985). The latter has the advantage of integrating the taxonomy of British *Sphagna* within Europe as a whole, but both treatments are broadly consistent with Isoviita's (1966) widely accepted revision of the genus. The "*subsecundum*" and "*recurvum*" groups are particularly relevant to the New Forest situation. *S.subsecundum* (*sensu stricto*) is relatively restricted, while both forms of *S.auriculatum* are widespread (although var *inundatum* less so), and Hill's scheme appears more appropriate (see Hill, 1975; Eddy, 1977). However, *S.recurvum* var *mucronatum* is distinctive and very frequent in the New Forest, whereas var *amblyphyllum* (= *S.flexuosum*) and var *tenue* (= *S.angustifolium*) are very scarce or rare, and the differences perhaps warrant specific status as suggested by Daniels and Eddy (1985). Other mosses follow Smith (1978) and liverworts Corley and Hill (1981)

Where the meaning is clear, some common species names have been shortened to genus, such as *Calluna* or *Molinia*.

1.4 Some key concepts

1.4.1 The community

Community ecology is characterised more by the spatial and temporal scales of investigation than by any particular paradigm or methodology (see, for

example, Gauch, 1982). The concept of the community has come to mean many different things. In plant ecology, divergent and contrasting ideas concerning the plant community have developed since the beginning of this century. These have been debated exhaustively and important reviews are provided by Westhoff and Maarel (1978) and Noy-Meir and Maarel (1987). These authors (see therein for references) distinguish a number of different theories concerning vegetation: (i) the organismal concept attributed mainly to Clements but supported by others and, to an extent, in the early writings of Tansley, where the community is viewed as a "superorganism"; (ii) the concept of social structure of Paczoski and many early Russian ecologists; (iii) the contrasting phyto-sociological concepts of Braun - Blanquet and Du Rietz (iv) the individualistic concept of Gleason, and also Ramensky, in which the community is viewed as a changeable mixture of "individualistically" distributed plant species; (v) Whittaker's concept of population structure, with the community as a system of interacting species and vegetation as a complex vegetation pattern.

A slightly different starting point is taken in this study. The community is regarded as the living component of the ecosystem. The community may be all of this component ("the biota") or it may be a particular group of similar organisms (e.g. the plant community, the invertebrate community, the decomposer community). The plant community is therefore a subset of the ecosystem concept, which was formally proposed by Tansley (1935) as a general term for both the biotic community and its habitat. An ecosystem occurs within a given area; it is a spatial phenomenon (see for example Odum, 1975; Whittaker, 1975). Lindeman (1942, p.400) defines an ecosystem as "any system composed of physical-chemical-biological processes within a space-time unit of any magnitude." Ecosystems may be conceived of and studied at varying scales - it is equally valid to talk of a tree rot-hole, a raised bog or an ocean as an ecosystem. Both the ecosystem and community are defined by the observer - they are human constructs which are useful in dealing with the living world.

It is possible to distinguish types of communities and patterns in the variation of vegetation. This is simply the classification of entities sharing the same characteristics into the same group. In this sense, the

community is an abstract unit of vegetation of any classificatory standing, following, for example, H J B Birks (1973) and Poore's (1955) general term "nodum". This does not imply a "community-unit" nor an individualistic organisation to vegetation. A general theory of plant community organisation is, in any case, likely to be pluralistic and will need to be tested by experimentation rather than observation of pattern alone (see Shipley and Keddy, 1987; Noy-Meir and Maarel, 1987).

1.4.2 Biological conservation

The basic tenet of biological conservation is that practical problems in the conservation of nature depend upon the availability of technology which, in turn, depends upon scientific research. The ethics of nature conservation are not discussed here (see, for example, the treatments of Ratcliffe, 1976; Harley, 1977; Mabey, 1980; Rackham, 1985), but the ultimate purposes of nature conservation are taken to extend beyond the material use of natural resources, to include aesthetic and intellectual considerations, including the advancement of knowledge.

The scientific basis to nature conservation was crystallised in the Government report on Nature Conservation in England and Wales (Command 7122), which heavily involved scientists in its formulation, as pointed out by Ratcliffe (1977b). Subsequently, the rationale was developed further; for example the British Ecological Society symposium held in 1970 (Duffey and Watt, 1971) and the discussion by the Royal Society in 1976. From this, several ecological concepts emerge as central to biological management for nature conservation purposes, notably succession, stability and the persistence of species' populations. This is based to a large extent on the observation that few ecosystems are in a state of stable equilibrium due to the intervention of man, and that changes will occur if this influence is altered (e.g. Pigott, 1977; Dempster, 1977).

Mires offer special potential for the investigation of processes affecting succession and stability, since they are characterised by the property that primary production exceeds decomposition (Moore and Bellamy, 1974). It is this phenomenon, the formation of peat, which sets mire ecosystems apart from others (Bellamy, 1967), and hence the environmental changes,

to which the community responds, are frequently due to plant growth itself. The synthesis by Rybniček (1973) of former and contemporary Central European mire communities has shown that consideration of past communities is important in understanding the mire vegetation found today. Mires present the only *in situ* record of vegetation change and, thus, the most direct evidence for testing the predictions of succession theory over ecological time (Watts, 1973; see also Gould, 1976). Palaeoecological investigations are (or at least should be) of both specific relevance to the study of living mire communities and their conservation, and general significance to ecological theory.

TABLE 1.2 Characteristics of the acrotelm and catotelm layers in mires (after Ivanov, 1981; Ingram, 1983).

[1] Declines rapidly with depth

[2] General level of microbial activity low

	Acrotelm (upper)	Catotelm (lower)
Exchange of energy	rapid	slow
Exchange of matter (incl. moisture)	high	low
Water content over time	variable	constant
Water table	present	absent
Hydraulic conductivity	high, variable[1]	low, ± constant
Water transmission	Darcyan	non - Darcyan (approximate?)
Aeration	periodic	anaerobic
Activity of aerobic microbes	high	nil[2]
Macroflora	matrix of living plant material	dead, except a few roots
Upper surface	Upward limit of matric forces	Lower limit of rapidly variable characteristics

1.4.3 The physical structure of mires

The recognition of Soviet research on mire hydrology has been one of the most significant recent advances for mire ecology in general. Of particular importance, is the distinction between the upper, periodically aerated

layer which contains living and actively decomposing plant material, and a lower, anaerobic and dead layer (except for aerenchymatous roots of specialised plants). This distinction was first made by Ivanov in 1953 and was also amplified by Romanov (see Ingram, 1978, 1983; Ivanov, 1981). Ingram (1978) has argued that the terms "active and inert layers" for the upper and lower layers, respectively, are confusing and misleading (especially in peatlands of frozen ground). Instead, he has suggested that these are replaced by the specific terms acrotelm and catotelm for the upper and lower layers (cata - may be the more appropriate root). The concept of the acrotelm and catotelm is of great functional significance to mire hydrology, which in turn is central to mire ecology. The characteristics of these two soil layers in mires are compared in Table 1.2. In passing, it should be noted that water table is defined as the surface at which the hydrostatic pressure of the soil water is zero (i.e. equal to atmospheric pressure). The upper limit to the zone of saturated soil pores is the capillary fringe (see Sjors, 1948; Ingram, 1981).

1.4.4 The significance of ecological "stress" to mire ecology

There are inherent differences in the primary productivity (or fertility) of ecosystems. The physical and biotic factors which, individually or collectively, limit productivity are often termed "stress" by ecologists. Recently, some workers have argued that the various forms of stress act similarly in terms of selective pressures, and they have sought to relate differences in stress - between and within environments - to plant life history strategies (Grime, 1979; Wilson and Keddy, 1986; Ellner, 1987). In this context, Grime (1979, p.21) has defined stress "as the external constraints which limit the rate of dry matter production of all or part of the vegetation". Harper (1982) is critical of the use of "stress" because he claims it is anthropomorphic, often redundant and is used to describe a force or stimulus rather than a response, which he infers is its correct biological usage (note that in mechanics stress is defined as a force per unit area acting between two bodies or parts of the same body). Harper (1982) is also critical of the use of "strategy" and "adaptation" in ecological writing, following from Gould and Lewontin's (1979) important critique of the "adaptationist programme".

It must be kept in mind that much of this debate centres on modes of explanation, rather than the validity of particular evolutionary mechanisms. The debate also stems from the differing scales of investigation in biology, which some chose to characterise as a reductionism - holism dichotomy (see, for example, Reed, 1981; Grime, 1982; Keddy, 1987; Noy-Meir and Maarel, 1987).

Almost by definition, mires impose particular limitations on the growth of plants, which are characterised by the anoxic environment which favours peat formation. The hydrology and nutrient dynamics of mires are closely linked, and together they provide an important gradient in ecophysiological stress between mire types (see Ingram, 1983 for a review). This ranges from ombrotrophic bogs, with low nutrient input and periods of stagnation and drought, to the deep and continuously flushed acrotelm of fens. The applicability of this concept to the New Forest mires is exemplified by Newbould's (1960) study of different vegetation types on Cranes Moor. The concept of stress and its relationship with life history theory is recognised here as providing useful insights into the interactions between species and their environment in mire vegetation. It is not suggested that such mechanisms are the only ones affecting the distribution and abundance of species in mire communities, and it is also recognised that falsification of these hypotheses requires experimentation, rather than the observation of pattern alone.

SECTION ONE THE ORIGINS OF NEW FOREST VALLEY MIRES

CHAPTER TWO: TESTING THEORIES OF PEAT INCEPTION IN THE NEW FOREST

2.1 Formulation of the problem

2.1.1 Definition of the system

Peatlands represent the interaction of biological and physical (hydrological) processes in the development of a 'landscape unit', through the build-up of organic matter. All too often, the standard model of peatland evolution is simple basin-filling (often termed "terrestrialisation"), even though a large proportion of the world's peatlands are attributable to other processes (Heinselman, 1975). The importance of hydrology in determining mire development and morphology is, however, well-recognised (Kulczynski, 1949; Gorham, 1957; Ingram, 1967; Bellamy, 1968; Ivanov, 1981). In most cases, the proximate cause of peat formation is waterlogging of the mineral substrate, since it is this which blocks the aerobic decomposition pathways and leads to sustained organic accumulation. The relationship between the biological and hydrological components of a wetland ecosystem is described, in the form of a feedback loop, by the conceptual model of Gosselink and Turner (1978), shown in Figure 2.1. In the case of mires, organic accumulation affects the hydrodynamic regime by raising the elevation of the mire surface and by changing the hydraulic conductivity of the substrate, which may block or direct earlier waterflows and change the rates of throughflow or overland flow (Ivanov, 1981). This simple model provides the framework within which the problem of mire initiation is to be investigated.

2.1.2 Methodological issues

Studies of peat formation have often been stimulated by the existence of large tracts of continental peatland and have led to a variety of mechanisms which may explain their origin (e.g. Kulczynski, 1949; Overbeck, 1975; Malmer, 1975; Sjors, 1976; Heinselman, 1975; Bellamy, 1972; Moore, 1975). However, many statements concerning peat inception are poorly defined with respect to the processes involved, and make little or

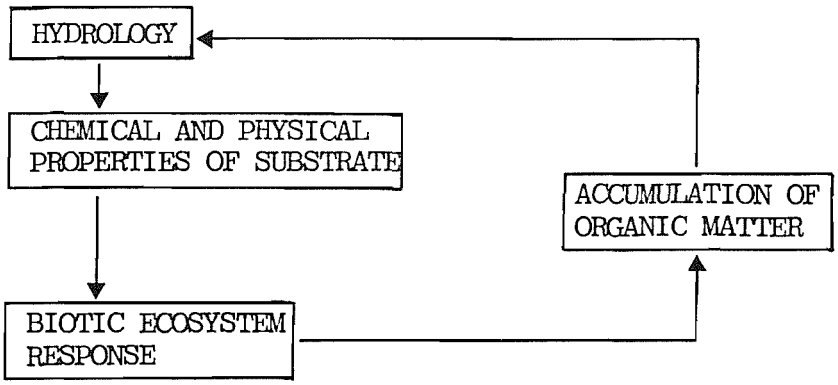


FIGURE 2.1 Conceptual model showing the role of hydrology in the development of wetland ecosystems (adapted from Gosselink and Turner, 1978)

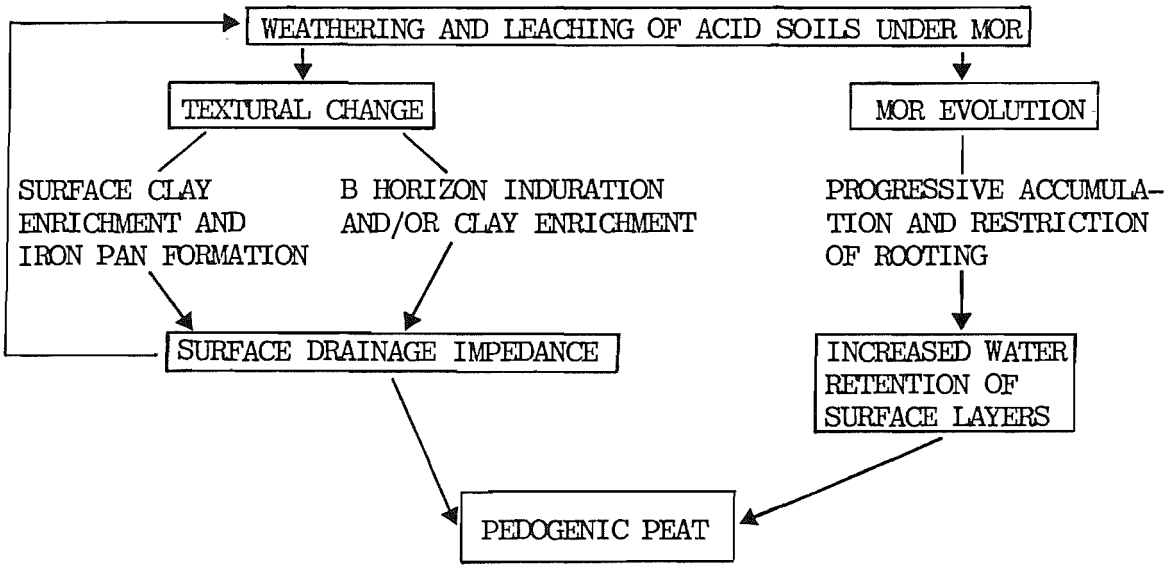


FIGURE 2.2 Model of pedogenic peat formation (after Taylor and Smith 1972, 1981)

no attempt to distinguish critically between alternative causal mechanisms of peat formation. The origin of a mire, and indeed any landform, is a difficult problem to study - it cannot be manipulated easily or experimented upon, and sampling is made complex by questions of spatial scale and time. The lack of discrimination in many studies of peatland origins has simply exacerbated the problem.

Given the range of possible causal mechanisms that have been proposed, there are two approaches to the study of mire origins. First, one may accept the possibility of equifinality. That is to say, the same type of mire (defined by its morphology) may arise from different initial conditions and in different ways. This is the logical conclusion implicit in much of the established peatland literature. However, equifinality does not provide any causal explanation of a landform's origin, since features only appear equifinal because they are defined by their form alone (Haines-Young and Petch, 1983). Definition solely in terms of morphology cannot provide scientific explanation (Popper, 1966). If the origin of a landform is to be explained, it must be defined from evidence of how it has functioned. The alternative is to adopt the method of multiple working hypotheses, i.e. the elimination of weaker or mistaken hypotheses by critically testing hypotheses against each other. This methodological framework of competing hypotheses is vital if the problem of mire origins is not to become intractable.

Haines-Young and Petch (1983) point out that two assumptions are necessary if questions of origin are to be pursued:

> "The assumptions concern the relationship between process (causal mechanisms) and landform (effect), and relate to the extent to which explanations of landscape features can be developed. The first assumption is that the operation of a process produces an effect which can be used as evidence that the process has taken place. The second assumption is that different processes produce different effects, and that these can be used as distinguishing criteria in order to determine which process, from a number of processes, has operated. Together, these two assumptions constitute the assertion that landforms contain evidence of how they were formed (or behave)." (*op. cit.* pp. 463-464).

In their conclusion, these authors comment further that

> "If two or more theories cannot be distinguished on the

> basis of the predictions they make about landform character then they are poor theories. To describe those features as 'equifinal' does not detract from this situation. Use of the term merely encourages the maintenance of those theories in an *ad hoc* and uncritical way. The aim.... should be to develop those theories so that they can be tested against each other (*op. cit.* pp. 465-466; added emphasis).

It is essential that the hypotheses are formulated rigorously in order to enable effective testing of each model of valley mire formation. Different authors vary in the hypotheses they recognise and the way in which they organise them. In this study the following scheme has been adopted for the various possible mechanisms of peat inception:

(i) Flush formation and nutrient loss ("paludification"),
(ii) Pedogenic peat formation,
(iii) Perturbation of catchment water balance,
(iv) Low hydrological competence mechanisms.

The next section will review these hypotheses from which a set of predictions are derived. By necessity, these represent a particular interpretation of the hypotheses for the reasons discussed here.

2.1.3 Review and formulation of hypotheses

2.1.3.1 Flush formation and nutrient loss ("paludification)

Ecologists in central and northern Europe and North America have attributed considerable importance to the phenomenon of "paludification", which is purported to explain the formation of "the larger part of the world area of peatland" (Sjors, 1976, p.22). The basic concept of paludification is the development of peat through the waterlogging of originally "less wet land" (Sjors, 1976, p.22), which usually would have been forest covered. However, the nature of the phenomenon varies according to the author, and the precise mechanism of paludification is not clear. In this context, the term paludification becomes dangerously empty and tautological. Despite criticising a modern English textbook for neglecting paludification, Sjors (1976) is far from explicit concerning its operation. Malmer (1975) expresses the Scandinavian viewpoint more cogently, but acknowledges that the reasons for paludification are not entirely clear. He stresses the importance of a depletion of mineral nutrients on flushed sites, thereby reducing productivity below the level required to maintain a forest ecosystem.

The large areas of North American peatlands, particularly in Minnesota, have led Heinselman (1970) to detail the development of these mires through paludification. Heinselman (1975) describes paludification, in contrast to Scandinavian workers, as resulting from an interruption - rather than a depletion - of Boreal forest nutrient cycles, coupled with the hydrologic characteristics of peat. On wet forest sites, humus recycling may be incomplete even after forest fire disturbances, and the sustained net accumulation of plant remains then begins the direct paludification of forest land. Rising water tables are facilitated by large decreases in the hydraulic conductivity of peat. In Minnesota, basal forest peats cover 48% of the peatland substrate which - one infers from Heinselman (1975) - were replaced because of the onset of anaerobic conditions rather than a threshold reduction in nutrient levels. There is no direct explanation of how initial waterlogging comes about but this is linked to macro-climatic change.

The concept of paludification essentially refers to land getting wetter as opposed to drier (compare with 'terrestrialisation' or basin-filling) - as such it is a descriptive term with little explanatory ability and does not refer to the processes underlying this phenomenon, so that its usefulness must be questioned. Paludification has been extended to the origin of British and Irish blanket mires (notably Osvald, 1949; Sjors, 1976 and Malmer, 1975), but workers within these countries place emphasis on processes which are not included in any strict definition of paludification. For these reasons, processes such as iron pan formation have not been amalgamated with the mechanisms most frequently referred to as "paludification" in this review. Paludification is regarded here as describing flush formation and nutrient loss in forested ecosystems only.

2.1.3.2 Pedogenic peat formation

In their investigations of blanket peat inception in upland Wales, Taylor and Smith (1972, 1981) stress the hydrological implications of soil horizon development. They invoke the hydrological changes associated with soil profile evolution as the specific cause of much of the area of these peatlands, which they term "pedogenic peat". In a sense, all peat

formed on a mineral surface (i.e. not over water) is 'pedogenic', but Taylor and Smith relate peat development directly to internal changes within the soil profile. This approach was based initially on the observation that iron pans and surface water gleying were frequently found in association with blanket peat deposits. Taylor and Smith propose a model which has two components resulting from the weathering and leaching of acid soils, in which peat development is a response to the combined effects of increasing surface drainage impedance and water retention by the organic surface horizon. The main elements of this model are shown in Figure 2.2, from which it can be seen that there is a close similarity in structure with Gosselink and Turner's (1978) description of wetland ecosystems (Figure 2.1). A less well-organised set of relationships affecting peat formation is given in their more recent paper (Taylor and Smith, 1981), which incorporates a variety of other possible causal mechanisms. This more generalised model has poor predictive value but the importance of peat formation as a function of soil profile development remains.

The role of profile evolution in the creation of surface waterlogging is well recognised by soil scientists (e.g. Thomasson and Bullock, 1975; Murphy, 1984 and Farmer *et al* 1984). The net accumulation of organic material is also regarded as an integral part of pedogenesis (Jenny, 1941; Duchafour 1982). Maltby and Crabtree (1976) adopt this approach in a contemporary and palaeoenvironmental investigation of blanket peat formation on Exmoor. This study is notable as one of the few examples where field observations have been used to test a predictive model of peat accumulation. Their findings emphasised the potential speed of pedogenesis and its effect on organic matter accumulation over a mineral soil.

There has been no specific investigation of the origins of valley mires in the New Forest, but several workers have suggested that surface waterlogging and peat development is due, at least in part, to subsurface impermeability of soil profiles (Rose, 1953; Newbould, 1960; Tubbs, 1968). Newbould (p.381) states "Bog formation in the gently sloping New Forest valleys is associated with surface drainage (caused either by humus or B-horizon impermeability), which becomes ponded back by peat formation or sometimes by a wedge of clay or other material". The evolution of

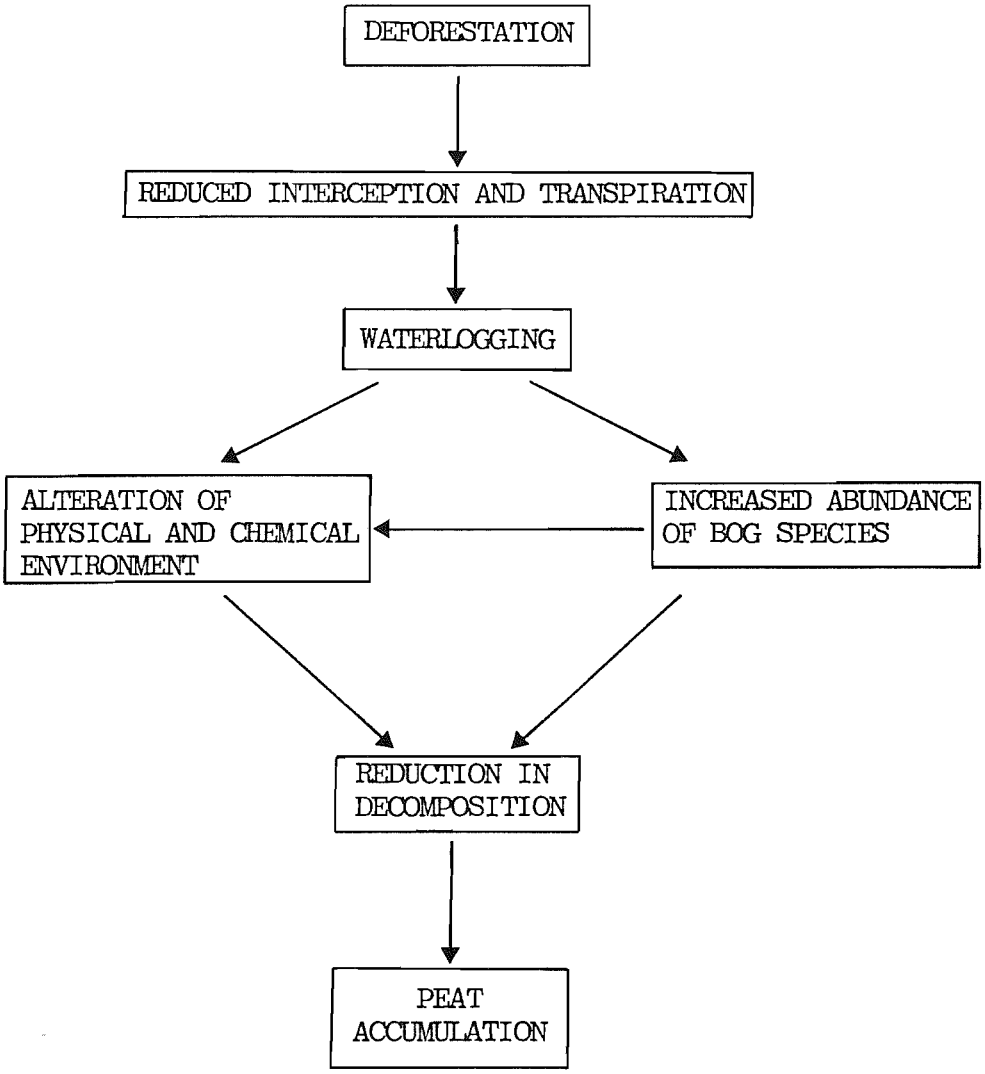


FIGURE 2.3 Model of peat formation through perturbation of catchment water balance by deforestation (adapted from Moore *et al*, 1984)

podzolic soils is seen as the most significant factor in the development of impermeability.

2.1.3.3 Perturbation of catchment water balance

An increase in the precipation/evaporation ratio could lead directly to the development of peat. This may have been an important factor, for example, in the widespread growth and expansion of mires towards the end of the Sub-Boreal period (see Simmons and Tooley (1981) for a review of this evidence). However, while the importance of macroclimate in providing the basic conditions for peat development has not been rejected, this simple climatic determinism is no longer regarded as sufficient (e.g. Taylor and Smith, 1972; Malmer, 1975; Moore, 1975). Individual sites show different responses to climatic change in such a way that any original relationship with climate is obscured - this is seen, for example, in the inception of blanket peat in S.Wales (Chambers, 1983; Moore *et al* 1984). These authors argue that the onset of peat development is best understood through hydrological changes associated with the activities of man and soil development. This approach reflects an emphasis on the proximate processes rather than the ultimate cause of peat inception.

Alteration of the hydrological balance may be achieved by a change in vegetation cover. Forest clearance by man has been widely proposed as the cause of subsequent peat formation (see reviews by Moore, 1975, 1979). The manner in which this mechanism is postulated to occur is shown in Figure 2.3. Newbould (1960, see also Rose, 1953) suggested that deforestation in the New Forest may have led to mire development not only through podzolisation, but also through increased run-off and waterlogging. In the only published investigation of lowland valley mire initiation, Moore and Wilmott (1976) propose such a mode of origin for the Thursley Common mire complex. They point to the correlation between the start of peat growth and clearance events, and to the presence of wood and charcoal in the basal peat deposits, concluding that deforestation would have led to a greatly increased water supply.

2.1.3.4 Low competence mechanisms

Used in the fluvial sense, competence is the ability of a river to erode,

i.e. the power of a river measured in terms of the size of particle it is able to transport. Bellamy (1972) emphasises the importance of basin hydrology and states that "any surface feature which reduces the competence of the water body to a level where sediments are no longer carried by traction, can constitute a template for peat formation" (*op. cit.* p.8). Bellamy uses the term in a very wide sense - competence is normally used only in relation to defined channels. His definition essentially states that peat formation can take place anywhere erosion is not occurring, and as such is too generalised to be useful. In this investigation, the concept will be restricted to open channels in the valley bottom.

Low competence may be brought about by several mechanisms. Firstly, by the creation of abandoned palaeochannels such as meander cut-offs. Secondly, supposedly through the achievement of "grade" (now an outmoded concept) as suggested by Newbould (1960) for the New Forest. Alternatively, low competence may be brought about by damming the channel. Either by debris dams (see Gurnell and Gregory, 1984; Gregory *et al*, 1985), or due to the activity of beavers. Rapidly expanding populations of the North American beaver (*Castor canadensis*), recovering from persecution, have been found to exert a pervasive effect on stream ecosystems (Naiman *et al*, 1986). The main impact is on channel geometry and a massive retention of sediments results from dam construction. Coles and Orme (1982) show some remarkable toothmark evidence in support of the influence of the beaver (*C.fiber*) on drainage patterns in the Somerset Levels during the Neolithic. Finally, Hudson (1957) has proposed that periglacial activity may have resulted in soliflucted clay plugging the stream at Fort Bog. It should be noted that, in the sense of Bellamy (1972), low competence is often just describing the process of basin-filling (or "terrestrialisation") and that even in the restricted sense used here the process involves the infilling of small pools in addition to the waterlogging of adjacent land.

2.2 A test of the hypotheses

2.2.1 A set of predictions from the competing hypotheses

From the various potential mechanisms discussed above, a set of predictions has been derived that may be tested with data collected from the New

Table 2.1 A set of predictions from the hypotheses reviewed (see text)

HYPOTHESIS	PREDICTIONS
Flush formation and nutrient loss ('paludification')	Basal wood peat (50% of area approx.)
Pedogenic peat formation	Iron pans Surface gley horizons
Perturbation of catchment water balance	Basal wood and charcoal Correlation with clearance events indicated by pollen analysis
Low competence mechanisms	Fine sediment/still water environments
Palaeochannels	Channel morphometry. Fluvial allocthonous sediments
Rivers at 'grade'	Long profile evidence. Fining upwards sediment sequences
Soliflucted clay plugs	Sedimentary characteristics and distribution
Debris/Beaver Dams	Basal wood peat Sedimentary evidence of still water environments (Toothmarks)

Forest mires (Table 2.1). Mutually exclusive predictions which can be feasibly tested are difficult to obtain from the various hypotheses which have been proposed - the predictions must concern stratigraphic and profile features which can be sampled in the present day. The set of predictions is, of necessity, a particular interpretation of the hypotheses since few of the authors make explicit predictions for the models of peat inception they propose.

The evidence has been drawn from a field survey programme designed to test the predictions and concentrating on basal and sub-peat stratigraphy. Additional data is provided by peat stratigraphic records from another ten sites, detailed macrofossil analyses, radiocarbon dates, and existing information on basal pollen assemblages and stratigraphy. These lines of evidence will be described first and then drawn together in a review of the hypotheses and prediction set.

2.2.2 Stratigraphic survey methods

A stratigraphic survey of nine mires was carried out, involving cross-sectional survey and supplemented by more detailed sedimentary analysis from one site (Stephill Bottom). Sites were selected in order to achieve a representative sample of the variation encountered. Stratigraphic sampling was carried out by coring. A 5 x 50cm Russian-type borer was used wherever possible, but the nature of the sediments frequently prevented its use and most samples were obtained with a 4 x 20cm Mackintosh auger modified to fit the Russian extension rods. Coring was hampered by the widespread occurrence of gravel, which imposed a considerable time constraint, so that cross-sections were generally restricted to one per site. Considerable care was taken, therefore, in positioning sections in order to obtain the most useful information, and was based on air photo survey, geological data, morphology and field inspection. Each section was levelled and all core points were related to an arbitrary datum. Core sampling points were stratified in relation to vegetation, landscape features such as breaks of slope, and to the rate of change in the samples obtained. Cores were continued until gravel or liquified material prevented sampling, or until the underlying parent rock had been penetrated (or where uniform deposits at depth were encountered in the cases where drift and parent lithologies could not be

reliably separated). Core samples were described in the field on the basis of colour, texture and handling consistency, and stone quantity and type (Ball, 1976). Basal peat layers were assigned to coarse categories required to test the predictions in Table 2.1. Troels-Smith (1955) symbols were used where appropriate to depict sub-peat stratigraphy.

2.2.3 Stratigraphic survey results

Site 1 - Hincheslea Bog This site occurs in an area of low relief in the south-west of the Forest. The mire occurs within a shallow valley between two spurs of a dissected Plateau Gravel terrace, and is surrounded by heathland and bracken communities although woodland occurs on outliers of the Headon Beds along the ridges of the two spurs. The section was located at SU 272 004, approximately mid-way along the mire, and is shown in Figure 2.4. A complex series of sediments was encountered in the valley and the stratigraphic data are presented in Table 2.2. Typical ground water gley soils (for terminology see Avery, 1980) occurred in the valley bottom overlain by 50cm of principally herbaceous rootlet peat. The mire has developed over poorly-sorted and varied infill sediments, beneath which Barton Sand was penetrated (although it was not clear whether this, too, had been reworked due to the presence of stones). However, it was possible to distinguish an assemblage of sediments which was repeated across much of the mire and also in cores taken 100m up-and downstream of the section. This is shown within the heavy box in Table 2.2, and comprises a series of mixed sediments which become coarser with depth beneath the peat. A sand and gravel layer at 1m depth proved highly resistant to augering and was only penetrated at one point (borehole 5) to reveal Barton Sand below. The fining upwards sequence of sediments suggests an environment of declining energy levels. However, the base of this assemblage (the sand-gravel deposit at 1m) was found to have the same gradient as the present surface, both showing a fall of 83cm over 200m, and the sediment sequence might be explained by a change in sediment supply within the valley. Boreholes (1 and 7) on the valley sides revealed complex soils formed in extensive drift deposits over Barton Sand. The drift or Head material is probably derived from the Plateau Gravels and Headon Beds, as well as reworked Barton Sand. Although these soils had podzolic E horizons close to the surface, both had gleyed clayey horizons

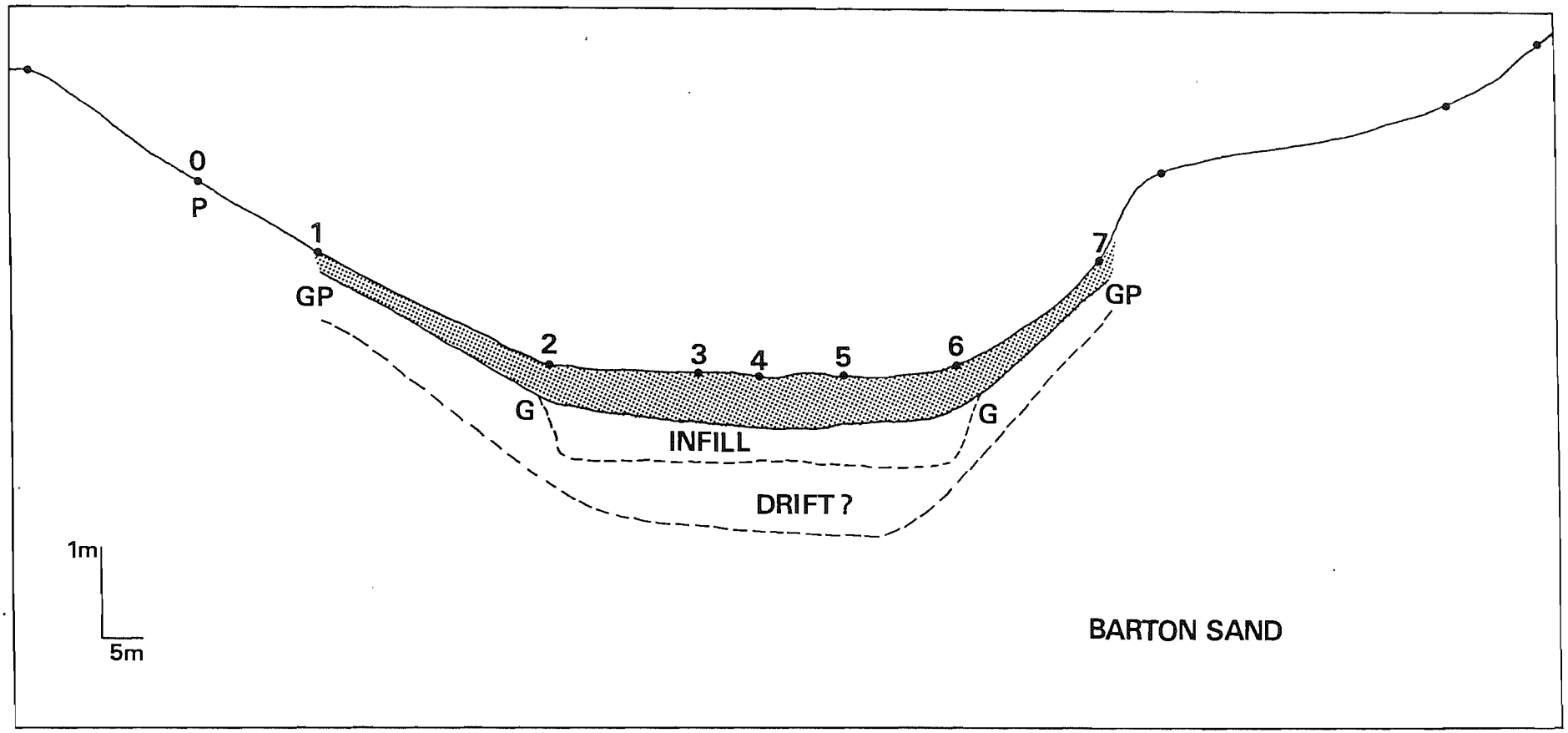


FIGURE 2.4 : Hincheslea Bog section. For numbered boreholes see text and table 2.2.
P = Humoferric podzol GP = Gley-podzol G = Groundwater gley.

Table 2.2 Hincheslea Borehole Data (see Figure 2.4 and text)

Depth (cm)	VALLEY SIDE	VALLEY BOTTOM					VALLEY SIDE
	1	2	3	4	5	6	7
0–10	Dark brown humose sandy clay loam	Loamy peat	Humified herbaceous rootlet peat	Herbaceous rootlet peat	Herbaceous rootlet peat with occasional *Phragmites* rhizomes near base	Rootlet peat	Dark brown humose sand
10–20	Grey sandy clay loam						Grey sand
20–30	Mottled sandy clay loam						Grey stony loamy sand, with bleached grains
30–40	Mottled clay loam						
40–50	Dark grey, slightly stony sandy loam	Grey humose sand					
50–60		Grey stony sandy clay with frequent orange mottles	Dark grey, sandy clay	Humose black silty clay	Humose black, slightly stony silty clay	Humose black silty clay	Grey sandy clay loam with frequent orange mottles
60–70	Grey, stony loamy coarse sand with abundant orange mottles						Grey sandy clay with abundant orange mottles
70–80		Grey stony sand		Dark grey sandy clay	Dark grey sandy clay	Dark grey sandy clay	
80–90	Grey stony sand with frequent orange mottles		Blue-grey stony sandy clay	Grey loamy sand	Grey loamy sand	Grey loamy sand	Grey sandy loam
90–100	Compact grey sand	Grey sand		Grey stony coarse sand	Grey stony coarse sand	Grey stony coarse sand	
100–110			Stopped by gravel	Stopped by gravel	Grey very stony laomy sand	Stopped by gravel	Compact grey loamy sand
110–120		Compact orange sandy clay					
120–130					Grey sand		
130–140		Grey sand					Grey stony sand
140–150							

Table 2.2 (continued) Hincheslea Borehole Data (see Figure 2.4 and text)

	VALLEY SIDE	VALLEY BOTTOM					VALLEY SIDE
	1	2	3	4	5	6	7
160							
170							
180							
190		Orange stony sand			Orange coarse sand		
200							
210							
220							

BARROW MOOR SECTION: ^{14}C SITE

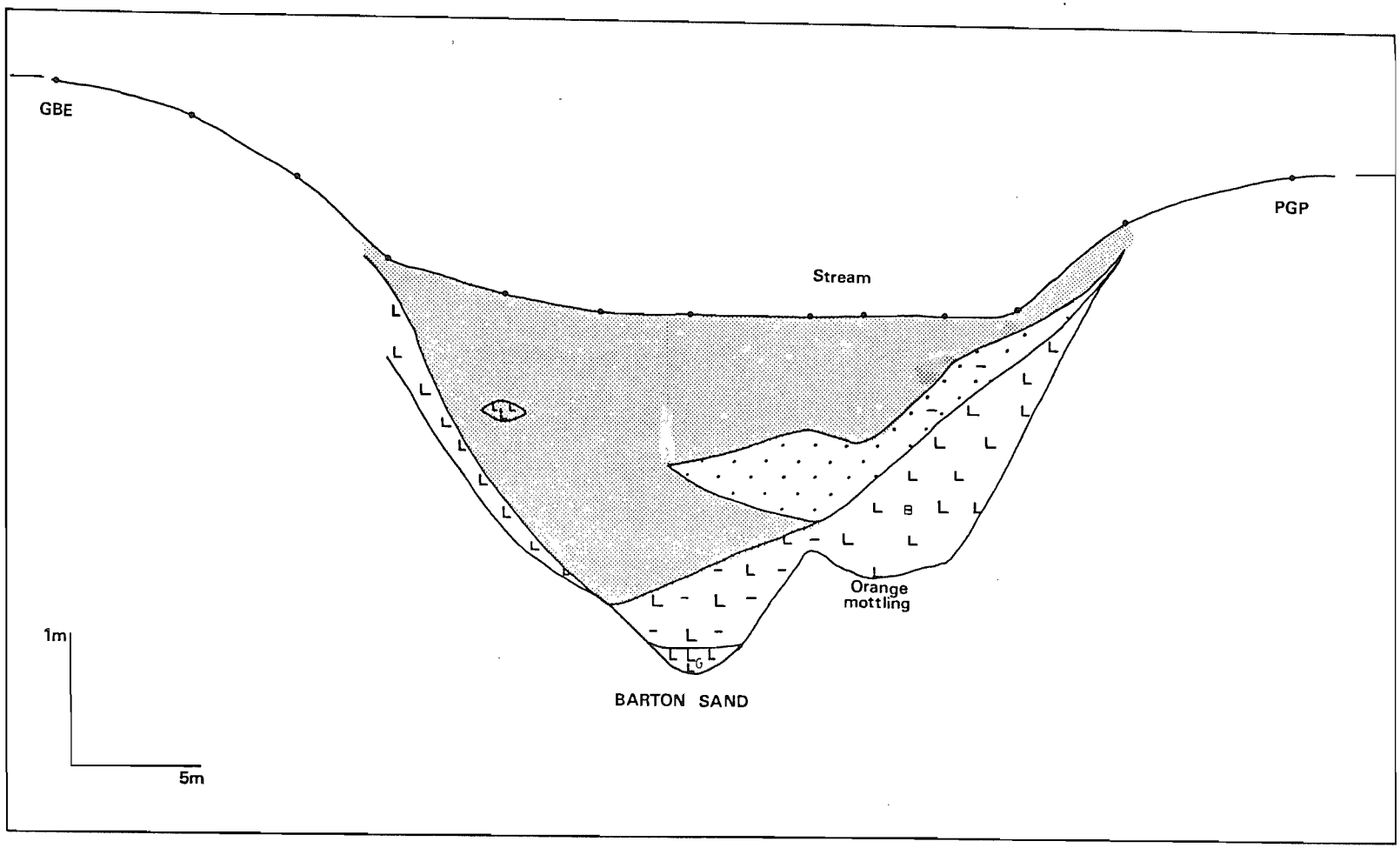


FIGURE 2.5 : PGP = Peaty (humic) gley-podzol GBE = Gleyic brown earth.

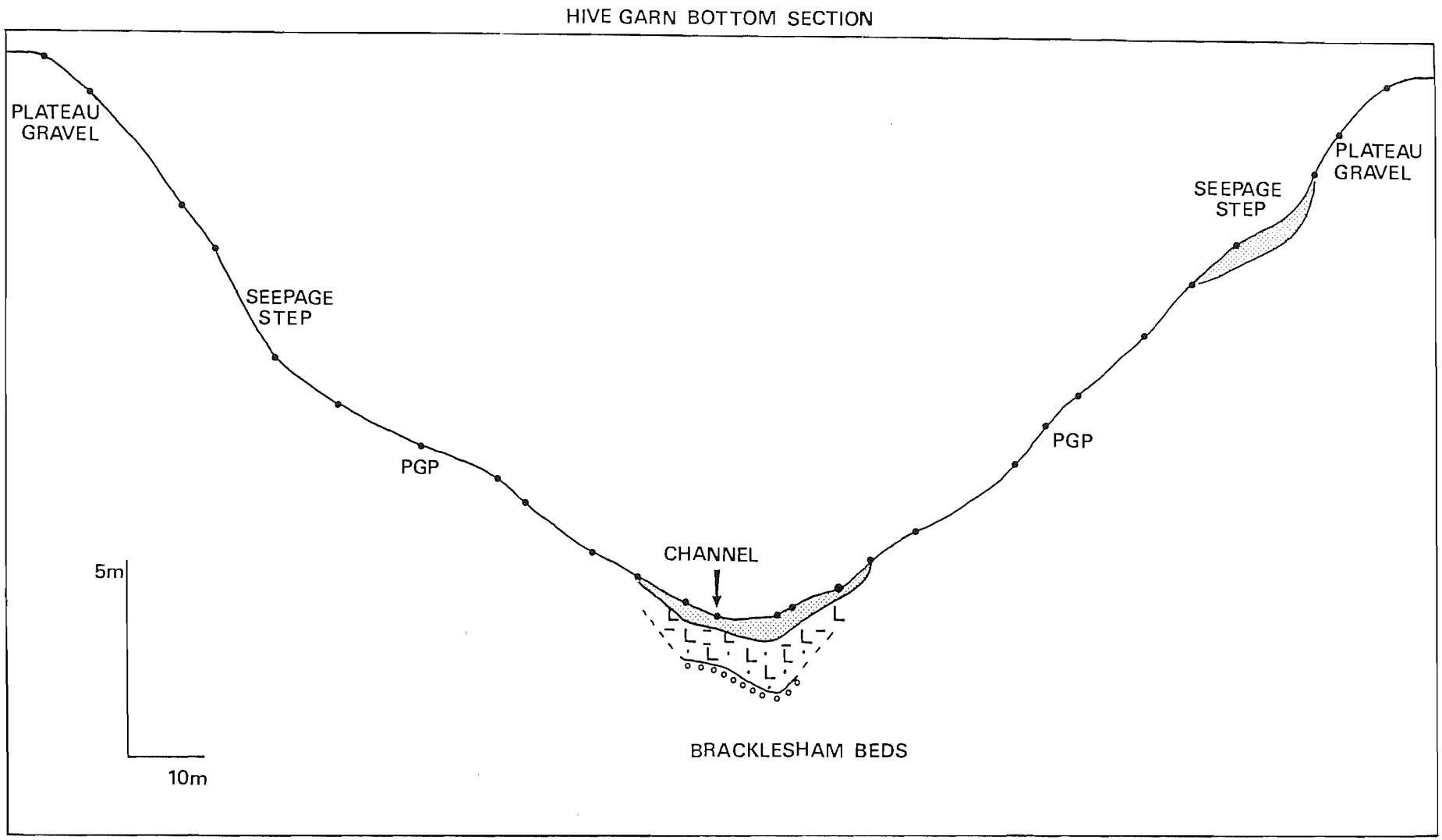


FIGURE 2.6 : PGP = Peaty stagnogley podzol.

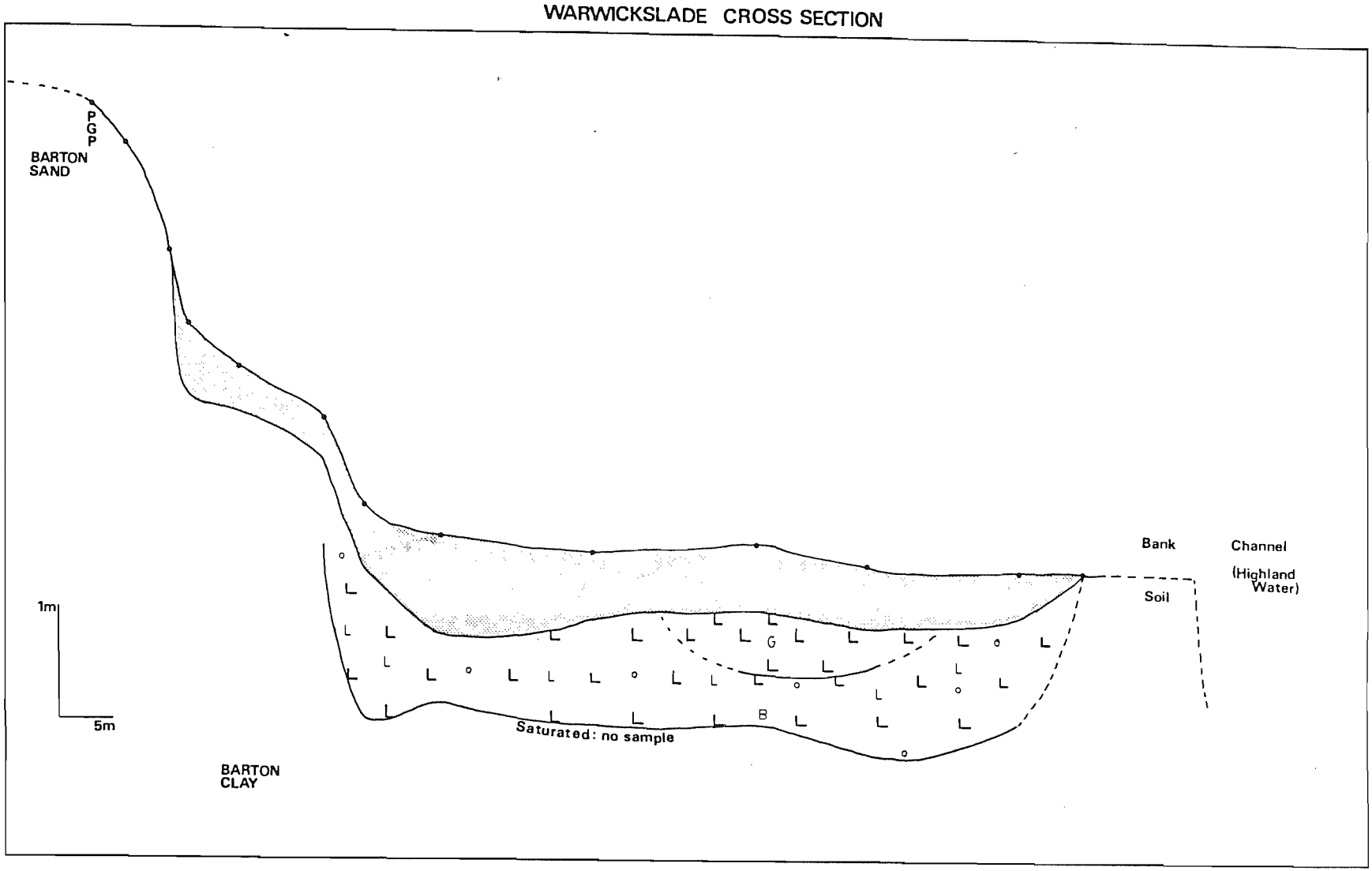


FIGURE 2.7 : PGP = Peaty (humic) gley-podzol.

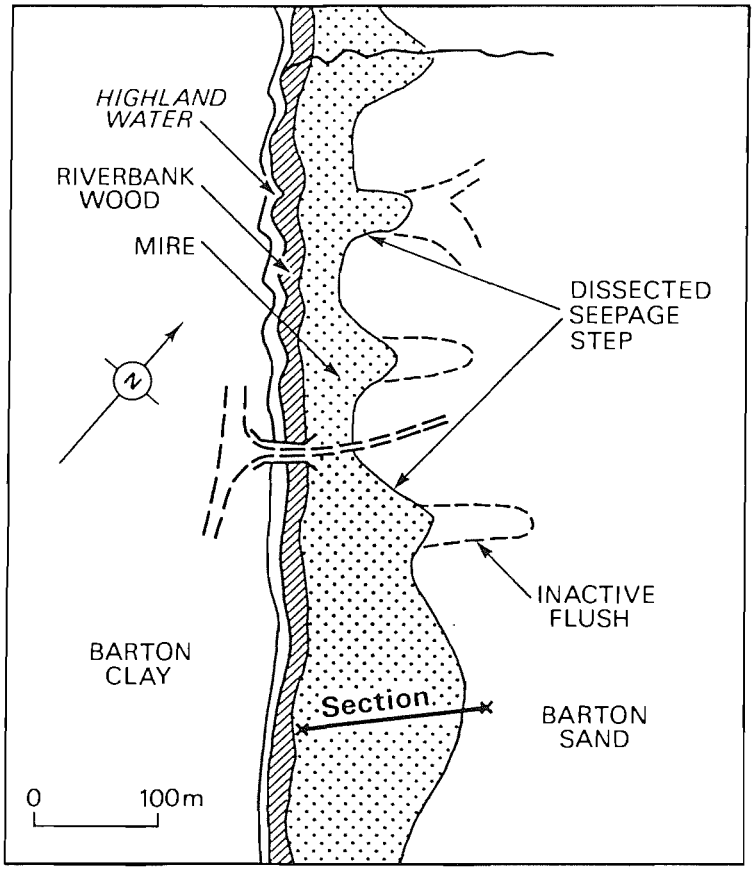


FIGURE 2.8 : Warwickslade seepage step (mapped from aerial photographs).

between 20 and 70cm with mottled horizons above. The brown coloured horizons, indicative of organic staining, suggest some degree of lateral water movement in the upper soil layers.

Site 2 - Barrow Moor This section (Figure 2.5) was located at the same site (SU247078) as Dawson's (1978) study, for which a radiocarbon date of 1455 $\pm$ 50 BP was obtained from a sample of peat between 1.4 and 1.6m depth (see Appendix 2). This gives a probable basal date for the mire of 1800-2200 BP. The narrow valley is flanked to the south-west by ancient deciduous woodland and by a more recent *Pinus sylvestris* plantation to the north-east. The valley sides comprised a gleyic, or stagnogleyic, brown earth supporting *Vaccinium myrtillus* and *Pteridium* beneath *Fagus sylvatica* (SW) and a gley-podzol with a thick humose surface horizon under *Pinus* (NE). The mire section itself was dominated by *Sphagnum recurvum* and *Juncus acutiflorus*, flanked by *Alnus glutinosa* and *Salix cinerea*. This was one of two sites in the survey where wood remains were at all common, and these were widely distributed throughout the peat deposits in the section. The inorganic valley sediments appear to have been deposited by colluviation.

Site 3 - Hive Garn Bottom This is a typical mire system from the north-west of the Forest, displaying seepage step and valley bottom mires with a complex distribution of humid and wet heath on the valley sides (Figure 2.6). The valley is steep-sided and the long profile of the valley bottom exceeds 5° (1 in 12) in places. The valley head was actively eroding during the winter of 1981/1982, but has subsequently been stabilised by *Pteridium*. Macrofossil analysis has been carried out on cores from the valley bottom and seepage step (Chapter 5) and this site was used for a detailed investigation of soil-vegetation relationships in collaboration with R.H.Allen, formerly of the Soil Survey (see Chapter 6). Wood remains (other than those derived from ericaceous shrubs) are absent from this mire complex - the basal plant assemblages will be considered in a later section (2.2.5). The peat in the valley bottom is underlain by a humose clay loam which becomes very stony with depth. The valleyside soils contain slowly permeable sub-surface horizons due to colluvial drift deposits (Clarke & Allen, 1986).

Site 4 - Warwickslade There is a complex situation at Warwickslade

(Figure 2.7) where an area of mire is maintained beneath a seepage step along the springline of the Barton Sand - Barton Clay junction, situated above the channel of the Highland Water. The peat is underlain by a very stony, clay loam which becomes liquified with depth, preventing further sampling. The probable date for the origin of the peat at this site is in the early Flandrian, before 8600 BP, based on palynological data (Barber, in prep.; see also Barber & Clarke, 1987) and radiocarbon dating (Appendix 2). It is possible that the mire has developed within a palaeochannel, but evidence from this investigation suggests that retreat of the seepage step may be the more important factor. There is no stratigraphic evidence for a well-defined palaeochannel, and mapping from corrected aerial photographs shows a dissected seepage step with inactive flush zones now in woodland (Figure 2.8).

Site 5 - Stephill Bottom A general feature of New Forest valley mires is that they are underlain by infill, which may form substantial deposits. At Stephill Bottom (Figure 2.9), the shallow valley is infilled to almost half its depth with chaotic and poorly-sorted material. These materials contain a large proportion of silt and clay and are very impermeable. This site was used for a more detailed analysis of sediments (see next section) and macrofossil analysis (see Chapter 5). From radiocarbon dating (see Appendix 2) it is estimated that peat accumulation began at approximately 3100 BP. It is interesting to note that the asymmetric sub-surface cross-sectional profile has been preserved beneath the infill. Small lenses of sediment containing organic remains were found within blue-grey clay infill material at 90-100cm (40cm below the base of the peat) and also at 200-240cm (140cm below the peat) in a core some 70m downstream of the section. The poor preservation of the material recovered prevented detailed analysis, but the following material was identified from the sample at 200-240cm.

Reproductive remains:	*Alnus glutinosa* - 2 fruits *Carex echinata* - 2 fruits *Carex* (undet) - 2 fruits *Potamogeton* (undet - 1 fruit)
Vegetative remains:	*Alnus* wood - forming the bulk of the sample *Calluna* - stem fragments *Erica tetralix* - stem fragments

A second section (Figure 2.11) was located near Stephill Bottom in a river

STEPHILL BOTTOM SECTION

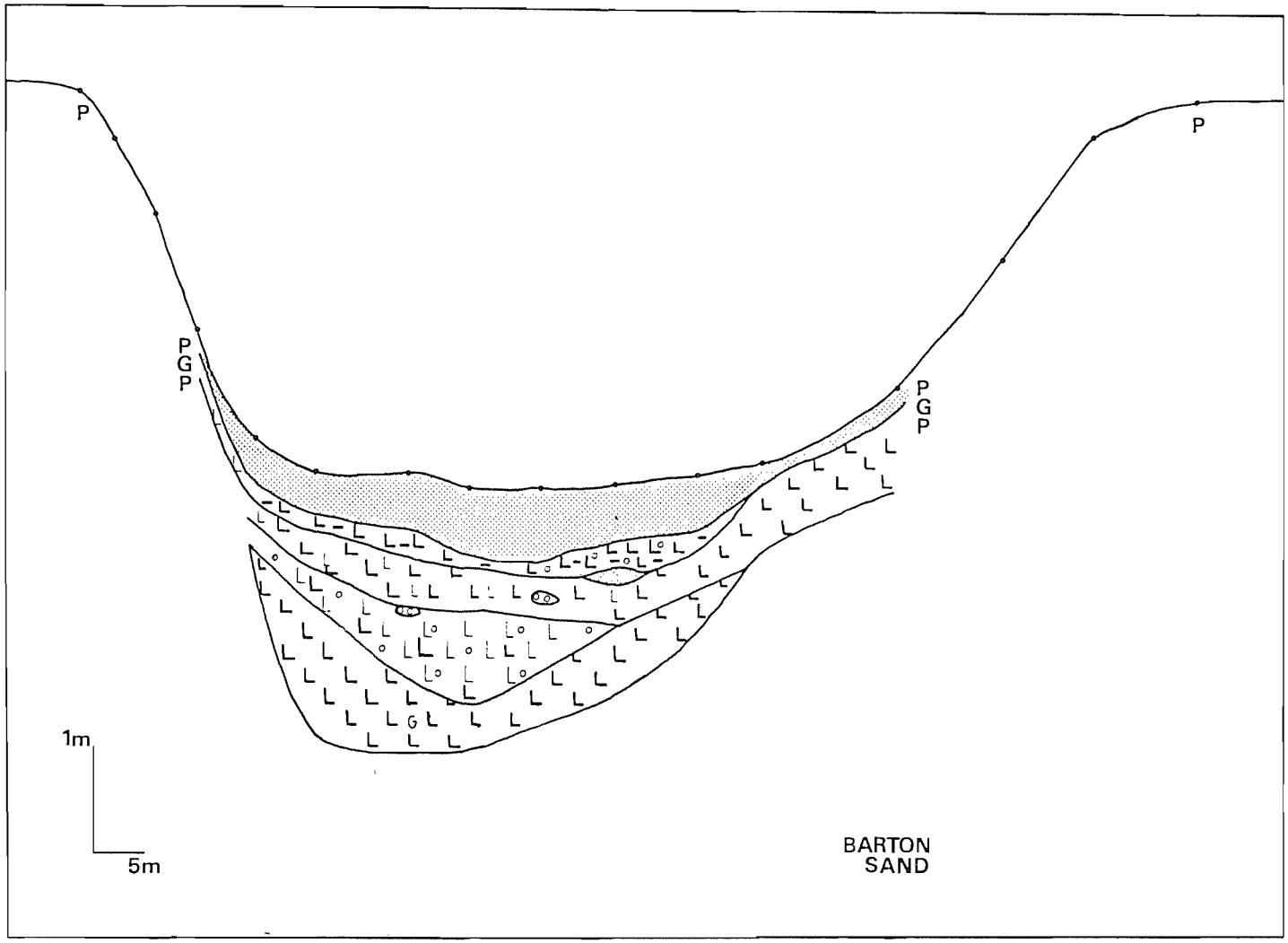


FIGURE 2.9 : P = Humo-ferric podzol PGP = Peaty (humic) gley-podzol.

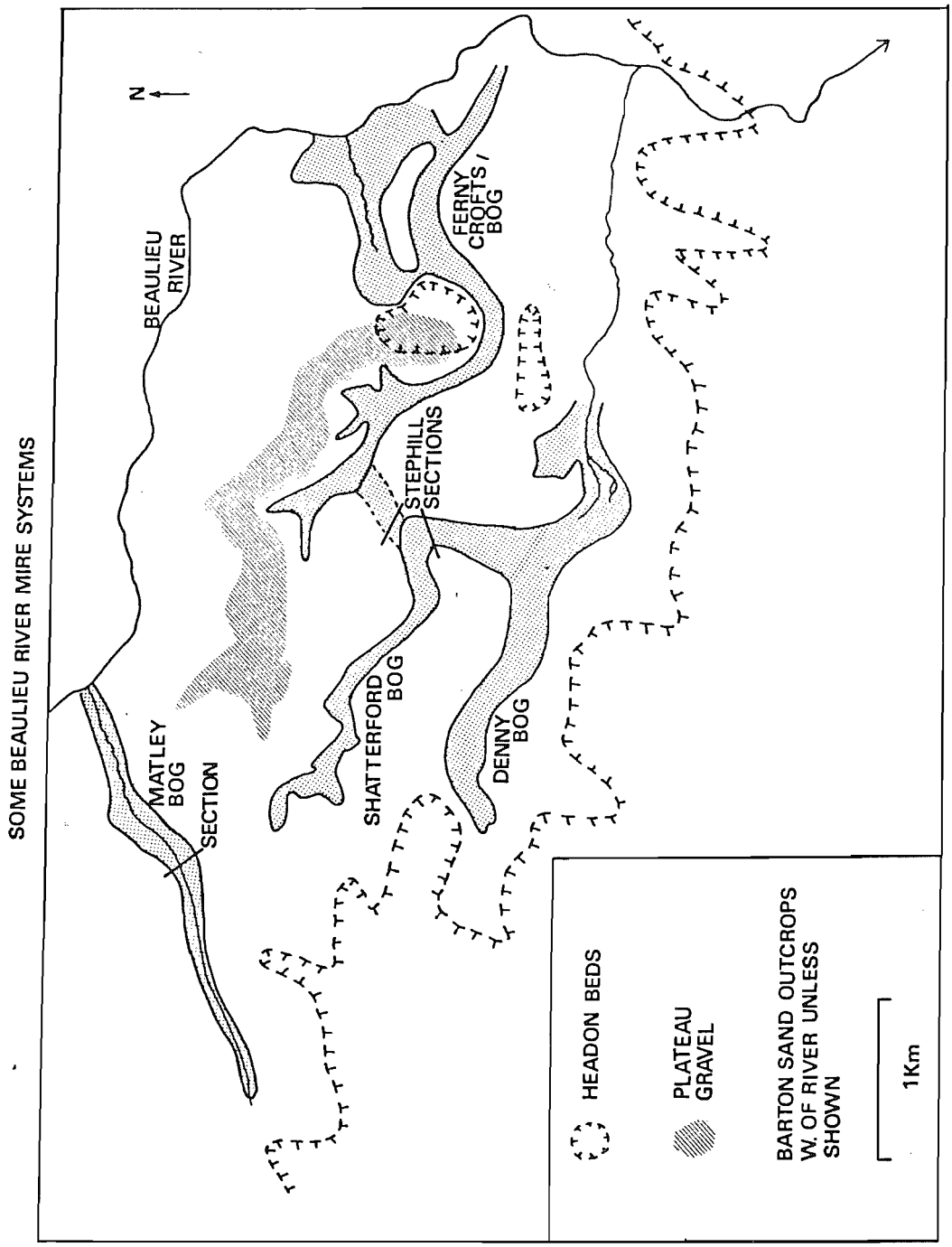

SOME BEAULIEU RIVER MIRE SYSTEMS
N
BEAULIEU RIVER
MATLEY BOG
SECTION
SHATTERFORD BOG
STEPHILL SECTIONS
FERNY CROFTS / BOG
DENNY BOG
HEADON BEDS
PLATEAU GRAVEL
BARTON SAND OUTCROPS W. OF RIVER UNLESS SHOWN
1Km

FIGURE 2.10

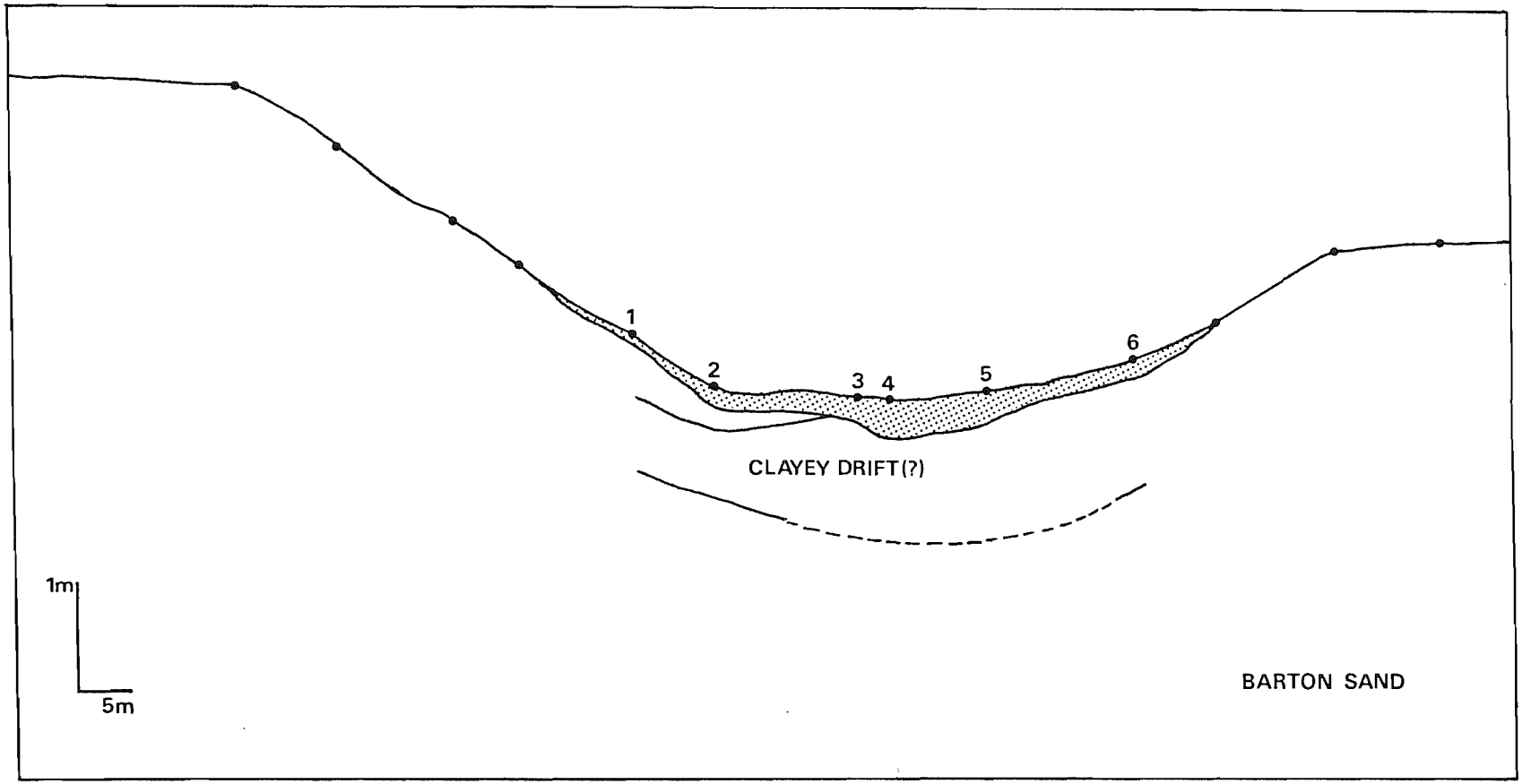


FIGURE 2.11 : Stephill River Capture section. For numbered boreholes see text and Table 2.3.

Table 2.3 Stephill river capture borehole data (see Figure 2.11 and text)

Depth (cm)	1	2	3	4	5	6
0	Humified loamy peat	Humified peat	Humified peat	Loamy humidified peat	Humified peat	Humified loamy peat
10						
20		Humose loamy sand				Brown clay
30	Yellow-ochre, stony loamy sand	Dark grey loamy sand	Humose black stony clay		Brown stony clay	Grey loamy sand with orange mottles
40	Orange sandy loam with grey mottling	Grey sandy clay with orange mottles	Liquid black, stony clay	Grey stony sandy clay with orange mottles	Grey stony sandy clay with orange mottles	
50	Orange stony sandy clay with frequent grey mottles		Orange, stony sandy clay with frequent grey mottles			
60					Grey stony sandy clay with orange mottles	Grey sandy clay with abundant orange mottles
70	Slightly liquid yellow-brown sandy clay with occasional grey mottles	Grey stony sandy clay with frequent orange mottles				
80		Grey stony clay with frequent orange mottles				
90	Orange stony sandy clay					
100		Grey stony sand				Grey stony sandy clay with abundant orange mottles
110		Orange loamy sand				
120	Grey sandy loam					Grey-green stony loamy sand
130	Grey stony sand					
140	Orange-brown sandy loam					
150	Brown loamy sand					

MATLEY BOG SECTION

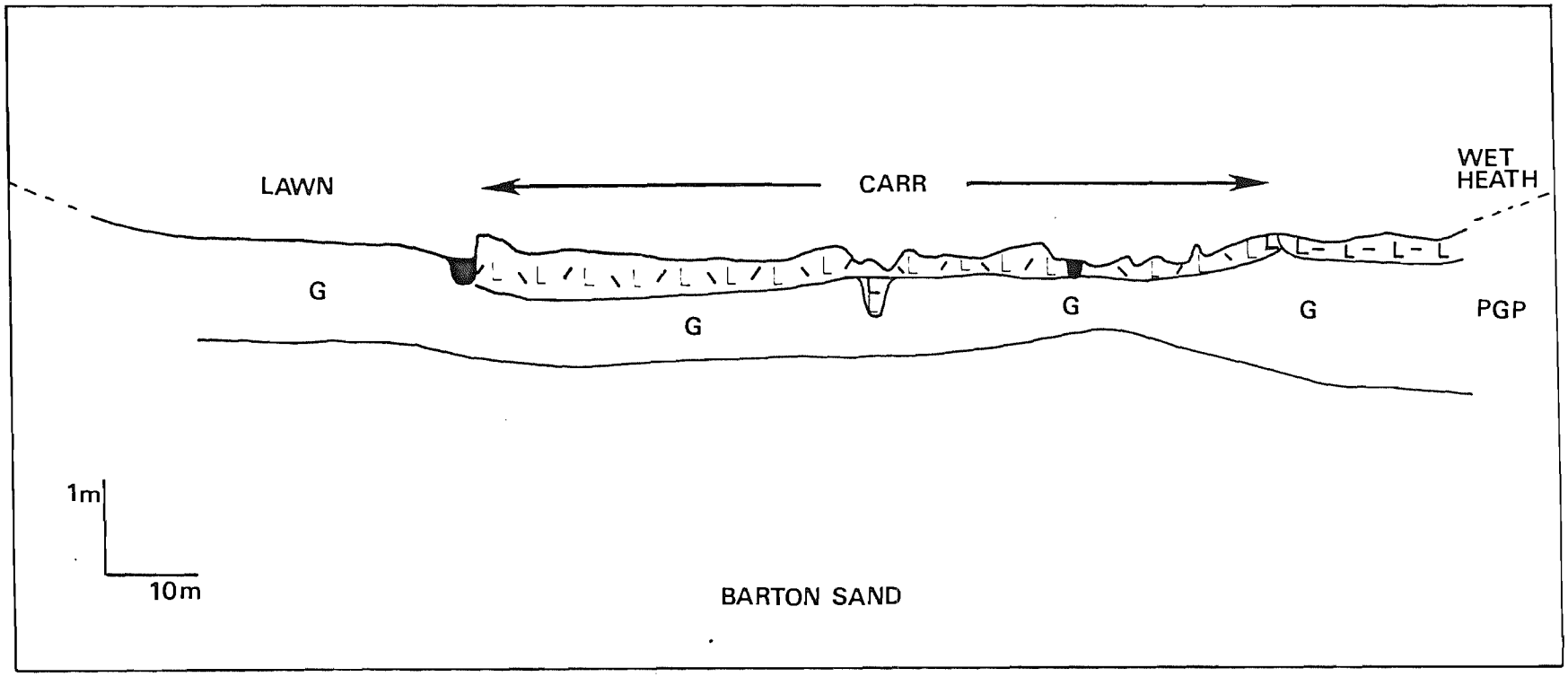


FIGURE 2.12 : PGP = Peaty (humic) gley-podzol. G = Alluvial groundwater gley. Lower line denotes limit of sampling due to gravel.

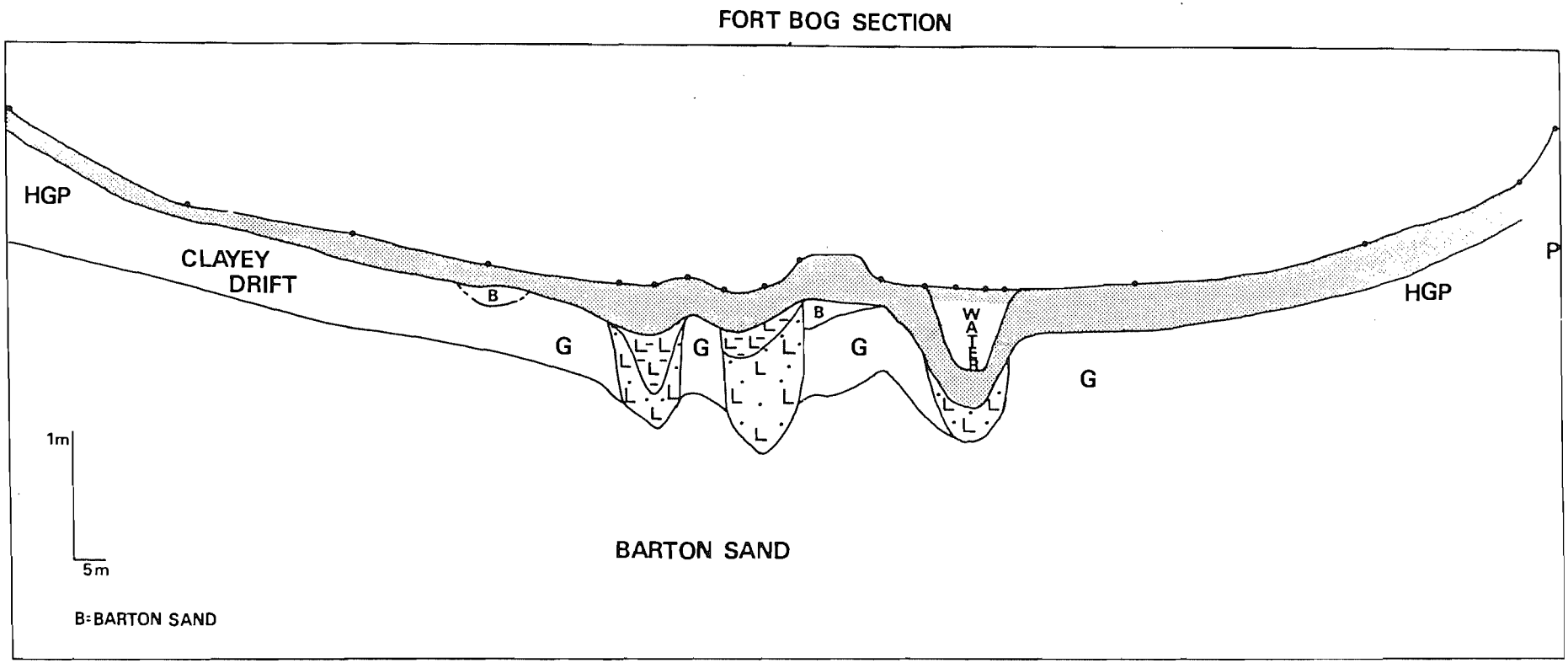


FIGURE 2.13 : P = Humo-ferric podzol HGP = Humic gley-podzol G = Argillic gley.

capture zone identified by Lewin (1966). There is only an emphemeral drainage network in this zone and well-developed soils extend across the valley floor. The valley bottom contains thick drift deposits dominated by sandy clays with frequent gravel, presumably derived from the Barton Sand and Plateau Gravel which is present nearby in small relict patches (see Tremlett, 1961). The soils are humic groundwater gleys with peaty topsoils passing directly into mottled mainly sandy clay which becomes stony with depth (Table 2.3).

Site 6 - Matley Bog This section was located across the alder carr which dominates much of this site (Figures 2.10 and 2.12). At this point, the mire has developed only limited peat deposits which comprise well humified silty peats with abundant wood fragments and a crumby soil structure. The soils are groundwater gleys developed in weakly bedded clay or silty clay alluvium. This has increasing gravel content from 50-100cm which limited sampling much beyond 100-120cm. A charcoal band below a 15cm surface layer of peaty clay was found in one borehole.

Site 7 - Fort Bog This section (Figure 2.13) was located downstream of the central alder carr at this site (at SU335085). The mire occurs within a shallow tributary flush of the Beaulieu River and is one of a series of mires which flank Longwater Lawn. The eastern side of the mire shows a gradation from classic humo-ferric podzols (Shirrel Heath series) on the valley side into gleyed Barton Sand in the valley bottom. The waterlogging is probably due mainly to the groundwater table but locally slowly-permeable horizons between 35 and 60cm may impede surface water drainage. On the west side a layer of brown sandy clay drift with occasional gravel and passing to Barton Sand within 80-110cm was found. This had developed argillic gley or stagnogley soils. Three small channels of unknown age were encountered, infilled with blue-grey sandy clay. These sediments yielded macrofossil remains after prolonged disaggregation treatment, as follows:

Sample 1: Reproductive remains: *Rhynchospora alba* - 1 seed
Vegetative remains : *Rhynchospora alba* - roots) forming bulk,
Myrica gale - roots) c90% of sample
Sphagnum papillosum - 1 branch with leaves
Betula (undet) - wood fragments

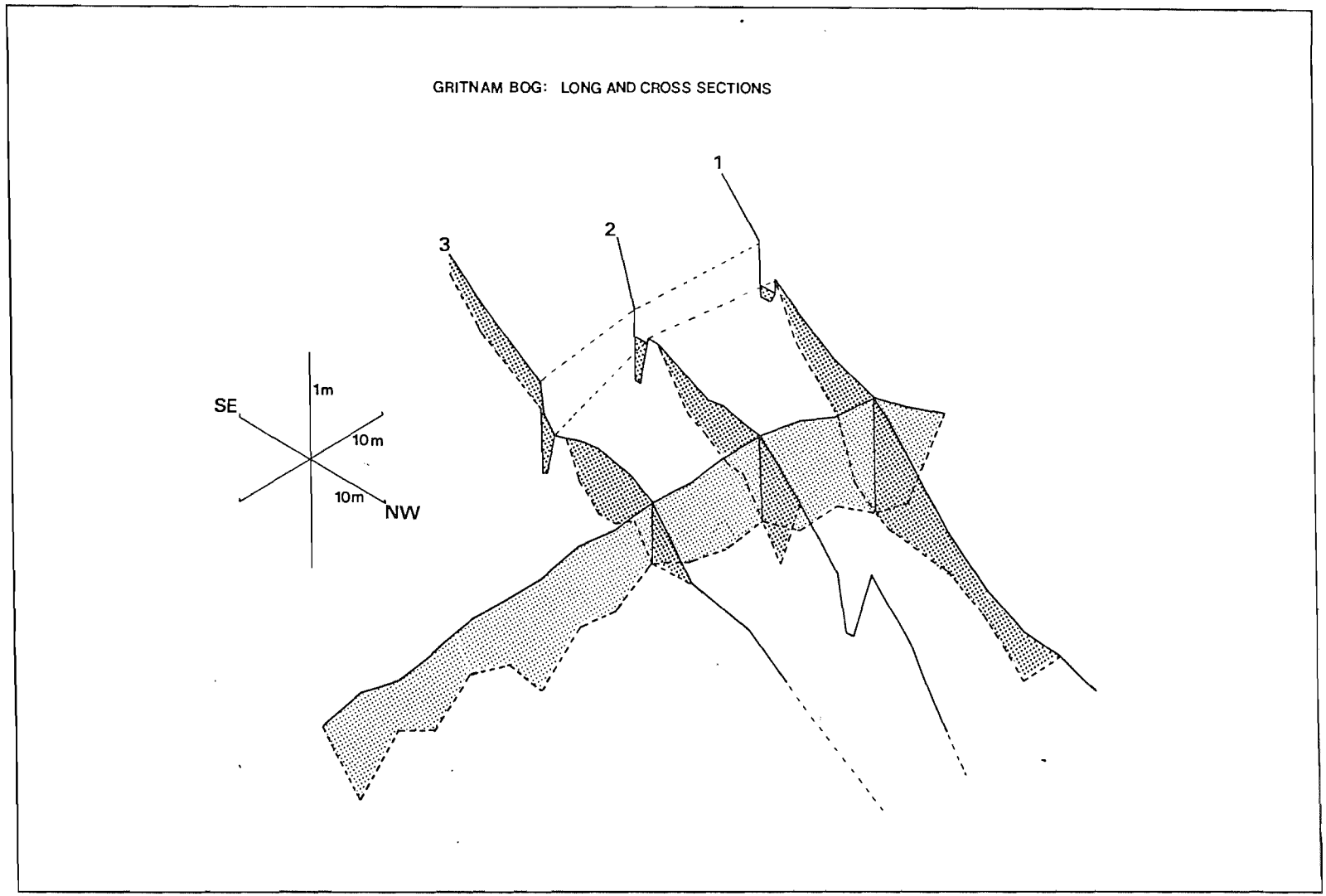


FIGURE 2.14 : For stratigraphy see text and Table 2.4, peat deposits are shown stippled.

Table 2.4 Stratigraphic data from boreholes along three cross-sectional transects of Gritnam Bog

Table 2.4a

GRITNAM BOG
TRANSECT -

7.5m :	0.40cm	Monocot rootlet peat ($Th^2 Sh^2$)
	40-60cm	Humified monocot rootlet peat with some wood fragments, increasing clay content from 50-60cm ($Th^1 Sh^2 Ag^1 Dl^+$)
	60-80cm	Loamy sand with fine angular gravel and rootlets ($Gs^2 Ga^1 As^1 Gg^+ Sh^+ Th^+$)
	80-100cm	Stiff blue-grey clay with some rootlets ($Al^4 Th^+$)
10m :	0-40cm	Fibrous monocot rootlet peat ($Th^3 Sh^1 Tb^+$)
	40-90cm	Loamy monocot rootlet peat with some wood fragments and fine angular gravel ($Th^1 Sh^2 Ag^1 Dl^+$)
	90-115cm	Black loamy clay with some humified monocot rootlet remains ($Al^2 Gs^1 Ga^1 Th^+$)
	115cm	Sharp junction into blue-grey liquified clayey soil ($Gs^2 Ga^1 As^1$)
15m :	0-65cm	Fibrous monocot rootlet pest becoming compact toward base ($Th^3 Sh^1 Th^+$)
	65-80cm	Loamy humified rootlet peat with fine-medium angular gravel ($Th^1 Sh^1 Ga^1 Gs^1 Gg^+$), grading into grey-black silty sand at base ($Gs^2 Ga^1 Sh^1$)
25m :	0-25cm	Fibrous rootlet peat ($Th^2 Sh^2$)
	25-50cm	Grey clay with fine-medium angular gravel ($As^4 Gg\ Gs^+$)

Table 2.4b

GRITNAM BOG
TRANSECT 2

2.5m :	0–25cm	*Sphagnum* peat ($Tb^2 Th^1 Sh^1$)
	25–40cm	Loamy rootlet peat ($Ga^1 Ag^1 Th^1 Sh^1 Tb^+$)
	40–50cm	Liquified rootlet peat ($Th^2 Sh^1 Ga^+$), firm at 50cm but no sample
5m :	0–25cm	*Sphagnum* peat ($Tb^2 Sh^2$)
	25–35cm	Sandy monocot rootlet peat ($Th^2 Sh^1 Gs^1 Ga^+$)
	35–40cm	Liquified grey sand ($Gs^3 Ga^1 Sh^+$)
	40–50cm	Grey sandy clay with some monocot (Molinia?) rootlets ($Ag^3 Gs^1 Th^+$)
10m :	0–35cm	Fibrous *Sphagnum* and monocot rootlet peat ($Th^2 Tb^2 Sh^+$)
	35–40cm	Clayey peat similar to above ($Ag^2 Th^1 Tb^1 Sh^+$)
	40–50cm	Liquified sandy clay with monocot rootlets ($Ag^3 Gs^1 Th^+$).
12.5m	0–60cm	Firm *Molinia*-dominated rootlet peat becoming compact 45–60cm ($Th^3 Sh^1 Tb^+$)
	60–70cm	Liquified grey sand ($Gs^3 Ga^1 Sh^+$)
	70–80cm	Grey clay containing wood and monocot roots ($Ag^3 Tl^1 Th^+$)
	80–100cm	Stiff blue-grey clay (Ag^4)
15m :	0–10cm	Unhumified *Sphagnum* and monocot peat ($Tb^3 Th^1$)
	10–75cm	Monocot rootlet peat ($Th^2 Sh^2 Tb^+$), becoming less consolidated between 50–75cm
	75–85cm	Liquified sand with monocot rootlets ($Gs^3 Ga^1 Th^+$)
	85–100cm	Stiff blue-grey clay with fine angular gravel and sparse woody roots ($Ag^3 Gs^1 Gg^+ Tl^+$)

Table 2.4c

GRITNAM BOG
TRANSECT 3

2.5m :	0–25cm	Unconsolidated *Sphagnum* peat ($Tb^2 Th^1 Sh^1$)
	25–50cm	Clay loam with some monocot rootlet remains ($Ag^2 Ga^1 Gs^1 Th^+$)
5m :	0–30cm	Quaking *Sphagnum* mat ($Tb^3 Th^1 Sh^+$)
	30–50cm	Highly liquified sand ($Gs^3 Ga^1$) becoming firm at base but no sample
7.5m :		As 5m borehole
10m	0–10cm	Unconsolidated rootlet peat – no sample
	10–40cm	*Molinia*-dominated rootlet peat ($Th^2 Sh^2 Dh^+$)
	40–55cm	Poorly consolidated loamy clay ($Ag^2 Ga^1 Gs^1$) becoming stiff towards base
12.5m :	0–20cm	Humose loamy clay ($Ag^2 Gs^1 Sh^1$)
	20–30cm	Stiff brown-grey clay (Ag^4)

Sample 2:	Reproductive remains:	*Menyanthes trifoliata* - 1 seed
	Vegetative remains :	*Rhynchospora alba* - roots and stems
		Myrica gale - roots
Sample 3:	Reproductive remains:	*Rumex cf acetosa* - 1 perianth fruit segment
	Vegetative remains :	*Myrica gale* - roots (c25% of sample)
		Monocotyledon roots (c60% of sample)
		Calluna vulgaris - flowers and branches
		Sphagnum (undet) - corroded leaf

Site 8 Gritnam Bog This is a small valley side seepage mire at the junction of the Plateau Gravels and Headon Beds (boundaries are uncertain), at SU284067, which was investigated at an early stage in the study in conjunction with the England Field Unit survey. Long and cross sections from this site are shown in Figure 2.14 and stratigraphic borehole data for the three cross sections are given in Table 2.4. The mire has a quaking, schwingmor-like surface in places, developed over liquid sediments, and the three-dimensional effect in Figure 2.14 shows the slightly 'bulged' profile of this mire, which is a feature of many valleyside, spring-line mires in the New Forest.

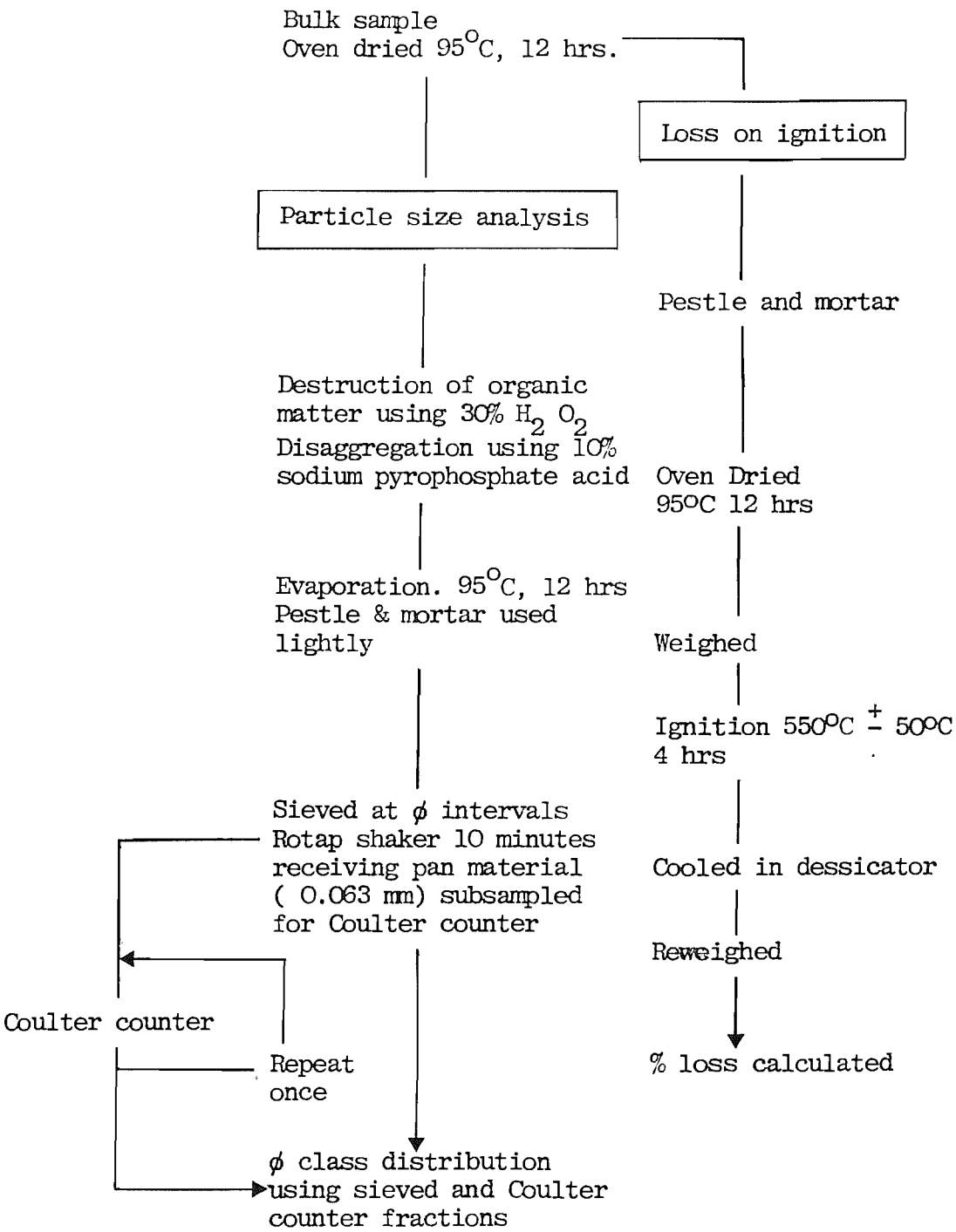
2.2.4 Detailed site study

One site was selected for more detailed study, including a series of soil pits, particle size analysis and loss-on-ignition analysis. This was carried out in order to quantify textural changes, to characterise the infill sediments underlying the peat, and to determine the amount of organic material in basal layers.

This enabled the peat deposits to be related more closely to soil processes. Stephill Bottom was chosen as the appropriate site and is typical of a large number of mires occurring in the Beaulieu River tributary system. It also represents the simplest geological situation in the New Forest since it lies in an area of uniform Barton Sand (Tremlett, 1961); so that geological variation is, to a certain extent, controlled for at this site.

Since the processes operating on either side of the mire are essentially symmetrical, only one half of the section was investigated. Seven sample points were selected along the steeper western half of the section and, wherever possible, soil pits were dug in order to obtain samples.

Figure 2.15 Flow-chart for sedimentary analysis procedures



Description of each profile was carried out before sampling for particle size analysis, in the manner described by Hodgson (1978). The required sample size (or weight) for particle size analysis is equivocal (e.g. Bascomb and Bullock, 1974 and Head 1980), so the upper figures given by Head (1980) were adopted in order to ensure an unbiased sample. Where it was impossible to dig a pit due to the water level, multiple cores were taken using a 5 x 50cm Russian corer.

Particle size analysis was carried out using the twin techniques of dry sieving for material from 32mm to 0.063mm and a coulter counter for finer material, 0.063mm to 0.005mm. Initial preparation included the addition of hydrogen peroxide in order to destroy organic matter (Bascomb, 1974) and the addition of sodium pyrophosphate to prevent clay aggregation. Dry sieving was carried out according to BS1377: 1975, using nested sieves of one ϕ interval and a Rotap shaker. Material retained in the receiving pan was subsampled for coulter counter analysis. The coulter counter (model TA11) measures particle size by disturbance of an electrical field, full details are given by Prowse (1980). A one tube test was carried out using a 280 aperture tube, which records on 13 channels from 0.063mm (4ϕ) to 0.005mm (7ϕ). Two replicates of all samples were carried out in the coulter counter to ensure consistency of results. Phi class intervals were calculated from the output and were fitted to the partical size distributions.

A small amount of the original sample material was retained for loss-on-ignition analysis. The optimum sample size is again difficult to determine - small quantities introduce problems of bias due to small-scale variability, whereas larger quantities may prevent complete combustion because of insulation effects. The quantity adopted was 1.5g, on the basis of a study by Brown (1983) on the effects of sample size or combustion. Combustion was carried out at 550°C to prevent loss of bound water from hydrated clay particles. A flow chart of these procedures is shown in Figure 2.15.

The results from particle size analysis (Figs. 2.16-22) can be treated in two groups, related to the Barton Sand and the valley infill. The

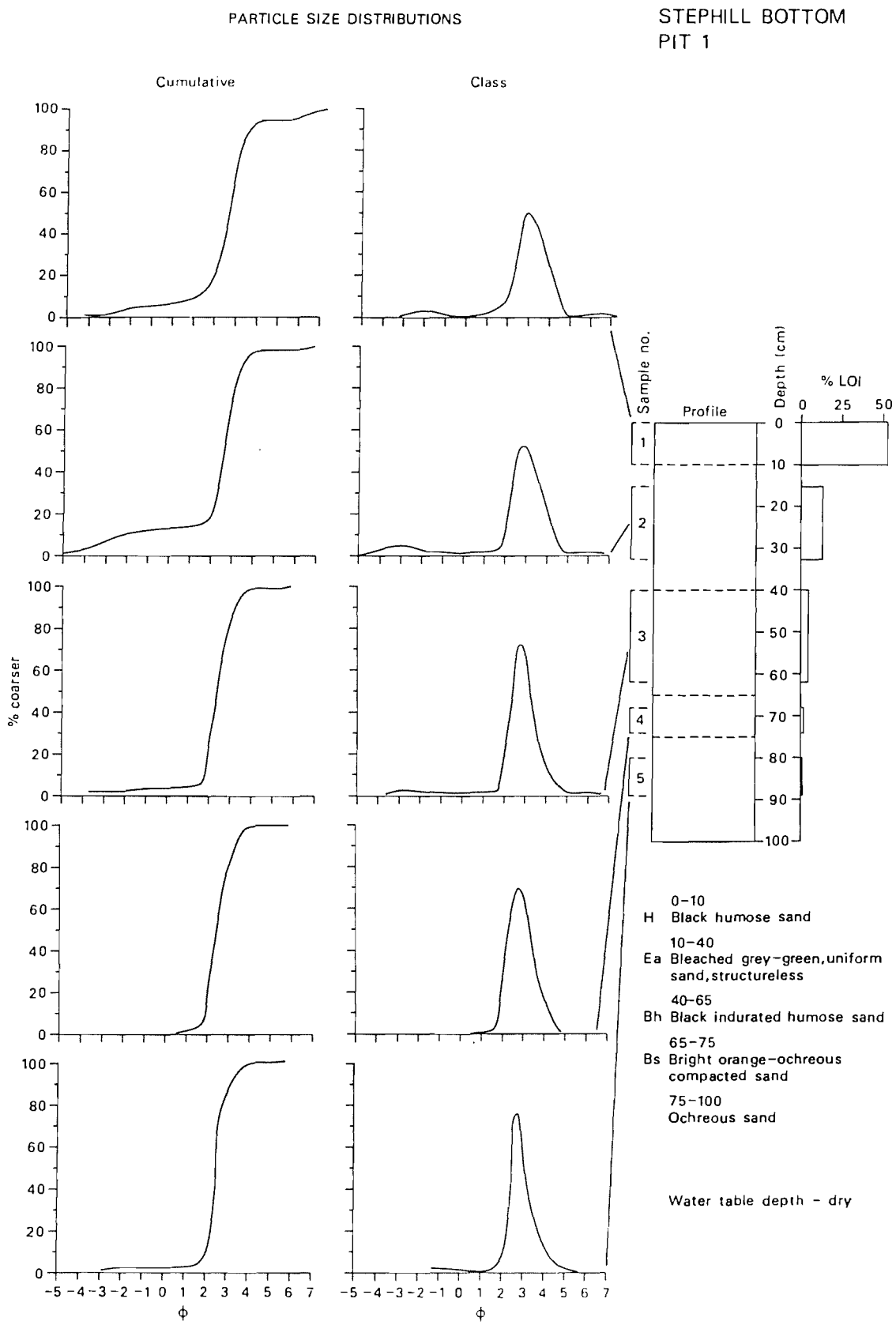


FIGURE 2.16 : Soil and sediment data from Stephill Bottom.

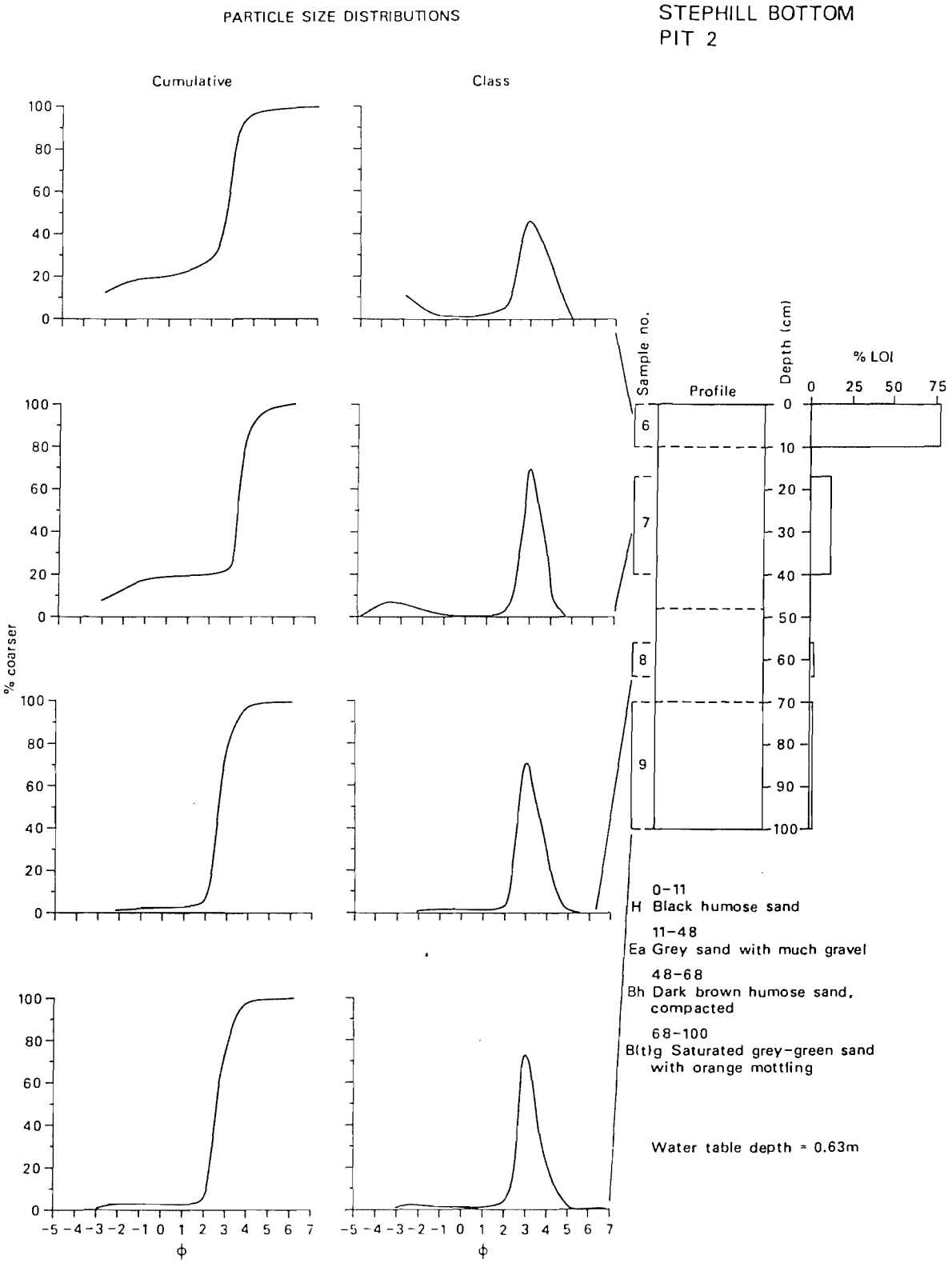


FIGURE 2.17 : Soil and sediment data from Stephill Bottom.

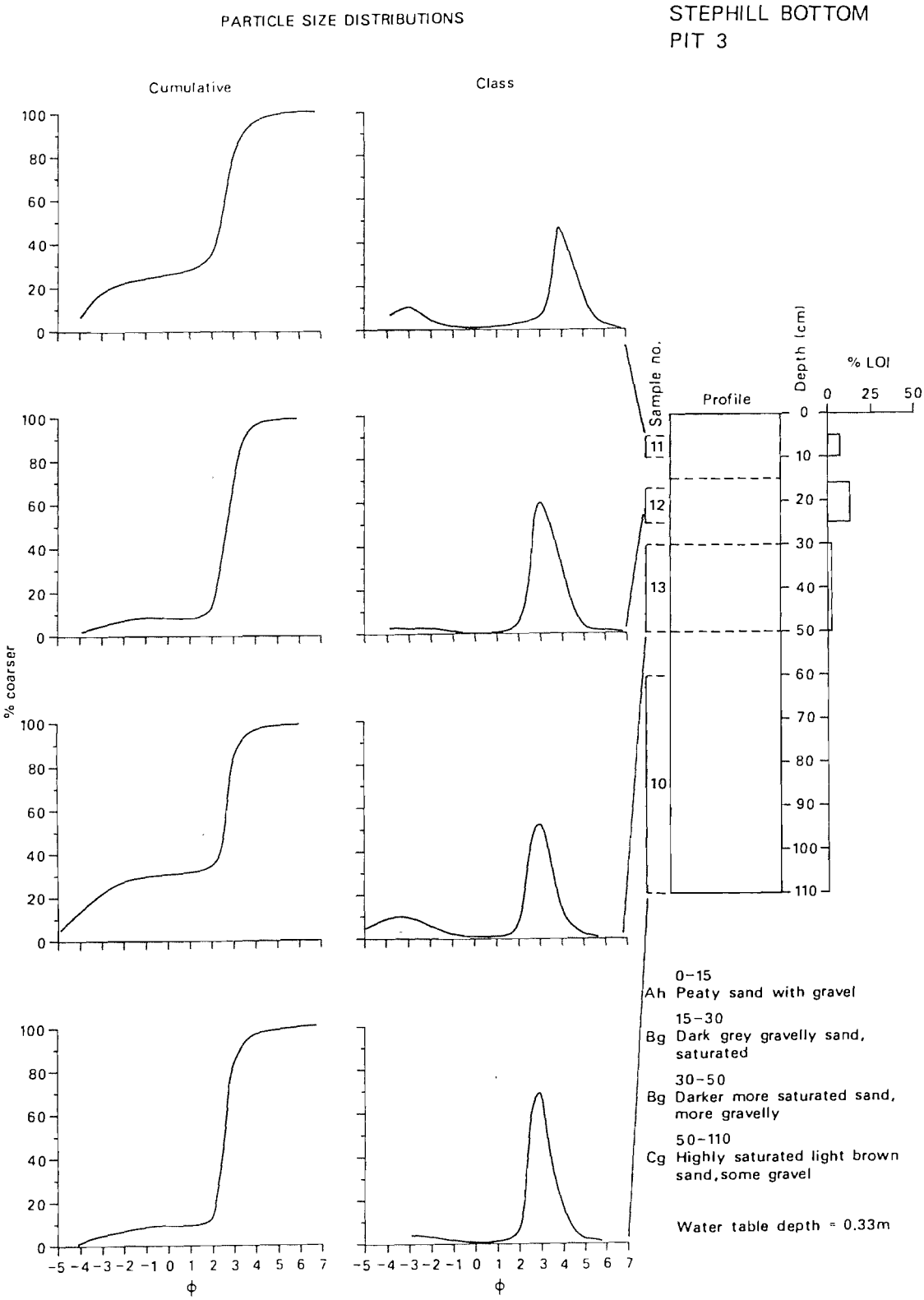


FIGURE 2.18 : Soil and sediment data from Stephill Bottom.

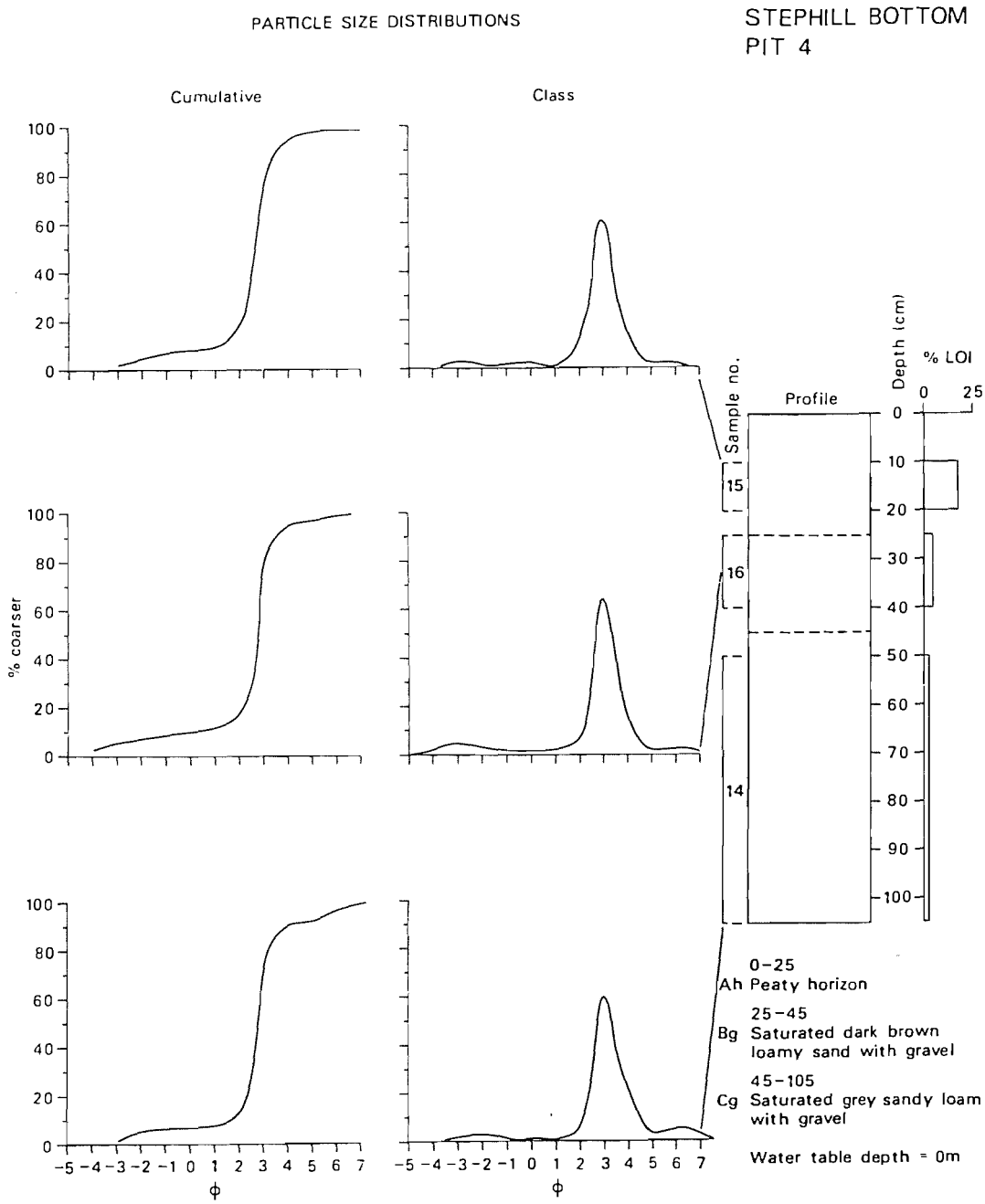


FIGURE 2.19 : Soil and sediment data from Stephill Bottom.

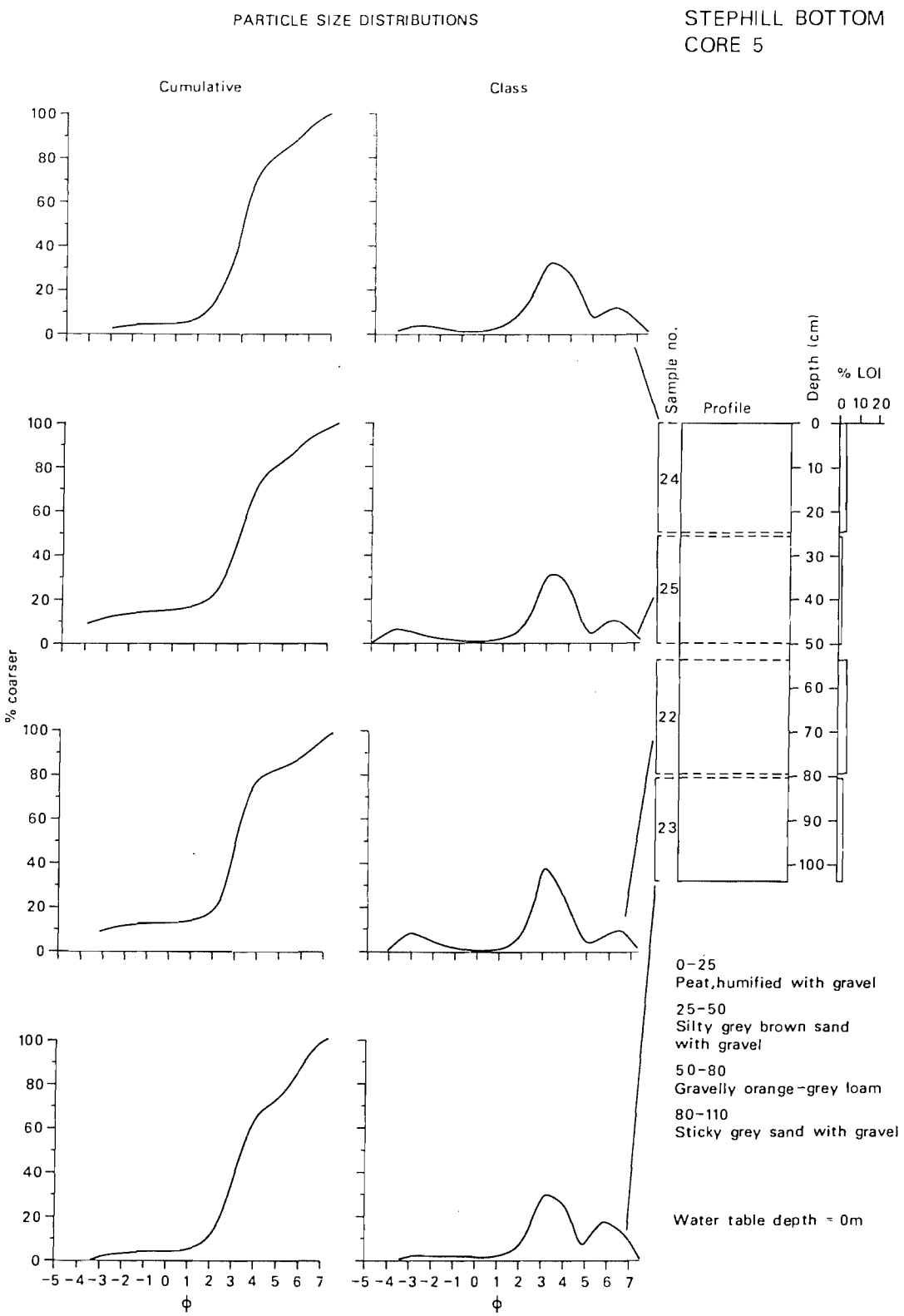


FIGURE 2.20 : Soil and sediment data from Stephill Bottom.

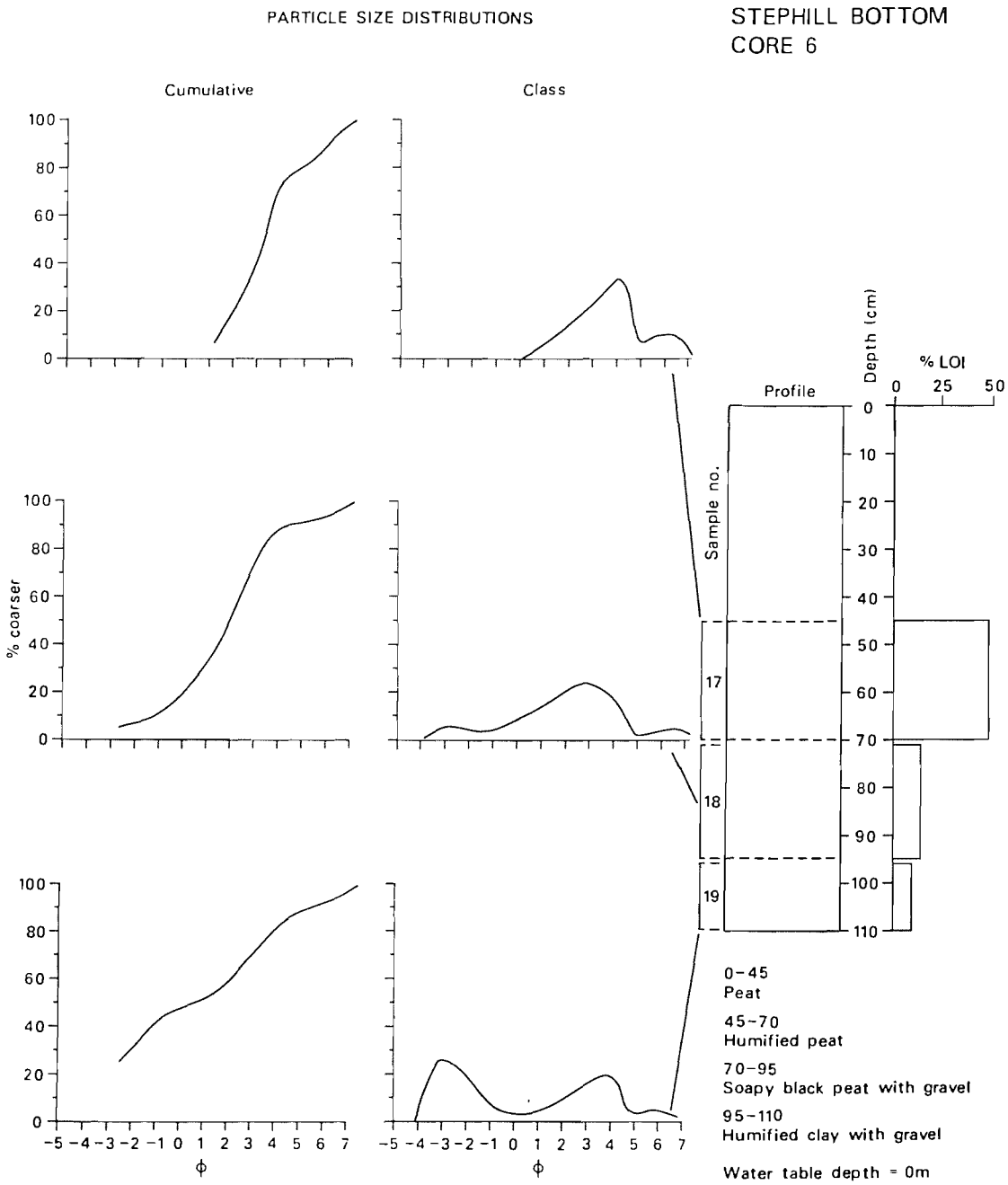


FIGURE 2.21 : Soil and sediment data from Stephill Bottom.

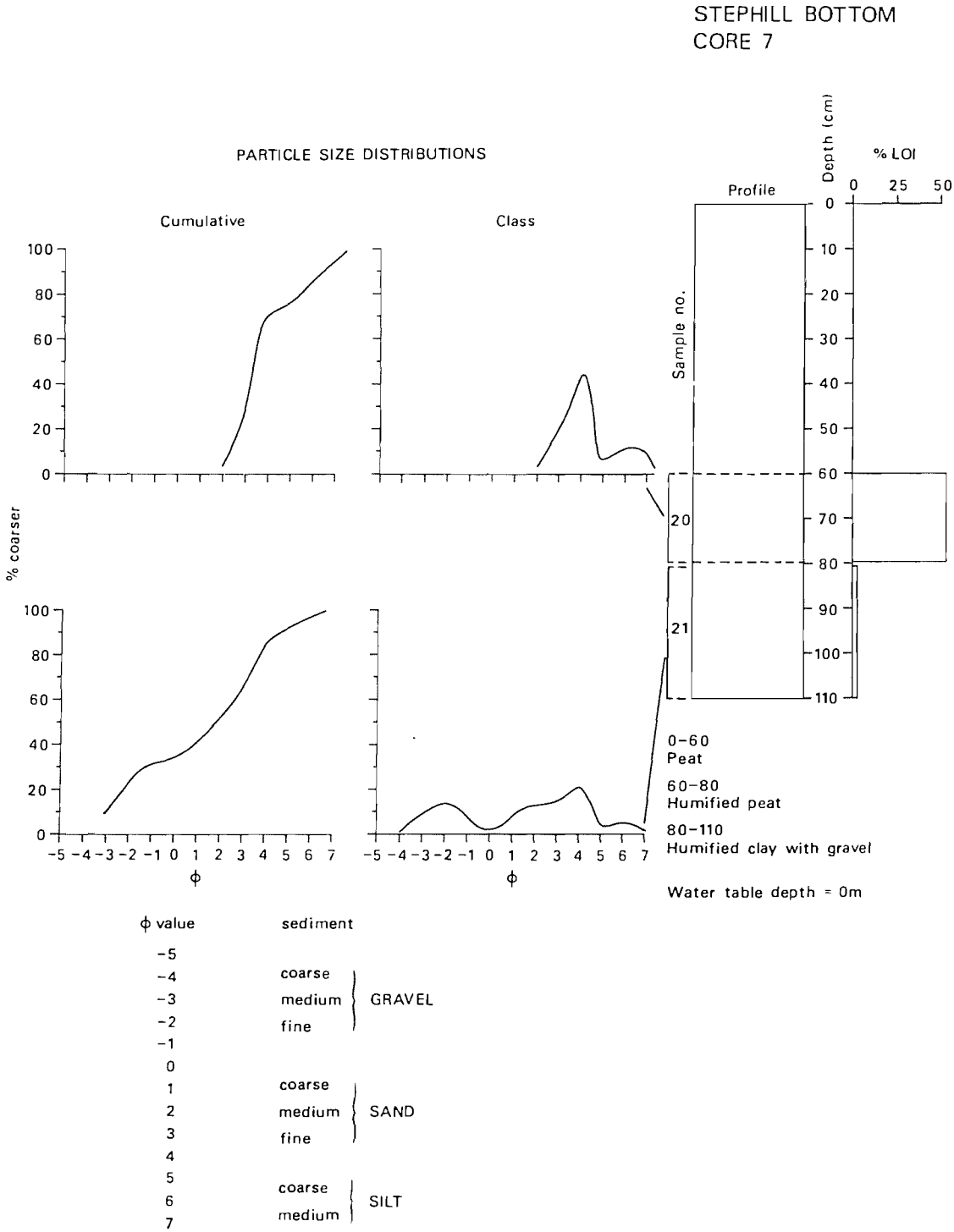


FIGURE 2.22 : Soil and sediment data from Stephill Bottom.

four profiles taken from the soil pits (Figs. 2.16-19) show an almost unimodal distribution centred on the fine sand fraction (3ϕ), showing soils developed in the uniform Barton Sand parent rock. A small secondary peak of medium gravel (-4ϕ to -3ϕ) occurs and increases slightly downslope, possibly reflecting a former Plateau Gravel covering. In contrast, the valley infill is markedly bi- or tri-modal and is poorly sorted (Figs. 2.20-22). Two main patterns emerge; firstly the basal peat sediments have a bimodal distribution, with a high loss-on-ignition (except for site 5 - see below). The sediment peaks correspond to Barton Sand and fine silt, presumably trapped in the peat from water percolating in water tracks. Secondly, beneath the peat, the sediment size class distribution is trimodal, with an additional gravel peak, probably derived from Plateau Gravel material. The very poorly sorted nature of these sediments is of considerable significance since it indicates that the peat did not originate in a still water environment, predicted by low competence mechanisms. Moreover, these sediments are clearly of mid- to late Flandrian age since they overlie deposits containing macro-remains of *Alnus* (see earlier).

The particle size data suggest that slope, rather than fluvial, processes are responsible for much of the upper layers of this infill material. The importance of slope processes in the vegetation-soil systems of New Forest valleys is also apparent from the loss-on-ignition data. Initially, the upper soil horizon is high in organic matter, but at the slope foot (sites 3, 4 and 5) where the wet heath-valley mire transition occurs, the peaty layer is less organic and tends to contain more fine material. In the centre of the mire, away from the slope, loss-on-ignition is higher. Similar downslope patterns of loss-on-ignition have been reported by Newbould (1960) for Cranes Moor and Rutter (1955) elsewhere in the Hampshire Basin.

2.2.5 Plant assemblages in basal peat deposits

The basal plant assemblages provide direct information on the first peat-forming communities and indicate the environmental conditions occurring at that time. Furthermore, the base of the peat deposits

often grades into inorganic sediments which contain plant matter, including above-ground remains. In fact, this is an almost ubiquitous feature of New Forest mires which is demonstrated most clearly by detailed laboratory-based analysis. These deposits are important since they provide evidence for conditions leading up to peat formation, rather than after it has started.

The frequency of different plant types in the basal organic-bearing sediments of 187 stratigraphic cores from 19 sites is shown in Figure 2.23 and Table 2.5, based on this study and a number of others for which adequate data is available (Table 2.5). There is good agreement between the frequencies derived from this study and those others (Table 2.4), although the data from the latter are biased more heavily by the sites involved. This is most pronounced in the frequency of wood remains which is heavily influenced by ten samples from Church Moor, a site dominated by an alder carr. Macrofossil analysis of five cores provides more detailed evidence (Chapter 5, Figures 5.4, .19, .14, .16, .17). The basal assemblages recorded are as follows: (1) The base of Cranes Moor (500-485cm) contained *Spagnum subnitens*, *Sphagnum cf cuspidatum*, *Calluna* and *Juncus acutiflorus*-type within a mineral matrix which hampered further analysis. Just above these sediments (485-470cm) there were abundant *Calluna* remains, *Sphagnum papillosum* and sections *Subsecunda* and *Acutifolia*. (2) The basal sediments at Church Moor (335-340cm) contained degraded monocot (*Carex*-type) remains with some *Sphagnum* (*S.palustre*, *recurvum* and *papillosum*) and a little wood (cf *Betula nana*). (3) The valley bottom at Hive Garn Bottom (HGBI) had a basal assemblage (98-100cm) dominated by monocot remains (thought to be of *Molinia*) with *Sphagnum auriculatum* and *S.papillorum*, *Erica tetralix*, *Potamogeton polygonifolius* and *Juncus acutiflorus*. (4) While the seepage step at Hive Garn Bottom (HGBII) had exceedingly inorganic (95%+) basal sediments containing *Molinia*, *Sphagnum tenellum* and *S.papillosum*. (5) Finally, the sediment immediately below the peat at Stephill Bottom (95-93cm) contained predominantly monocot remains (of *Rhynchospora alba* and probable *Molinia*) but also *Sphagnum auriculatum*, *S. cuspidatum*, *S.papillosum*, *Juncus acutiflorus* - type, *Potamogeton polygonifolius* and *Hypericum elodes*.

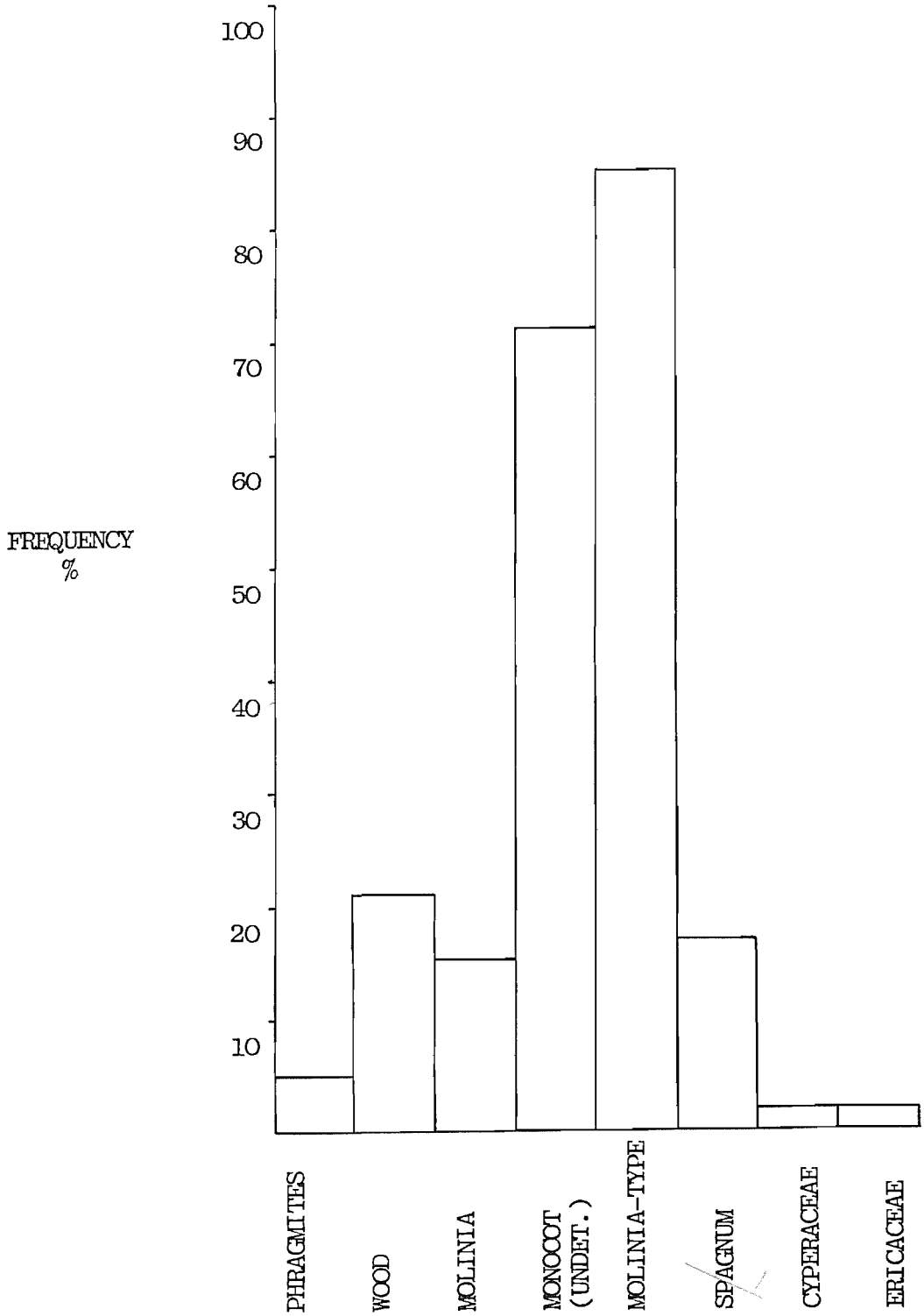


FIGURE 2.23 Frequency of plant types in basal assemblages (Based on all data, n = 187, see Tables 2.4 and 2.5)

Table 2.5 Frequency of plant types in basal assemblages

[1] Note that laboratory and field studies suggest that most undetermined monocot rootlet material is probably sieved from *Molinia*, which often required microscopic examination to confirm its identity Hence, the pooled category *Molinia*-type gives a truer estimate of its frequency

* (= 23% excluding 10 cores from Church Moor)

** (= 19% excluding 10 cores from Church Moor)

% FREQUENCY	PHRAGMITES	WOOD	MOLINIA	MONOCOT[1] UNDET.	MOLINIA TYPE	SPHAGNUM	CYPERACEAE	ERICACEAE	No. SAMPLES	No. SITES
THIS STUDY	7	17	16	69	85	18	2	3	130	17
OTHER STUDIES	0	32*	9	75	84	12	0	0	57	5
TOTAL	5	21**	15	71	85	17	2	2	187	19

Table 2.6 Sites where basal stratigraphy was investigated

THIS STUDY

Fort Bog
White Moor
Row Hill Bog
Matley Bog
Stephill Bottom
Gritnam Bog
Warwickslade
Barrow Moor
Church Moor
Hincheslea Bog
Cranes Moor
Avon Water E.
Wilverley Bog
Cadnam Bog
Digden Bottom
Hive Garn Bottom
Holmsley Bog

OTHER STUDIES

The Noads - Dobson (1975)
Digden Bottom - Davies (1972)
Barrow Moor - Dawson (1978)
Burley Common Moor - Miller (1979)
Church Moor - Mires Research Group (unpubl.)

Table 2.7 Basal age estimates based on radiocarbon dating (years BP) and palynological data

RADIOCARBON DATING	
Stephill Bottom	3080 ± 210
Hive Garn Bottom I	2700 ± 70 or earlier
II	c2700
Church Moor	c12500+
Cranes Moor : *Sphagnum* Bog	c10100
Flush Bog	c10300
Warwickslade	8600+
Barrow Moor	c2200
RELATIVE DATING	
Post- *Alnus* expansion:	
Burley Common Moor	Miller (1979)
Rakes Brakes Bottom	Marshall (1980)
Gritnam Bog	Puzey (1982)
Pre- *Alnus* expansion:	
Digden Bottom	Seagrief (1955)
The Noads	Dobson (1975)

Two main features emerge from these results. Firstly, *Molinia* or *Molinia*-type remains are found at the base of 85% of peat deposits. By contrast, *Phragmites* occurs in only 5% of basal samples and wood (mainly *Alnus*) in approximately 20%. Moreover, the occurrence of 'wood-peat' is much less since the figures in Table 2.4 include all samples in which any wood was recorded - basal peat dominated by wood remains was recorded in 12% of cores and these were all taken from extant carrs (note, however, the buried remains at Stephill Bottom which were not included in the analysis). Secondly, mire and heathland plant assemblages are already present before the start of peat accumulation proper. Furthermore, macrofossil analysis has shown, in several instances, strong similarities in the species composition between not only basal deposits and the main peat column, but also with the present vegetation. Examples of this are *Sphagnum auriculatum var auriculatum* and *Hypericum elodes* at Stephill Bottom, and *Sphagnum tenellum*, *S. papillosum* and *Molinia* at HGBII. Such close correspondence suggests that similar hydrological and geochemical conditions to the present day were in existence immediately before and at the start of peat formation.

2.2.6 Dating the start of peat growth - radiocarbon and pollen evidence

Samples from three sites (SBI, HGBI, HGBII) have been dated radiometrically in order to determine the age of the basal peat deposits (New Forest Series II). In addition, radiocarbon (New Forest Series I) and/or palynological data allow some estimate to be made for the date of peat inception at another ten sites (Table 2.7). Previous radiocarbon dates from the New Forest (Series I) had not been obtained in direct relation to the problem of peat inception and were taken from mainly deeper and older sites in an investigation of Late Devensian and early Flandrian vegetational change. The dates obtained in this study (Series II) are from sites representative of the more widespread shallower and younger mires, for which only palynological evidence has previously been available. The remaining sites do not have radiocarbon dates but an approximate age (or period) for their origin can be made by relative dating with radiocarbon-dated pollen profiles (Barber and Clarke, 1987; Clarke and Barber, 1987). The most useful episode of vegetation change in the New Forest is the expansion of *Alnus* conven-

tionally marking the start of the Atlantic period, although this is known to be diachronous in the Forest (see Chapter 5.2) between c 5000-7000 BP. Two sites, Digden Bottom and The Noads, originate before the *Alnus* expansion. Analysis by Seagrief (1955) indicates that peat formation at Digden Bottom began shortly before the Boreal-Atlantic transition. While the basal peats at The Noads also appear to be of late Boreal age, since Dobson (1975) found 12cm of peat accumulation beneath the *Alnus*-expansion horizon. The pollen assemblages of the bottom samples were dominated by Graminae with low amounts of arboreal pollen, comprising *Quercus, Pinus, Betula* and *Ulmus*. The three remaining sites all post-date the *Alnus* expansion. Rakes Brakes Bottom may originate relatively early on after this event because 30cm of peat had accumulated before the first episode of forest clearance took place in the pollen profile (Marshall, 1980) and *Ulmus* is present at relatively high frequencies in these basal deposits (8% arboreal pollen). The pollen spectra at Gritnam and Burley Common Moor, however, provide no further evidence as to the date of their origin, although they are not recent.

The first significant point to observe is that a number of valley mires, from a variety of situations, originate during the Late Devensian or early Flandrian. Several other valley mires in the region also commenced growth during the early period in the postglacial, such as on the Isle of Wight (Scaife, 1980) and in Purbeck (Haskins, 1978). Van Zeist (1964) describes a valley mire from St. Michel-de-Brasparts which contains Late Devensian inorganic sediments containing macro-fossils from mire vegetation. This is overlain by about 2.2m of peat, separated by a hiatus in sedimentation, which has been dated to 5400 $\pm$ 60 BP (GRN 1983) at about 130cm (the elm decline). A second site, Ménez Cam near Spézet, yielded a radiocarbon date of 3930 $\pm$ 75 (GRN 2161) at about 205cm, some 50cm above the beat base which post-dates expansion of *Alnus* (van Zeist, 1964).

The fact that mire formation has taken place throughout post-glacial time means that it should be regarded as a rate-governed process and attention focussed on the factors which have caused the rate of formation to increase or decrease. Unfortunately, the bias towards

older sites (especially those with radiocarbon dates) prevents the data in Table 2.7 being used to obtain a generalised history of mire formation for the Forest as a whole. Nevertheless, although basal dates are widely distributed through the post-glacial, the evidence suggests a concentration of dates clustered around 2-3500 BP, indicating an increase in the rate of mire formation. This appears to have been a regionally-widespread phenomenon (e.g. Moore and Wilmott, 1976); Scaife, 1987; see also review in Nicholls and Clarke, 1986). More radiocarbon dates are required (within an appropriate sampling framework) before changes in the rate of peat inception can be identified with confidence.

2.3 A review of the hypotheses and the problem

2.3.1 Review of results and hypotheses

It becomes necessary, within a framework of competing hypotheses, to decide on what logical grounds hypotheses are rejected. This is not a straightforward issue in the philosophy of science, yet the procedure by which conclusions are reached must be clear if explanation is to be sound. The very nature of scientific theory poses a problem to the method of falsification. This is because the construction of scientific theory requires simplification of reality, both in the selection of relevant variables and in the hypothesising of relations (law statements) among them - such ideal theoretical models are, therefore, inconsistent with reality. Bunge (1967) has pointed that all theories can be falsified on *a priori* grounds, i.e. all scientific theory is factually false. This arises because the idealisations inherent in the initial assumptions of a theory will be propogated to its testable consequences - sooner or later a discrepancy between theory and the outcome of empirical testing will emerge. This is an inevitable consequence of the conceptual nature of scientific knowledge, and presents a dilemma to the falsificationist when deciding which theories are 'acceptable' and which have been refuted. The criteria concerning the elimination of a theory have been an important problem in the development of scientific methodology (e.g. Popper, 1963; Lakatos, 1970; Kuhn, 1970; Weimer, 1979). Lakatos (1970) reformulates the dogmatic approach to rejection by requiring elimination to be a

cautious process that waits until there is a more corroborated alternative. This approach has been termed 'sophisticated falsificationism' and developed in response to the opposing view of science held by Kuhn (1970).

From the debate over scientific discovery it is clear that, in this study, hypotheses must be rejected not solely in terms of falsification of predictions, but also in terms of additional corroborative evidence and hypotheses which they can account for. The initial hypotheses can be reconsidered in relation to the predictions outlined earlier given the evidence which has been presented, and the outcome of simple falsification is summarised in Table 2.8. Rejection implies that either the hypothesis or the assumptions associated with it are not true.

Flush formation and nutrient loss ('paludification')

This hypothesis predicts that substantial amounts of basal wood peat should be present, approximating half the total area of peatland (Heinselmann, 1970). The stratigraphic evidence from the New Forest (Figure 2.23, Table 2.4), however, shows that the valleys were not heavily wooded prior to peat accumulation and that at least some mire and heathland species were already present. Moreover, this hypothesis requires that wood peat is present in areas where trees are now absent or scarce. This in contrast to the valley mires where most wood peat deposits are associated with extant mire woodland or carr (see Chapter 5.6).

The paludification hypothesis also involves the role of capillary water held by *Sphagnum* plants (e.g. Bellamy, 1972; Gosselink and Turner, 1978). However, Ingram (1983) has pointed out that this view of capillary action is based on a misinterpretation of the processes involved - the matric forces involved in capillary action have no direct effect on the water table (see also Ingram, 1982). Ecophysiological studies by Clymo (e.g. Clymo and Hayward, 1982; Hayward and Clymo, 1982) serve to reinforce this point; *Sphagnum* does not have any specialised water-conducting tissue in its stem and it has been long

Table 2.8 Testing predictions of competing hypotheses by simple falsification (see text)

HYPOTHESIS	DATA	DECISION
Flush formation and nutrient loss ('paludification')	Basal wood infrequent (12%)	Reject
Pedogenic peat formation	Impermeable iron pans rare/absent Frequent groundwater gleys But evidence of impeding horizons	Unable to reject
Perturbation of catchment water balance	Scarcity of wood peat/remains Charcoal very rare in basal deposits Late Devensian and early Flandrian sites	Reject
Low competence mechanisms	Valley bottom and valley-side mires with high gradients - all hypotheses	
Palaeochannels	No morphometric or sedimentary evidence	Reject
Rivers at 'grade'	Chaotic sedimentation and coarse particle fraction abundant (10%+ by mass in some basal samples) Knickpoints	Reject
Solifluted clay plugs	No morphometric or sedimentary evidence	Reject
Debris dams/beavers	Basal wood peat rare and other stratigraphic evidence absent	Reject

known that water moves up to the capitulum by capillary films. The driving force of this movement is evaporation due to the low relative humidity of the air, and *Sphagnum* rapidly dessicates on lowering of the water table.

Perturbation of catchment water balance.

Although the stratigraphic evidence has proved negative, the possibility of mire development through water balance perturbation by forest clearance is more difficult to test directly. However, there are also *a priori* difficulties with this hypothesis. The inception of peat due to clearance by man has been proposed principally for the blanket mires of upland Britain. The evidence to support this theory is based on the correlation between the start of peat growth and data suggesting possible widespread human activity and forest clearance (Moore, 1975, 1979). Deforestation, it is suggested, would have important hydrological consequences resulting in the lower interception of precipitation, less evapotranspiration, greater soil evaporation, greater run-off and, hence, longer periods of high soil water tables (Moore, 1975). The proposed changes are based on experimental watershed deforestation studies, but these are difficult to interpret in application to the problem of peat inception. First, comparisons of the water balance for forested and deforested areas have been based on differences in run-off from basins. These values apply to the basin outlets and may not reflect the water balance on the interfluves - the areas now covered by blanket peat. Indeed, greater runoff from a deforested basin could lead to lower water availability in the rest of the catchment. Second, the direction and magnitude of change in run-off following deforestation is not consistent (Ahlgren and Ahlgren, 1960; Branson, 1975). Some watershed studies have shown increases (e.g. Borman *et al*, 1968; Swank and Douglas, 1974), but others have exhibited no significant difference (Brown, 1970) or have even resulted in reduced run-off (Branson, 1975). Branson (1975) reports on the conversion of pinyon-juniper woodland to grassland, where run-off and available sediment increased during the first two years following treatment but subsequently dropped to below the original,

pre-clearance values for the rest of the study. Some of this variation may depend on whether the forest cover is deciduous or not (see Rutter *et al*, 1975). Third, the response of the channel, in terms of erosion or deposition, depends not only on run-off and discharge, but also on the amount of suspended sediment, according to drainage basin dynamics (Schumm, 1977).

In a more recent review of blanket mire origins, Moore *et al*, (1984) no longer recognise a clear link between peat inception and the activity of man. They show that there is wide variation in the date of blanket peat initiation, and conclude that far more radiocarbon dates are required before firm conclusions can be reached as to the causes of peat formation. There is an even greater need, however, for process-orientated studies which are designed to examine the changes in soil water table following experimental deforestation of catchments, including fluctuation over time and across whole catenas. This reflects difficulties in the approach which has been used in the investigation of peat formation (see below).

Turning to Thursley Common in lowland Britain, Moore and Wilmott (1976) put forward a similar argument of forest clearance resulting in increased water supply to soils and peat development. They support their case with a pollen profile showing a basal clearance episode in the bottom 30cm of peat - though it must be noted that mire initiation, therefore, took place <u>before</u> that particular clearance event occurred. If discharge did increase with Bronze Age clearance, the consequences may be quite different in the water-receiving areas (the valley bottom) than on the water-shedding areas (as in blanket mires). It should also be noted that in the New Forest mire vegetation and peat is widely distributed on the valley-sides as well as in the valley bottoms; nor are valley-side mires restricted to areas where peat also occurs in the valley bottom. Nonetheless, the temporal correlation between the start of peat accumulation and forest clearance appears compelling, but a direct link between peat inception and a change in run-off, as proposed by Moore and Wilmott (1976), is far from clear. The presence of Late Devensian and early Flandrian valley mires in the New Forest (and adjacent regions) further demonstrates

the inadequacy of a simple equation between mire formation and the activity of man. It may be postulated that the rate of peat inception has been accelerated by environmental events in the Atlantic and more recent periods, but the underlying processes have been operating throughout post glacial time.

Low hydrological competence mechanisms

The existence of mires on steep slopes in areas of high relief in the New Forest (e.g. the north-west sector) and the widespread distribution of valley-side peats demonstrate that low competence *per se* is not a sufficient condition for peat development. Furthermore, mire development in the Forest is frequently restricted to valley-head flushes and the upper reaches of stream networks. The lower sections with well-defined channel flow lack peat, despite having a lower gradient. This pattern of mire distribution may be seen in the Latchmore Brook, Crockford Stream and parts of the Beaulieu River catchments, for example.

The hypotheses concerning low competence involve mechanisms which are, essentially, "point events" relating to zones of discrete channel flow. They are restricted in scope and in the extent to which they explain the continuum of both valley bottom and valley-side peat deposits, and the distribution of transition zones into wet heath. In terms of hydrology, the development of a flush-type flow rather than defined channel flow is a more relevant problem. There is a need for more ecologically-relevant studies into the factors leading to a diffuse drainage network or water track, which favour peat formation, rather than a well-defined open channel. Ingram (1983) has stressed the ability of the acrotelm to transmit high rates of discharge without erosion, despite the high water table and absence of an open channel network in most mires. This is a significant property of mires in the context of this problem.

The hypothesis of rivers at grade suffers from the fact that this concept was never well-defined (Dury, 1966). Its implication in peat development partly depends on the misconception that stream velocity

decreases with distance downstream. The dynamics of rivers are best considered as a multi-dimensional, rather than a simple two-dimensional (long-profile only), problem. The achievement of 'grade' has, in any case, never been demonstrated for the New Forest. Many landforms in the Forest may be regarded as relict features (principally periglacial in origin), including not only steep slopes but also persistent low-angle surfaces which are resistant to contemporary environmental processes (see, for example, Tuckfield, 1973; Rose *et al*, 1979; Brunsden and Thornes, 1979). Moreover, peat inception has been taking place since the previous interstadial of the Late Devensian and is therefore not dependent on equilibrium conditions. It should be noted that fining-upwards sediment sequences are open to other interpretations, such as point-bar migration and the development of mobile, lag and immovable layers (e.g. Reading, 1978; West, 1978). Although some peaty-infilled meander cut-offs are present on the floodplains of the larger New Forest streams (such as the Ober Water, the upper reaches of the Beaulieu River, and the Highland Water), these are small-scale features. The evidence reviewed above does not support palaeochannel infill succession as a major factor in the formation of New Forest valley mires.

The absence of significant wood peat deposits and poorly-sorted sediments immediately below peat argues further against debris or beaver dams as a principal cause of peat formation. Elsewhere, Heinselmann (1975) is sceptical that the beaver *Castor canadensis* played a vital role in the formation of North American peatlands. The former impact of the beaver is, however, extremely difficult to assess. *Castor fiber* was present in Britain and Europe throughout most of the Flandrian, and was active in wetlands, as the finds from the Somerset Levels demonstrate (Coles and Orme, 1982). But, if the beaver had such a significant impact on peat formation in the New Forest, then data from North America predict that much more abundant evidence should be present than is the case (Knudsen, 1962; Heinselmann, 1975; Naiman *et al*, 1984, 1986). Naiman reports that present-day densities of beaver dams along streams are in the order of 10 per kilometre, that each dam may persist from 400 to 800 years and that the mean consumption of wood by beavers is approximately 1 tonne/beaver/year. Since this hypothesis of mire

development requires peat formation to be a subsequent step, it is reasonable to expect at least some preservation of the large quantities of wood in these constructions. Moreover, beaver dams in North America are most frequent - and have the greatest effect - on the floodplain rather than the upper reaches and valley-heads of a catchment system. Subsequent vegetation development favours meadow grassland rather than mire communities (Knudsen, 1962). Thus, although there is considerable interest in the effect of the beaver as a geomorphological agent, there is no evidence to maintain this hypothesis in the case of New Forest mires.

Pedogenic peat formation

From the evidence reviewed here, it is not possible to reject the effect of soil profile development on soil hydrology and peat formation. However, this evidence is not consistent with the hypothesis as outlined by Taylor and Smith (1972) and earlier authors. Firstly, soils comprising stagnogley horizons above an iron-pan are absent from the New Forest. Indeed, iron pans are very rare in the Forest (Staines, pers comm; Kear, pers comm) and are discontinuous where they have been found within some of the higher Plateau Gravel terraces. An iron pan is defined as a 'Sharply defined, black to reddish brown, brittle or cemented B horizon less than 10mm thick... enriched in pyrophosphate extractable iron and carbon.' (Avery, 1980, p.18). Second, drainage impedance is not attributable to the often highly indurated Bh horizon of the classic New Forest podzols, such as those illustrated in Dimbleby (1962), which are examples of the freely-draining Shirrel Heath series (Jarvis *et al*, 1984). There was no evidence for water impedance in the podzol at Stephill Bottom (pit No.1, Figure 2.16). A similar profile has been analysed by Allen and Staines (1984), developed in the same parent material at Denny Lodge, 2km away from the Stephill Bottom section. The Bh of this profile was very porous and had a moderately high air capacity (c25% by volume), there was no iron pan and the Bs horizon also showed a high air capacity (c20% by volume). Podzols of this kind in the New Forest have relatively low extractable Fe and Al content.

Impeding horizons were found at various sites but they were not always present and their type and distribution is complex. Many of the soils in the New Forest have slowly permeable horizons at depth, such as the widespread Wickham and Kings Newton series (Jarvis *et al*, 1984). The valley bottom soils at Stephill Bottom are ground water gleys but the mire and wet heath zone extends up the valley sides, some 1.4m above the water table in the valley bottom. The vegetation reflects the distribution of the ground water table, which was found to be at the surface throughout this zone (June 1982). Gurnell (1981) describes a related phenomenon at Withybed Bottom, where an artesian pressure head effect can occur. Such a hydraulic gradient must result in a lateral water flow being generated in the upper horizons of valley side soils, which appears as seepage. The development of lateral flow coupled with frequent impeding horizons is clearly an important component of permanently high water tables which may allow peat formation to take place.

2.3.2 Testing the theories of peat inception - conclusions

In this chapter the ideas concerning the origin of peatlands have been developed in such a way that they can be tested against each other for applicability to the New Forest valley mires. Relevant data have been collected and the hypotheses re-examined. It has been concluded that none of the hypotheses outlined at the beginning of this chapter can be applied directly to the formation of peat in the New Forest. Examination of the literature on mire origins reveals little consensus over the relationships between the relevant processes, a wide variety of approaches to the problem and low integration between studies. Why should the problem of mire inception seem so intractable?

At least part of the problem can be traced to the form of explanatory argument that is used, of which three general features may be identified. First, all theories of peat inception are confounded by the existence of multiple correlations, the 'Man vs climate' debate perhaps being the most notable example. This is because the causal explanation of peat inception has been based largely on inductive logic

in many studies. That is to say, one event (the start of bog growth) is found to be associated with another, say clearance, so that bog growth is inferred to occur with clearance and a causal explanation is offered. This is a highly simplified illustration but the point is that inductive arguments will be, at best, never more than probable (Russell, 1912). Hence, given that there are a set of multiple correlations, the question of mire origins cannot be answered using the inductive method, since it is not possible by induction to distinguish which of the correlated processes are responsible for peat inception from those which are not.

Second, little attempt has been made to identify the scale at which an investigation is conducted, nor the level of causal explanation sought. This may be regarded as a major factor limiting cross-comparison between studies. By way of illustration, consider the two following hypothetical statements based on the literature of bog origins. 1. 'Peat development occurred because the litter derived from the vegetation entered an increasingly waterlogged environment, where the redox potential dropped to about -400mV. This resulted in a much lower decay rate so that production exceeded decomposition, which led to peat formation in association with the development of feed-back mechanisms.' 2. 'Peat development occurred because the North Atlantic atmospheric circulation system altered to produce a more cyclonic weather pattern. As a result, a more oceanic climate developed with an increased precipitation to evaporation ratio. An increase in waterlogging led to the formation of peat.' The former statement is concerned with the <u>proximate</u> causes of peat formation (litter decomposition, mineral recycling), wherever the latter deals with <u>ultimate</u> processes (large scale climatic change). The point is that mire inception is open to investigation at various levels. Further illustration of this argument is obtained by comparison of two important papers by Moore (1975) and Taylor and Smith (1981). These authors lay stress on different processes involved in blanket peat formation: Taylor and Smith emphasize internal pedogenic factors, while Moore propounds the importance of hydrological changes. Yet, it is clear that they are essentially discussing the same set of processes.

Indeed, it is ironic that deforestation by man figures so prominently in both models - the difference lies in the level at which the investigators are operating.

Third, there has been a failure to specify the logical structure of the explanatory arguments used. Temporal modes of explanation rely on the assumption that a particular set of circumstances may be explained by examining the origin and subsequent development of phenomena by the operation of process laws. In formal terms, causal explanation consists of a set of initial conditions which are governed by a set of physical laws, leading to the event to be explained. In the study of peat inception, however, it is not yet (never?) possible to define the full set of initial conditions. There is simply insufficient information on which to base a formal statement of the theory of mire formation, with explicit assumptions, because of the technical difficulties in its investigation. This is not a unique problem. But, it is essential to recognise it explicitly as a problem, to expose the logic of the explanation being used and to consider what criteria are required to distinguish, as Harvey (1969, p.98) puts it, "speculative fantas ies from 'scientific theory'". Indeed, it would seem that much of the methodological debate in the natural and social sciences has left the study of mire inception behind.

The deductive framework of this chapter has allowed much to be discounted, but it has not been possible to put forward a model of peat inception apart from implicating the role of soil profile evolution. This is in part due to the inductive basis of the hypotheses that have been tested. It seems that an alternative approach to the formulation of a hypothesis of peat inception is required, and this is the object of the next chapter.

2.4 Summary

1. Competing hypotheses of peat inception are reviewed, and a set of predictions are derived which are applicable to New Forest mires.
2. The predictions are tested with data from a range of sites, based principally on (i) the stratigraphy of basal peat, sub-peat and

valley-side sediments, (ii) a case study involving more detailed sedimentary and soil analyses, (iii) plant macrofossil analysis of basal peat samples, (iv) radiocarbon dating and relative dating by pollen analysis.

3. It is concluded from empirical and theoretical evidence that none of the hypotheses are directly applicable to the origin of New Forest valley mires. It was not possible to reject the general role of soil profile evolution in the generation of lateral water flow, which may allow peat development to take place.
4. The methodological problems associated with causal explanation of peat inception are discussed. Many studies are confounded by inductive logic and multiple correlations. There has been a failure to specify the scale of investigation and level of explanation sought. This has made it difficult to compare critically many of the hypotheses which have been proposed.

CHAPTER THREE: AN INTEGRATED APPROACH TO MIRE FORMATION IN THE NEW FOREST

3.1 Introduction

In his book on peatland hydrology, Ivanov (1981) discusses the general laws affecting the transformation of land into mire, which he believes to be fundamental to the understanding of peatland development. He states:

> "The amount of mire in any area is immediately connected with the relation between the items in its water budget (precipitation, evaporation, efflux), the quantity of heat it receives, and the mechanism whereby excess moisture finds its way into the river network that constitutes the natural drainage of the area. The combined action of these factors at every point on the earth's surface determines the water and heat regime in the soil and on its surface, whether it be favourable or unfavourable for mire formation. The volume of efflux is mainly determined by climatic conditions, but the amount of mire also depends on the relief of the area, the natural drainage of its river network, and the permeability of its strata." (Ivanov, 1981 p.3)

These relations can be formalised into a general equation which defined the shape of the groundwater table, and depends on three universal variables: (i) the mean long-term meteoric supply of water (effective precipitation), (ii) the drainage network density, (iii) the permeability of the soil (Ivanov, 1981). Together, these factors determine the free profile of the water table within an interfluvial region, but such a profile can only exist if all points along the earth's surface exceed the water table curve (see Figure 3.1a). If certain points along the surface are lower than the water table profile (Figure 3.1b), then hydrological conditions will naturally favour the development of peat. In these areas, overland and internal movement of water takes place and the upper soil horizons are subject to continuous or very prolonged saturation. It is important to note that mire development can take place in this way under any combination of values for the three variables that exceeds the critical profile. The equation in the form presented by Ivanov (1981) is too idealised in most situations due to spatial variation in lithology and soil permeability (see also Chapter 5.3).

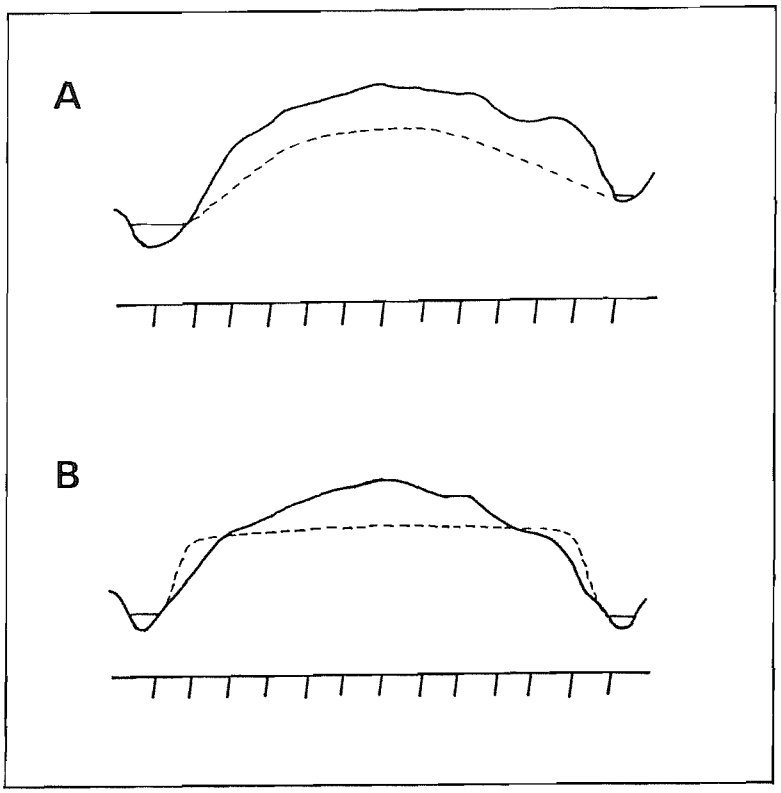


FIGURE 3.1 Model of the general laws affecting peat development - a schematic diagram showing the potential groundwater profile in an interfluvial massif of porous rock underlain by an impervious layer (hatched).

In (a) the variables are such that the potential profile of the groundwater table is attained (see text).

In (b) the factors determining the potential groundwater profile are such that it exceeds the earth's surface, creating suitable conditions for peat development. (After Ivanov, 1981).

The form of the equation determining the groundwater profile is given in Chapter 5.3.

However, the significance of this approach is that it provides the first principles of mire formation.

The starting point for a hypothesis of peat inception is, then, the question 'What processes currently maintain valley mires in the New Forest?'. A causal explanation may then be sought in terms of how these processes have operated over time to produce the present situation. This is essentially an evolutionary or developmental explanation of mire origins (Harvey, 1969). It is a more parsimonious approach than searching for particular formative events which initiate peat accumulation but with subsequent maintenance due to other factors - a feature of several hypotheses reviewed in the previous chapter. The aim is, therefore, to deduce the causes of the present valley mire water regime and to investigate how these processes have developed

3.2 Maintenance of the present valley mire system

3.2.1 The valley mire water budget

The water balance of any wetland ecosystem is concerned with the inputs, the outputs and the associated changes in storage of water. The water input to mires (or recharge) is comprised of direct precipitation and water derived from the surrounding catchment. These two types of recharge are of fundamental importance to present day mire ecology and this functional division is also of significance to the origin of different peatland types. The catchment-derived input, in turn, may be split into several components comprising seepage, pipe flow, diffuse surface flow (or run-on) and flow from upstream through an open channel network (Ingram, 1983). Both types of input are clearly significant to the water budget of a valley mire but groundwater flow is relatively difficult to investigate, and is usually the residual term in the water balance method (Ivanov, 1981). Compared to ombrotrophic mires, there has been little attention paid to the hydrology of groundwater-fed mires (Ingram, 1983). In this respect, the study by Daniels and Pearson (1974) at Roydon Common, Norfolk is all the more significant.

Daniels and Pearson carried out an investigation of the water budget of

a valley mire which is closely related floristically to those of the New Forest (Daniels, 1978). Using a simple equation for the water budget, they evaluated the inputs for the mire. For a system which depends on a larger surrounding catchment, such as a valley mire, the water budget may be expressed over a given period of time as:

$$P + G = E + \Delta S + R$$

where P = precipitation, G = influx of groundwater from the surrounding catchment, E = evapotranspiration, ΔS = change in storage by the soil, and R = runoff. The contribution of precipitation to the maintenance of the valley mire is the 'precipitation excess' (P-E), that is the net precipitation after evaporative losses. This is the concept of 'effective precipitation' of Gore (1983). By simple algebra, Daniels and Pearson were able to compare the contribution of the geogenous water supply to the mire with that derived from direct precipitation on to the mire over an annual cycle. They found that the value for groundwater influx was approximately thirty times the precipitation excess over the same period of time.

A comparative approach is hampered by the difficulty in defining the area of the groundwater catchment (Ingram, 1983). However, it is clear from this result that the water supply to valley mires from the surrounding catchment will be one to two orders of magnitude greater than that received directly from precipitation. Gosselink and Turner (1978) identify lateral flow from the catchment as a distinguishing feature in the hydrodynamic regime of valley mires. An earlier study of a valley mire and heathland catchment in north Hampshire by Rutter (1955) also emphasised the significance of the geogenous water supply. Rutter demonstrated that most of the groundwater moves laterally in a permeable zone just beneath the surface and above less permeable horizons deeper in the soil.

Lateral groundwater seepage is also the dominant input for sites within the New Forest. This is particularly evident where the channel is incised below the level of the mire, such as the mires along the Dockens Water, including the Digden Bottom/Linwood Bog system. In mires with a central water track (see Ingram, 1967), the marginal zone is often above

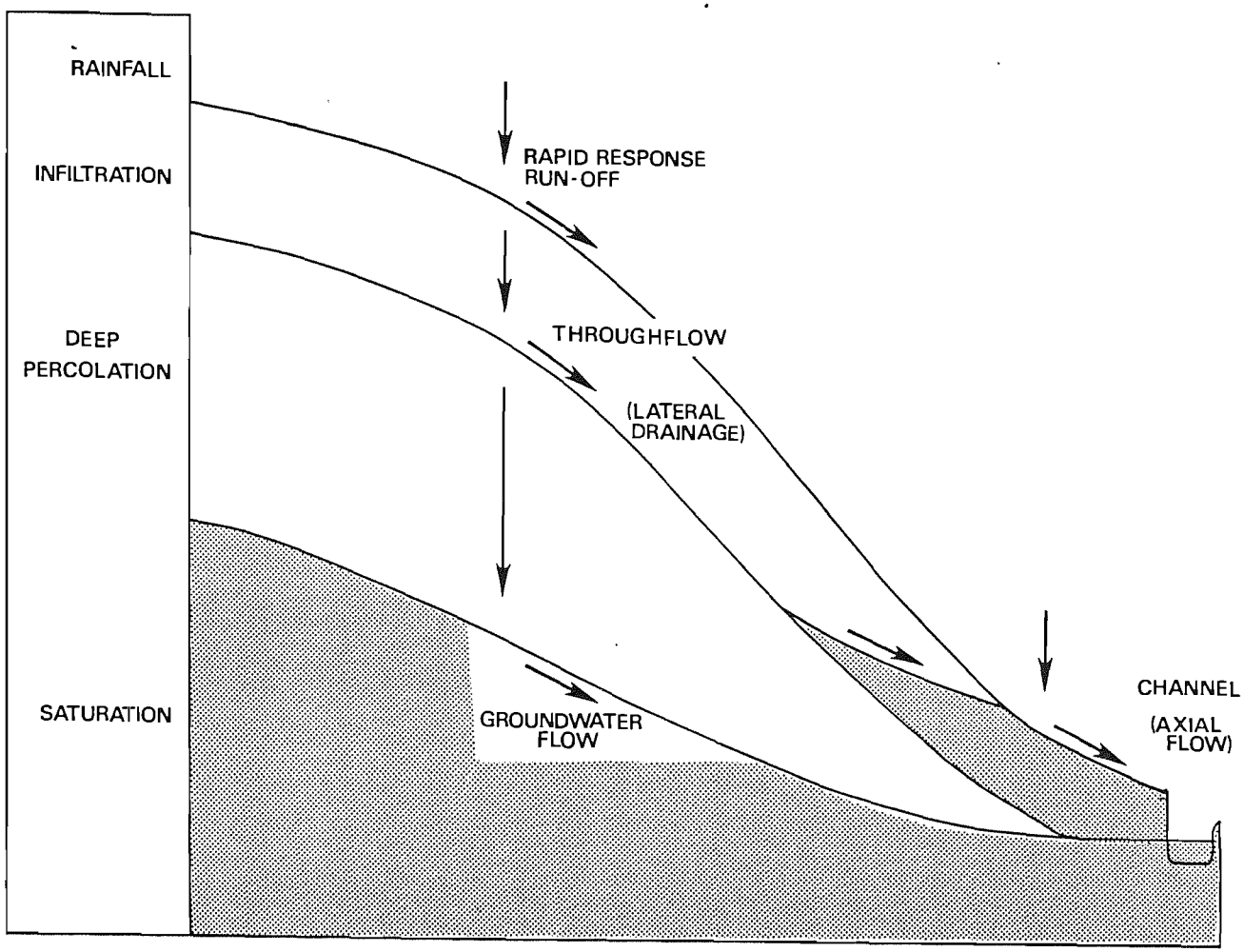
the water table in the mire centre and is hence solely dependent on lateral flow and precipitation. The hydrological relationships of New Forest valley mires are shown very well by the Silver Stream - Holmhill Bog - Redhill Bog system. An artificial drainage ditch in the lower reaches of the mire has had the effect of depriving this section of any axial inputs from upstream. The drain was last excavated in 1970, and although this may be regarded as an opportunistic experiment, it has had a highly deleterious effect on the mire. The present plant distribution, downstream of the passage at SU269022, shows that the ditch has created a central draw-down strip along its length, some 15 - 30m wide on either side. This is dominated by *Calluna vulgaris* and *Molinia caerulea* tussocks with *Erica tetralix* and *Myrica gale*, forming a mosaic with a short sward of *Carex panicea*, *Molinia*, *Agrostis stolonifera*, *Carex demissa* and *Cirsium dissectum*. The vegetation lies over a shallow humified peat, or humose surface horizon. The water table lies well below the surface in summer and the level of base flow in the drainage ditch is approximately 60cm below the surface. The draw-down strip is flanked by a diverse mire community in an approximately 10m wide zone along the slope foot (especially to the west). This comprises abundant *Rhynchospora alba*, *Narthecium ossifragum*, *Molinia*, *Eriophorum angustifolium* and *Phragmites*, growing over an almost continuous lawn of *Sphagnum papillosum* and *S. auriculatum*. The water table remains at or near the surface throughout the year and, other than direct precipitation, is derived entirely from lateral flow. In places the mire surface 'quakes', indicating an underlying saturated mineral substrate under positive water pressure due to the groundwater flow (see Bolton, 1979). This phenomenon is common in the New Forest (sometimes referred to as "running sands" locally) and has been described in the stratigraphy of some mires investigated in Chapter 2 (such as Gritnam Bog). In contrast, upstream of the active knickpoint created by the drain, the axial flow along the valley is in the form of a water track and similar wet mire communities extend across the valley floor with scattered willow thicket.

Two types of water movement beneath the soil surface may be distinguished (Ward, 1975). Firstly, on infiltration, water may percolate down through soil horizons to the zone of permanent saturation and gradually emerge at

the channel as groundwater flow. Alternatively, the downward movement of water in the soil may be hampered by less permeable horizons such that it moves laterally as throughflow (or interflow) in the upper soil horizons, in the direction of greatest hydraulic conductivity. The flow may be unsaturated but commonly forms a saturated 'perched' water layer. Throughflow is recognised as a major component in the hydrology of many catchments (Ward, 1975).

In a New Forest catchment, Gurnell (1981) found that areas of high *Sphagnum*, *Juncus* and *Erica tetralix* cover tended to have relatively lower drainage densities during ephemeral flow regimes because the soils are more able to transmit the moisture beneath, but near, the surface. Observations by Hughes (1984) show that rapid rates of throughflow can develop at the base of any peat cover. Both processes, throughflow and groundwater flow, are important agents of surface saturation and act in similar ways to produce high water tables - conventionally groundwater flow is thought to dominate on flat areas, while throughflow acts more on steeper slopes (Ward, 1975). In Rutter's (1955) study, however, the high water table was due mainly to groundwater but the greatest movement, i.e. the greatest rate of supply to the wet heath and mire vegetation, was in the more permeable upper horizons of the soil. In the water budget of a valley mire, the mechanism of supply from either process is linked very strongly to the presence of permeable over less permeable soil horizons.

A simple model of the hydrologic processes discussed above is illustrated in Figure 3.2, and demonstrates one example of the way in which a waterlogged soil may develop in a valley bottom by lateral flow due to a relatively impermeable soil horizon. This idealised situation is made more complex by the spatially, very variable surface lithology in the New Forest. There are also conditions under which soil water surfaces do not directly accord with topography (Anderson, 1982). However, this model provides a theoretical base for understanding the development of the present-day valley mire water budget and the next step is to consider the variation in soil type and water regime occurring in the New Forest.



SPATIAL CHARACTERISTICS OF MAJOR RUN-OFF PROCESSES.
FIGURE 3.2

Adapted from FARQUHARSON et al (1978)

3.2.2 A review of the principal soil types and their water regimes in the New Forest

New Forest soils exhibit great heterogeneity even in small areas due to the variability of the exposed Tertiary sequence and to the variation in composition and distribution of drift deposits. Soils may be classified into a set of soil associations, each composed of a number of soil series which have a defined range of diagnostic properties in common (Avery, 1980). Soil series are defined on the basis of textural, substrate and mineralogical criteria (Clayden and Hollis, 1984). In practice, it is often difficult to assign soil profiles in the New Forest to those soil series which have been described so far (see Jarvis *et al*, 1984). This is probably because the classification scheme is based mainly on agricultural areas in which the spatial variation of soils has been reduced by Man, in contrast to the heterogeneity of the New Forest which is the largest surviving area of semi-natural habitats in lowland England. Nevertheless, several recognised soil associations commonly occur in the semi-natural areas of the Forest and most soils show close affinities to them, the most significant being the Wickham 3, Holidays Hill and Boldrewood associations. The following account summarises the main features of these soil associations in the New Forest, and is based largely on published (see Jarvis, *et al*, 1984; Allen and Staines, 1984) and unpublished information from the Soil Survey of England and Wales.

Wickham 3 association These soils are extensively distributed in the New Forest on the Bracklesham Beds and the more clayey facies of the Barton Clay, Barton Sand and Headon Beds where they occur within most of the semi-natural habitats, including broadleaved woodland, heath and acid grassland. More than half the soils in this association have slowly permeable clayey subsoils which impede vertical water movement and generate lateral flow. Some of the soils, such as the very common (in the Forest) Kings Newton series, have coarser topsoils resulting in high infiltration and greater lateral flow. Others have more clayey surface horizons (e.g. Denchworth series), resulting in seasonally very high water tables.

Holidays Hill association Soils of this association are found in the

New Forest under woodland and heathland on Bagshot Beds, Barton Clay and Barton Sand. They are acidic, podzolic soils and most have impeded vertical water movement due to slowly permeable clayey horizons or compaction at depth. The dominant series (c40%) is the Holidays Hill, a stagnogley soil, which has clayey subsurface horizons but sandy horizons above allow lateral flow of surplus water. The common Rapley series, also a stagnogley-podzol, is developed in deeper sandy deposits and seasonal waterlogging is caused by slowly permeable compact subsoils. More freely-draining soils, such as the humo-ferric podzols of the Shirrel Heath series, have a prominent and frequently indurated Bh horizon in which sand grains are coated by metal-organic complexes.

Boldrewood association. This association covers areas in the Forest where stagnogley-podzols are predominant on drift deposits, notably the Plateau Gravels. Most of the soils occur in the open Forest, especially in heathland but also under broadleaved woodland. The dominant Boldrewood series may be extensive - at Beaulieu Heath, for example - and vertical water movement through this soil is restricted by dense subsoils and slowly permeable clayey substrates.

3.2.3 The water regime of two contrasted valley mires

The water regime is the set of hydrological conditions under which ecological and pedological processes occur. Stephill Bottom and Hive Garn Bottom were chosen as contrasting sites, following stratigraphic survey (Chapter 2), in order to investigate the variation in the water regimes of the valley mires. Both are typical of the regional variation in the valley mires of the New Forest. Hive Garn Bottom represents, a more complex situation than Stephill Bottom, with very variable lithology and much steeper relief, in association with both seepage step and valley bottom mires. As will be seen, these differences are reflected in the water regimes operating at each site. Soil and sedimentary analyses were carried out at Stephill Bottom and the methods and data are presented in Chapter 2. Hive Garn Bottom formed the study site for a joint research project with R.H.Allen (formerly of the Soil Survey of England and Wales) into the relationships between the soils and mire and heathland vegetation. Morphological, chemical and textural characteristics

of soil profiles were used to deduce their water regimes. This approach has the advantage of providing information based on features developed over larger time scales than would have been available from a one, or two, year process-monitoring study.

Stephill Bottom Both the field and laboratory data from the Stephill Bottom section (Figures 2.9, 2.16-22) can be used to relate the soil pits to soil series, and to incorporate catenary relationships into a soil water regime model for the site (Figure 3.3). The soils at Stephill Bottom can be assigned to the constituent sub-groups and related soil series of the Holidays Hill association, which is the dominant soil association in the Denny Lodge area.

Soil pit 1 (Figure 2.16), on the slope-crest, is a well-developed humo-ferric podzol of the Shirrel Heath series, exhibiting an albic E horizon and prominent Bh horizon. The indurated Bh horizon is a distinctive feature of these soils in the New Forest but, as was discussed earlier, this horizon is freely permeable and does not form an impeding layer. In a similar profile nearby (SU335020), analysis has shown the air capacity to be high throughout its depth (18% or more of total volume), creating a freely-draining soil (Allen and Staines, 1984).

Pit 2 is a humo-ferric gley-podzol which may be assigned to the Rapley series. The main zone of gleying is beneath the compacted horizon showing that the waterlogging is due mainly to the groundwater table. Lateral flow may develop above the compacted zone during periods of high rainfall and this may be responsible for the organic enrichment in the upper Bg horizon of pit 3. The absence of mottling suggests that the upper horizons in pit 2 remain free of waterlogging for most of the year. Pits 3 and 4 were sandy throughout and both could be related to the Isleham series, which develops in conditions of high groundwater throughout the year.

The section through the catena at Stephill Bottom is relatively straightforward and represents the simplest case in the New Forest. This is a function of the relatively pure fine sand facies of the Barton Sand exposed at this site with only a small drift component. Waterlogging

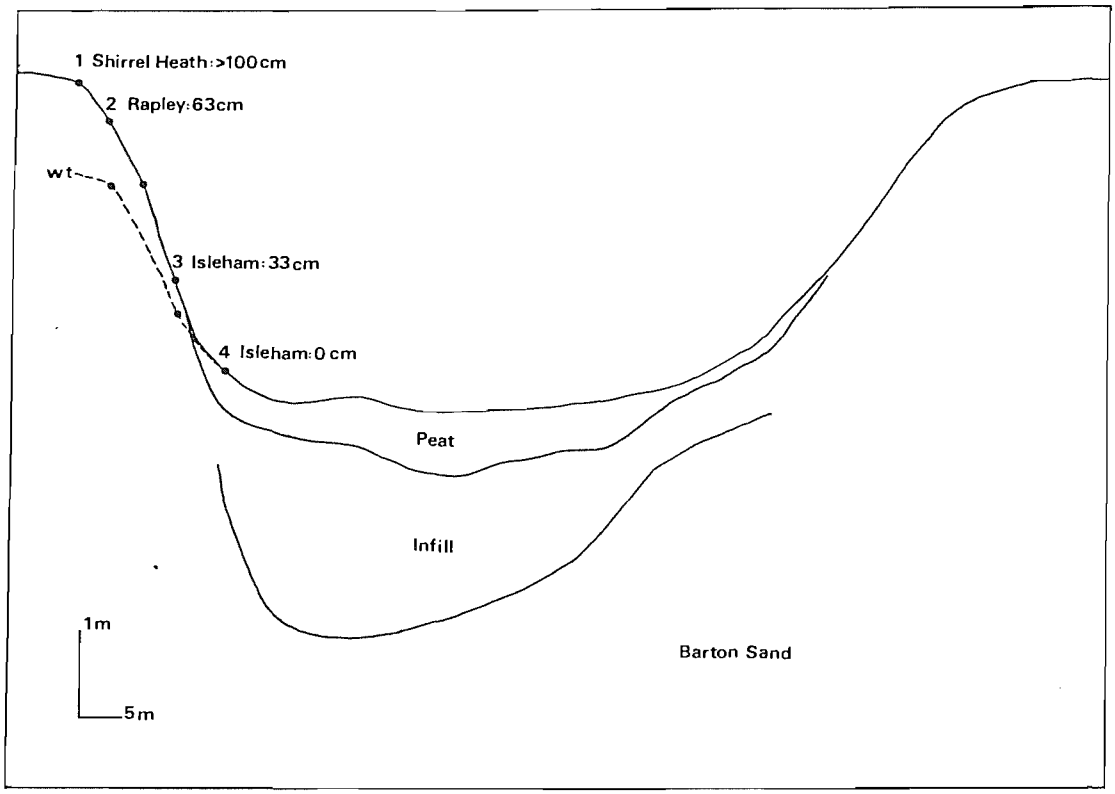


FIGURE 3.3 : Valley mire soil water regime for Stephill Bottom, showing the water table profile (June 1982). Depth of water table and soil series are given for pits 1 - 4 (see text).

in the Stephill Bottom area of the Denny Bog system is due mainly to groundwater. The high water table in the marginal zone of the mire and the wet heath is due to seepage from lateral movement near the surface, above the level of the central water track. This is perhaps the closest analogy to the ideal - and simplified - case in Ivanov's (1981) model of peat development (see Fig 3.1b). The data suggest a rapid flattening of the groundwater table at Stephill Bottom (Figure 3.3), reflecting the freely-permeable facies of the Barton Sand at this site. The discrepancy between the potential groundwater profile and the earth's surface in this case may be seen as, principally, a reflection of past periglacial processes in the New Forest. These have produced a landscape in which many facets are now relict features.

Hive Garn Bottom This is a small, steep valley cut into the edge of a high level terrace (at 105m O.D.) in the northwest of the Forest. The flinty loamy terrace deposits are thin and the soils contain subsurface seams of clay. At the terrace edge, where permeable deposits overly slowly permeable clays and loams, water seeping through heterogeneous Head (or colluvium) is associated with a seepage step mire. Below the seepage step, humid and wet heath communities occur on soils in this colluvium and further mire occurs in the valley bottom. The valley bottom mire and the seepage step mire are continuous at the head of the valley.

Systematic sampling of soils and vegetation was carried out within a 1ha (100m x 100m) plot extending from the terrace edge to the valley bottom. Thirty-six sample points were spaced at the intersects of a 20m grid, after a reconnaissance survey had been conducted to determine the spatial variability of soils and vegetation. Soil properties at the centre of each vegetation quadrat were examined in shallow pits and by augering. Their profile features including thickness of peaty and humose surface layers, and the particle size class, colour, mottling and stoniness of subsurface horizons were described using standard terminology (Hodgson, 1976). Profiles of five soils and a peat core were described in detail to help define the main soil classes identified.

The morphological properties of the soils sampled were used to infer the

main soil forming processes in operation. Samples were taken from key horizons for laboratory determination of particle size distribution, pH, cation exchange capacity, base saturation, organic carbon, nitrogen, pyrophosphate-extractable iron, aluminium and carbon, dithionite extractable iron and manganese and exchangeable cations. Undisturbed samples were taken for thin section examination and determination of water retention characteristics.

Using the classification system of Avery (1980) four map units were defined (Clarke and Allen, 1986) corresponding to the principal landforms (Table 3.1). These comprised two simple map units (1 and 4) in which all profiles share certain profiles, and two complex units in which a range of contrasted properties occur.

The soil and topographic data were used to develop a soil water regime model which may be used to explain the vegetation patterns (Figure 3.4). The surrounding gravel-capped ridges provide a catchment area in which water moves vertically and laterally through permeable soil horizons in drift deposits, or laterally through permeable strata within the Bracklesham Beds. Movement of water into the soils on the seepage step occurs mainly just below the ground surface, and so the soil water regime depends on the seasonal supply of water from the immediate plateau catchment. During drought conditions, the water table in the seepage step mire may drop below the level of the peat (e.g. summer 1984), resulting in significantly more decomposed peat deposits compared to the valley bottom mire which remains waterlogged. Water movement downslope of the seepage zone is laterally through permeable soil horizons, and depends on slope, thickness of permeable horizons and irregularities in the sub-surface slope of the underlying Tertiary deposits. Figure 3.5 shows the contrast in air capacity between the upper permeable horizons and the lower impeding layers from a soil pit on the valley-side. The permeability decreases abruptly with depth and, as shown by the reduction in air capacity, is very low below 55cm. The valley bottom mire, being in a central and lowlying situation, receives laterally flowing water from a wider catchment than the seepage step mire and sustains a continuously high water table.

Table 3.1 Distribution of soil types at Hive Garn Bottom (from Clarke and Allen, 1986)

Map Unit	Landscape Position	Soil characteristics	Soil subgroups after (Avery, 1980)
1	Terrace margin	Occasionally waterlogged stony sandy or loamy soils with bleached subsurface horizons over slowly permeable compact subsoils	Stagnogley podzols
2	Seepage step	More or less permanently waterlogged loamy or loamy over clayey soils with humose or peaty surface horizons and compact subsurface horizons	Argillic stagnohumic gley soils and argillic gley soils
3	Irregular slope	Seasonally waterlogged stony loamy or loamy over clayey soils with variably developed bleached subsurface horizons and slowly permeable subsoils	Stagnogley podzols, stagnogleyic argillic brown earths and typical argillic gley soils
4	Valley bottom	Permanently waterlogged loamy or loamy over clayey soils with thick peaty topsoil horizons and intensely gleyed subsoils with some soils in thick peat	Typical humic gley soils and raw oligofibrous peat soils

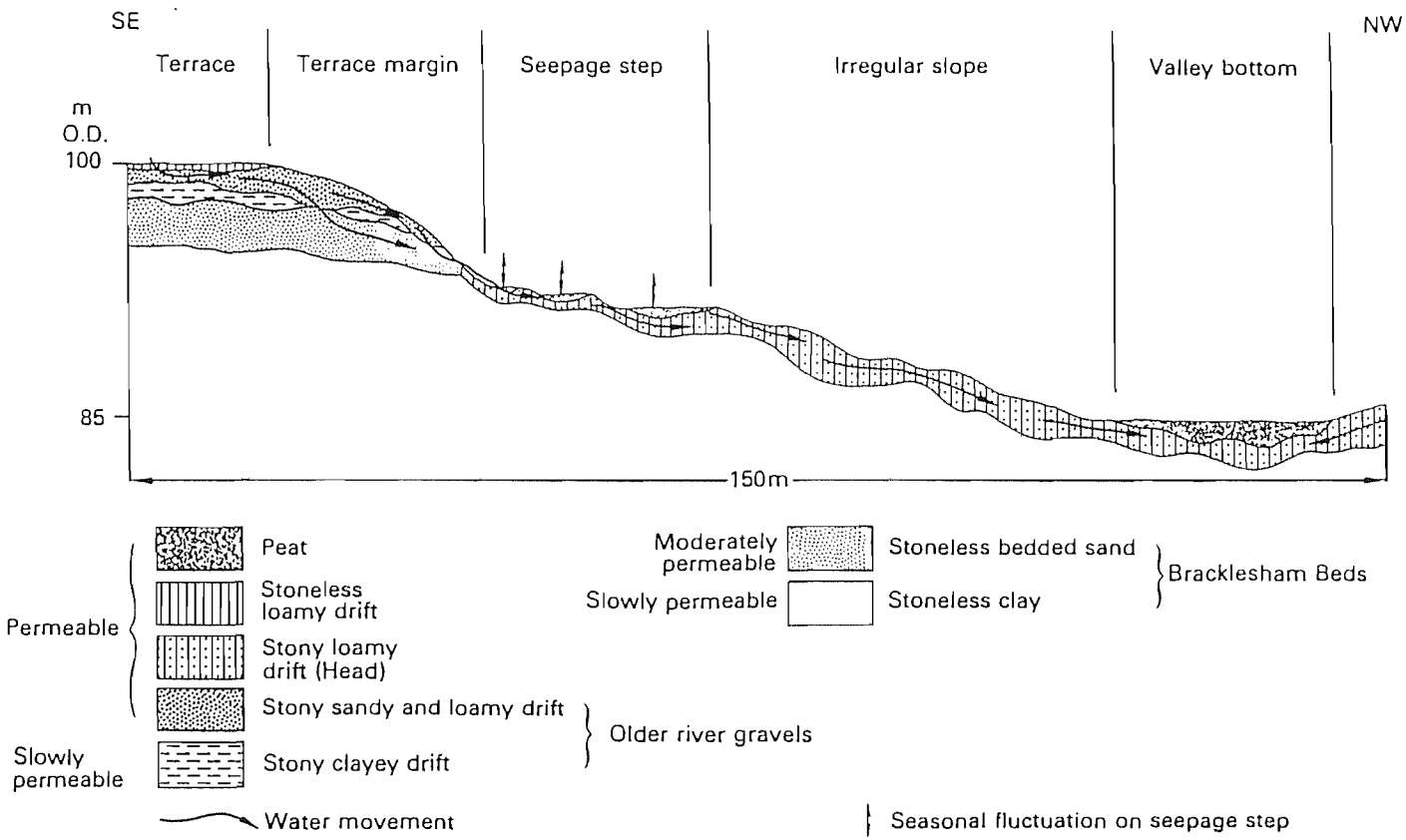


FIGURE 3.4 : Soil water regime for Hive Garn Bottom (from Clarke and Allen, 1986).

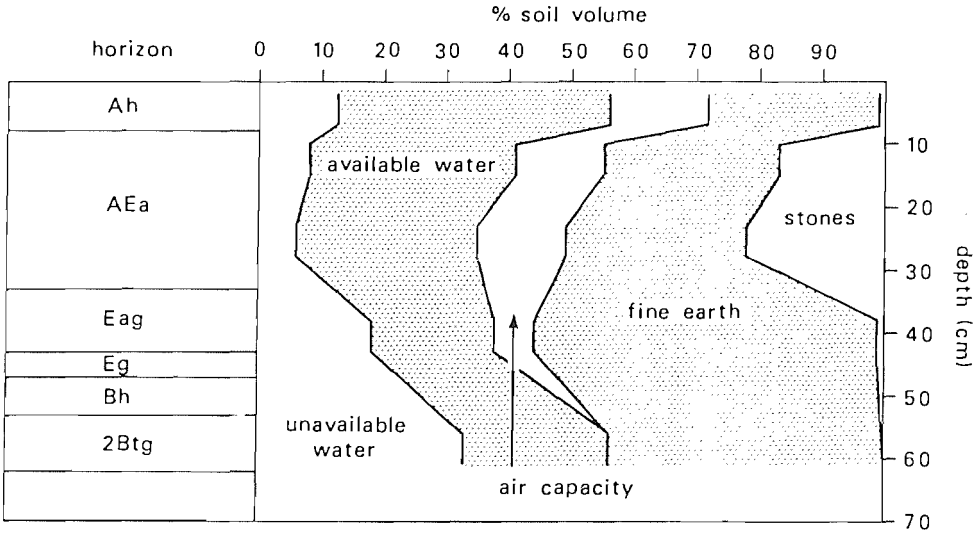


FIGURE 3.5 : Water release profile from a valley side soil in the Hive Garn Bottom study plot (analysis by Soil Survey).

3.2.4 Summary

The argument developed so far can be summarised in the light of the data reviewed above:

1. The soil water regimes of a large proportion of New Forest soils have one feature in common, which is the presence of relatively permeable upper horizons over slowly permeable lower horizons.
2. Groundwater flow and throughflow moving laterally in the upper soil horizons are the most important components of the valley mire water budget. The mosaic of different plant communities is largely dependent on the pattern of soil distribution and their associated water regimes, particularly the three dimensional variation in soil hydraulic conductivity.
3. These runoff processes are similar ecologically in that they produce surface saturation. Therefore, the dynamics of these hydrological processes over 'ecological time' is reflected by changes in plant community composition.
4. Thus, the development of peat is related to the development of the soil profile and its water regime. In order to explain the more ultimate causes of mire formation, causal relationships must be established first at a more proximate level - the level of the soil profile.

3.3 Peat inception and soil profile development

3.3.1 General concepts of pedogenesis and long-term vegetation change

1. The functional distinction made in Chapter 1 between mires as plant communities and as peat-accumulation systems is an important concept to the investigation of mire origins. The production of peat is a soil process and peat inception is an integral part of pedogenesis. The conventional model of pedogenesis was first formulated in Russia during the nineteenth century, and was expressed by Jenny (1941) who stated that soil formation or development(s) is a function of parent material (p), climate (c), vegetation and other organisms (o), relief (r) and time (t), such that the relationship may be expressed

as follows:

$$s = f\ (p,c,o,r,t)$$

Theoretically, this equation may be differentiated with respect to each variable so that the rate of change in soil development due to various factors can be determined. Jenny's work was seminal in that it emphasised the dynamic nature of soil development and attempted to formalise the factors affecting soil development. However, the model has proved difficult to apply quantitatively in this form because some variables are discrete, non-overlapping units and others are composite in nature. Nevertheless, an important result from this formulation is the observation that, even if the intensity of all factors (except time) remains constant, pedogenesis will still take place. In other words, changes in the properties of soil profiles may be due simply to constant processes acting over time alone and no other change in the system; there does not need to be a change in the intensity of causal factors to bring about peat inception. The timing of peat formation during the postglacial may represent no more than the period of time required for this feature to develop as a result of the operation of a constant set of processes (the relaxation time of the system). Indeed, depending on the length of the relaxation time, a direct temporal correlation between the causal event and peat inception should not be expected. A discussion of the geomorphological factors affecting the relaxation time in landform evolution is given by Brunsden and Thornes (1979). In mires, the strength of coupling between the hydrological and biological components of the system will be most important in determining the relaxation time and sensitivity of the system to changes in external variables. It should be expected that different mire types (e.g. geogenous vs ombrogenous) will show different degrees of coupling between different components of the system. This also applies to minor variations in type, such as the water-receiving and water-shedding zones in blanket mire. In the New Forest, there will be not only spatial variations in the initial conditions controlling peat development (e.g. lithology), but it is also probable that there will be variation in the degree of coupling (e.g. valley bottom and seepage step mires). This variation will be expressed in the time required for the soil to reach a certain state,

such as peat inception. Thus, variation between sites in the rate of peat inception is possible without any change in the intensity of causal factors over time. This argument may be summarised as stating that peat development is a natural consequence of interglacial conditions in the New Forest, and that there is no particular formative event for the specific timing of peat inception, which merely represents the relaxation time of the system. Spatial variation in the rate of peat inception simply reflects spatial variation in the initial conditions and the degree of coupling between the components of the system. Such a model, however expressed, is fundamental to soil and vegetation change and has logical primacy over hypotheses invoking deforestation, climatic change, etc. As such it should be regarded as a null model of peat formation against which all other causal hypotheses should be tested.

2. Two cyclical schemes of soil and vegetation change (Iversen, 1958; Turner and West, 1968) are relevant to the observation that changes may occur purely as a function of the relaxation time required to reach a new equilibrium. Both models are based on palaeoecological data from interglacial periods, and make the assumption that glacial periods limit vegetation growth and renew soil-forming surfaces. The latter assumption, at least, cannot be applied simplistically to areas such as the New Forest, which have escaped glaciation. Iversen (1958) describes a cycle of change which proceeds through several stages:

cryocratic ▶ protocratic ▶ mesocratic ▶ telocratic ▶ cryocratic

During the cryocratic stage, coldness is at its maximum and stable vegetation is unable to develop. With the retreat of ice, raw mineral surfaces remain with neutral or basic nutrient status (the protocratic) and a closed vegetation cover develops as plant colonisation takes place. As climate approaches its optimum, forest cover reaches a maximum and fertile soils have developed (the mesocratic). Towards the later stages of the interglacial (the telocratic) soils become leached and forest receeds with the development of heath. Although Iversen envisages a climatic oscillation, from glacial to interglacial, these stages are essentially a function of soil weathering over time. Turner and West (1968) distinguish four zones between glacial periods. Like

Iversen's model, the series of vegetation changes is driven by soil development under climatic oscillation, but Turner and West also incorporate differential species responses in terms of their dispersal biology:

Zone I	Pre-temperate	*Betula* and *Pinus* dominate
Zone II	Early temperate	mixed oak forest
Zone III	Late temperate	late immigrating species dominate, such as *Abies* and *Carpinus*
Zone IV	Post-temperate	*Betula* and *Pinus* dominate again

3. A catena is a topographic sequence of soils whose differences result from the downslope changes in soil wetness, and this is the most appropriate scale of investigation into peat inception in the New Forest for two reasons. Firstly, it has been shown that the water regime of valley mires is dependent on groundwater and soil variation in the whole catchment. The valley mire communities and the surrounding semi-natural vegetation of their catchments are a reflection of present-day catenas. Secondly, changes in soil wetness over time will be linked across a catena, so that evidence for the cause of soil and vegetation change may be obtained from the whole catena (see, for example, Cruickshank and Cruickshank's, 1981, study of podzolisation and associated peat development). Thus, in order to explain the cause of the present valley mire water regimes, it is necessary to consider the soil-forming processes that have operated in the New Forest at all points along the catena. In addition to gleying and peat formation (both expressions of waterlogging), the following factors have been involved in the development of New Forest soils:

(i) clay illuviation
(ii) subsoil compaction
(iii) slope deposits
(iv) loess
(v) podzolisation

The rest of this section will review the evidence for pedogenesis in the New Forest and will discuss the possible relationships between these factors and the development of valley mire water regimes. Despite a growing body of recent research on heathland soil development, including the New Forest, there has been little attempt so far to integrate the various processes which have been shown to occur.

3.3.2 Pedogenesis in the New Forest

3.3.2.1 Clay illuviation

Clay illuviation refers to the development of a B horizon enriched in clay due to the movement of clay particles suspended in the soil solution from A and E horizons above. The resulting illuviated zone is referred to as an argillic (Bt) horizon (Avery, 1980), which can be defined on the basis of several micromorphological criteria indicating evidence of clay translocation (McKeague *et al*, 1980). This is normally shown by the presence of strongly orientated clay-size material occurring as coats (argillans) around larger particles or as concentrations within voids (pore fillings, papules or disrupted argillans).

This process has been a common feature in the genesis of many soils in Britain and is even more developed in continental Europe. Clay illuviation is an important palaeo-environmental indicator because of the conditions necessary for the process to occur, and is present in many soils as a 'relict' feature (Catt, 1979a). The optimal conditions for clay movement are in the pH range 5-7 (Stobbe, 1961; Deshpahande *et al*, 1968; Zonn, 1975); at higher pH values carbonates promote flocculation of clay particles and, conversely, with increasing acidity the particles become strongly bound to aluminium ions. The clay is washed down pores and cracks in the soil, particularly in a seasonal wet-dry climate where summer drying produces shrinkage cracks (Burnham, 1967; Keely, (1982).

Illuvial clay features can be divided into two groups; those which are the result of Flandrian (and possibly Late Devensian) processes, and those which are attributable to pre-Devensian pedogenesis. The latter are encountered in 'palaeoargillic' horizons, occurring as clay aggregations which have been disrupted by periglacial activity and no longer show any relationship to the present soil fabric. The soils have other features of intense weathering which can also be attributable to warm interglacial stages before the Devensian (Catt, 1979a).

Micromorphological analysis of soils in the New Forest (Eide, 1982; Allen and Staines, 1984) has shown illuviated clay horizons to be widespread. Figure 3.6 shows the distribution of clay illuviation features in soils at the Hive Garn Bottom site. The presence of palaeorgillic horizons, due to pre-Devensian weathering, in the terrace soil demonstrates that at least two phases of clay alluviation have taken place on the plateau (see also Reynolds, 1987). Palaeoargillic horizons are absent away from the Plateau Gravel deposits here and elsewhere in the New Forest. The terraces and slopes are of different ages and have undergone different geomorphological development, with the plateaux having been relatively stable since at least the last interglacial, whilst the slopes are primarily a Devensian feature. This contrast is reflected by the distribution of soils and vegetation (Fisher, 1975b; Clarke and Allen, 1986), and emphasises the distinction made by Fisher (1975a) of soil and vegetation units in the New Forest based on geomorphological criteria. Similar palaeoargillic soils are found on pre-Devensian terraces elsewhere in southern England, including the Thames, Kennet, Severn and some East Anglian and Wealden river basins (Bullock and Murphy, 1979; Catt, 1979a; Abbas, 1979; Abbas and Burnham 1983). Clay orientated with respect to the present soil fabric is indicative of Flandrian illuviation and occurs in the terrace soils, the plateau-margin and elsewhere on the valleyside, except in the mineral sediments beneath the valley mire (Figure 3.6).

Flandrian clay illuviation is generally thought to be a relict feature from earlier in the post-glacial, reflecting brown soil conditions. The main phase of illuviation is conventionally regarded as having taken place during the so-called 'climatic optimum' of the Atlantic and Sub-Boreal periods (see Bullock and Murphy, 1979), although there is evidence of illuviation during the Late glacial/early Flandrian in southern England (Weir *et al*, 1971) and the Alleröd in central Europe (e.g. Schönals, 1960). Although timing of events is uncertain, clay translocation has preceded more recent podzolisation in British, Western European and Russian soils (Guillet, 1970; Zonn, 1975; Valentine and Dalrymple, 1975; Abbas, 1979; Eide, 1982). Inhibition

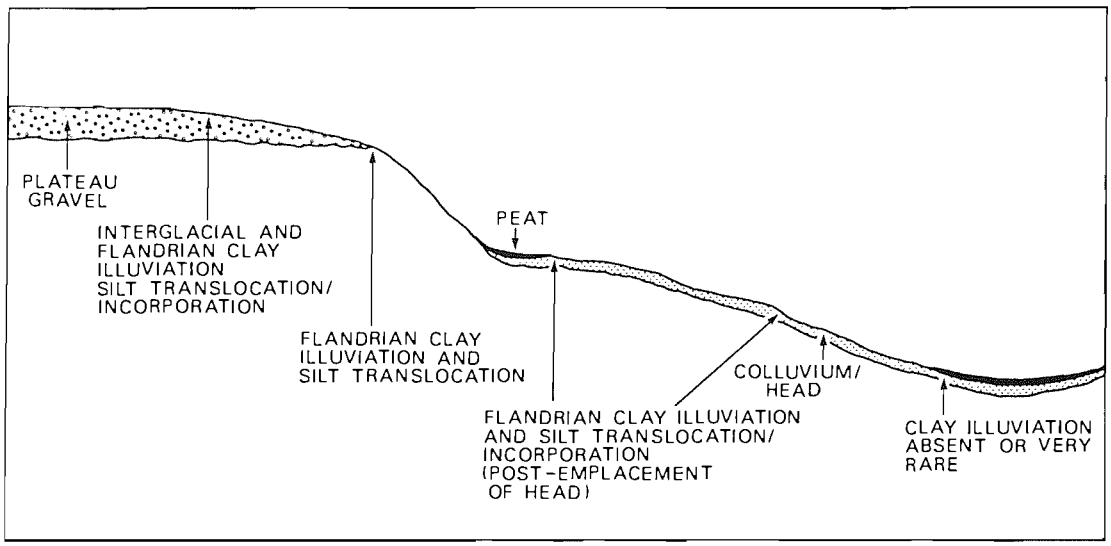


FIGURE 3.6 : Distribution of translocated clay and silt in the Hive Garn Bottom catchment (Clarke and Allen, unpublished data).

of clay illuviation by podzolisation is to be expected since the increasing soil acidity would create conditions which are incompatible with the movement of clay, as discussed above. Some archaeological studies (Evans, 1972; Limbrey, 1975) have inferred clay movement as a direct result of forest clearance and agriculture. Fine structure analysis of argillans by Scaife and MacPhail (1983) has been correlated with land-use history from the Neolithic, through Saxon to Mediaeval periods at Selmeston, East Sussex. However, such detailed interpretation is difficult and the present archaeological evidence is not conclusive. In Eide's (1982) study of buried soils under abandoned enclosure banks in the New Forest, there was no evidence for clay illuviation occurring after the banks had been constructed. Clay illuviation had taken place earlier than 1200+ BP at Burley Moor and c2500 BP at Dark Hat, the former age estimate being based on radiocarbon date from the buried Ah horizon of 2235 $\pm$ 80 (see 3.3.2.5 for a discussion of dates). Clay illuviation has been shown to have taken place in the absence of Man at several sites (e.g. Hammond, 1968; Zonn, 1973; Valentine and Dalrymple, 1975); the evidence is best interpreted as reflecting a major phase of illuviation in the early-mid Flandrian (Catt, 1977, 1979a), most of which was simply a function of soil chemistry over time and climate.

The redistribution of clay within the soil profile is obviously significant to the soil water regime and the genesis of waterlogged soils; it may also help to explain the widespread occurrence of peat formation in the mid- to late Flandrian in the New Forest. The formation of surface-water gleys is attributable to clay translocation in some cases (Bouma and Van der Plas, 1971; Thomasson and Bullock, 1975; see also Murphy, 1984), and has been linked with the development of blanket peat by Taylor and Smith (1972, 1981) as discussed earlier. Zonn (1975) describes how the development of an illuviated horizon within forest soils in eastern Europe creates a seasonal stagnant-lateral outflow water regime. In the New Forest, clay illuviation appears to have been an important factor in the present water regime of many valleys containing mires.

3.3.2.2 Subsoil compaction

Many New Forest soils have compact subsoils or horizons with high packing density, but most are not sufficiently well-developed to meet fragipan criteria (indurated horizons - see Avery, 1980). At Hive Garn Bottom, compact horizons, or those with high packing density, were found on the terrace (104-156cm), the terrace margin (60-86cm) and beneath the seepage step mire (70-90cm) but were not detected further downslope or in the valley bottom. The compaction was coincident with the occurrence of slowly-permeable zones, but the latter also coincided with lithological discontinuities. Compaction in this case, therefore, should be regarded as a contributory, rather than primary, cause of reduced soil permeability (although more research is required - the widespread Rapley series, for example, has reduced permeability mainly due to compaction). Avery (1980) suggests that many slowly-permeable soils are related to the development of compacted horizons. Reynolds (née Eide) and Catt (in press) describe much shallower (15-27cm) fragipan horizons from three soils at Dark Hat, which are hard, brittle compact zones with high bulk density, but no cementation, and sharply defined lower boundaries. They suggest that these horizons originated through compaction by cultivation of the soil when its moisture content was at, or above, field capacity. These differ from the more widespread compacted subsoils such as those described above from Hive Garn Bottom.

Subsoil compaction occurs in other heathland areas where semi-natural soils are preserved, including Ashdown Forest (Abbas, 1979), Surrey (MacPhail, 1983) and Lorraine, France (Guillet, 1970). The persistence of poorly-structured, impermeable subsoils in Ashdown Forest is promoted by low cation exchange capacities of clayey horizons. This means that they have poor shrink-swell characteristics (Abbas, 1979). The low cation exchange capacity of most heathland soils may be significant to the survival of such features, which are generally attributed to the effect of permafrost (see Fitzpatrick, 1955). The soils in Ashdown Forest exhibit more extreme subsoil compaction, including the presence of fragipans, compared to other lowland heathlands. Abbas (1979) attributes their origin to cryostatic pressures generated under

a periglacial environment. Catt (1979a) suggests that cementation of some fragipans is probably a Flandrian feature, and that the cementation was localised by earlier compaction resulting from the repeated formation of ice laminae near the junction of permafrost and seasonally thawed active layers. Contemporary freeze-thaw action in the Alps has been observed to cause reduced soil permeability and peat development (Bouma and Van der Plas, 1971). This aspect of New Forest pedogenesis would benefit from further investigation.

3.3.2.3 Slope deposits

Colluvium is an unstratified or crudely stratified deposit that has accumulated as a result of slope and mass movements, and is sometimes distinguished from 'head'. The latter term is often confined to material formed under periglacial conditions, but is also frequently used to encompass not only solifluction deposits but also intermediate sediments between colluvium and true alluvium. In this respect, narrowly-defined terms are unhelpful for two reasons. Firstly, the role of fluvial processes in the former periglacial environment has been underestimated, and water erosion and deposition was probably the most important element in the periglacial landscape of southern England (Worsley, 1977). Secondly, the evidence from the New Forest suggests that slope or colluvial deposits are compound sedimentary units with components derived from both Devensian and Flandrian phases of deposition.

Slopes in the New Forest are mantled by drift deposits and the presence of colluvium (Figure 3.4) at Hive Garn Bottom has a profound effect on soil-vegetation relationships. This results in bisequel soil profiles with contrasted hydraulic conductivity characteristics in the two layers. On the valley-side, the reduction in permeability corresponds to the junction between the light grey clay of the Bracklesham Beds and the overlying colluvium comprising brown loamy sand with gravel, at approximately 53cm for the profile in Figure 3.5. This creates the conditions for lateral flow of water (Clarke and Allen, 1986).

The colluvium on the slope at Hive Garn Bottom, from particle size

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analysis, comprises drift derived from the Plateau Gravel and from upper sandy facies of the Bracklesham Beds. The lower, sandy horizons of colluvium also contain loessial inclusions. In the absence of dated material, it is frequently assumed that such colluvial deposits originate from the main Devensian period or the Loch Lomond Stadial, the last known cold stage. The evidence from Hive Garn Bottom is consistent, in part, with this view. Firstly, the distribution of palaeoargillic horizons shows that, in contrast to the terrace, the slope was relatively unstable during the Devensian with significant erosion. Secondly, the deposition of colluvium precedes vertical translocation of both clay and silt into its lower horizons. Thirdly, the micromorphology of the sandy drift with loessial inclusions shows characteristic tight packing in thin section (J.Hollis, 1984, pers comm), indicative of periglacial activity. While the underlying clayey Bracklesham Beds also show signs of periglacial disturbance with loessial inclusions. Fourthly, the long axes of stones show a down-slope alignment, suggesting periglacial mass movement. However, two radiocarbon-dated macrofossil cores (see Chapter 5.5) show significant sediment accumulation during the mid-Flandrian. These deposits are at least 34cm thick in the valley bottom (118-84cm) and 16cm at the seepage step (63-47cm).

The end of the mid-Flandrian phase of deposition is more precisely defined than the beginning. Macrofossil and sedimentary analyses show a progressive decline in inorganic sedimentation between c2500 and 1500 BP. This was accompanied by woodland regeneration (Willis, 1985) with high frequencies of *Betula* in association with *Quercus* and coryloid pollen. Since then sedimentation has continued to the present at much lower rates. A radiocarbon sample from the middle of the sedimentary unit in the valley bottom (95-98.5cm) yielded a date of 2700 $\pm$ 70 BP but, for reasons discussed in Chapter 5.5, this is thought to be an underestimate of the real age by as much as 1000 years. Overall, the radiocarbon dates show a period of deposition corresponding to the Middle-Late Bronze Age and early Iron Age periods (see Appendix 2). The upper part of the sediments coincides with two clearance episodes separated by a regeneration phase, while the pollen assemblage in the lowest sample (118cm) from the valley bottom sediment contained

a high percentage of shrub, mainly Coryloid, pollen (Willis, 1985). There were indicators of relatively open habitats, including Ericaceae, in the assemblage and the main tree taxa were *Quercus*, *Tilia* and *Alnus*.

There is further evidence from Stephill Bottom of mid-Flandrian deposition of colluvium as slope-foot and valley infill deposits (see Chapter 5.4). The uppermost (largely) inorganic unit has been dated to 3080 ± 210 BP (macrofossil assemblage zone 1). This is overlain by a zone of declining inorganic sediment deposition and increasing organic accumulation (m.a.z.2). From sediment accumulation rates (see Chapter 5.4), this phase can be inferred to have occurred between 3000 and C1600 BP. The inorganic infill contains preserved organic remains up to 1.4m below the 'peat' base (m.a.z.2), as was described in Chapter 2, including remains of *Alnus*. Pollen analysis shows similar spectra (Dodd, 1985) in both macrofossil assemblage zones 1 and 2. Several herb taxa are restricted to these zones and there are relatively high frequencies of Ericaceae pollen comparable with present levels. The main tree taxa represented are *Betula*, *Quercus* and *Alnus*, with abundant Coryloid pollen.

There is other less well-dated evidence of mid-Flandrian colluvial deposition in the New Forest. Inorganic sediments within valley mire peats were first noted by Rose (1953) at Wilverley Bog, and have since been found to be widespread in the Forest including Digden Bottom (Davies, 1972), The Noads (Dobson, 1975) and Barrow Moor (Figure 2.5 and Dawson, 1978), amongst other sites. Eide (1982) found evidence of surface erosion in the soil buried beneath the bank soil at Long Slade Bottom, and suggested that this may have been the source of colluvial fill in the valley below. The valley bottom colluvium overlies a buried soil which, itself, is developed within silty colluvium indicating two phases of colluvial deposition at Long Slade Bottom during the post-glacial (Catt *et al*, 1987). Interpretation of the pollen assemblages from this site is extremely complex due to the progressive (and probably episodic) deposition of sediments, in addition to the 'normal' complicating factors associated with soil pollen assemblages. However,

the presence of weak clay illuviation in the lower colluvium suggests an early Flandrian date for this sediment. The pollen spectra in the buried soil indicate the thicker, upper colluvium post-dates the expansion of *Alnus* and the decline of *Ulmus* (i.e. less than c4500 BP - see Barber and Clarke, 1987).

In his study of dells in the north-west of the Forest, Tuckfield (1986) distinguishes two types of superficial slope deposit on the basis of inferred process. The first is a lower deposit of sandy or clayey head containing fragmented flints which, from lithology, particle form and sedimentary structure, has the characteristics of a periglacial solifluction deposit. Tuckfield assigns this, by default, to Zone III, the Loch Lomond Stadial. This is overlain by a complex of colluvial deposits - variously comprising sand, reworked head, and sand and clayey sand with stones - which are attributed to slumping and slope wash during the Flandrian. At Long Bottom (only 1400m from Hive Garn Bottom), buried soil horizons were found beneath 70-75cm of sediment. These contained a pollen assemblage (including *Sphagnum* spores) which post-dates the expansion of *Alnus*. The overlying sediments comprised a stony sandy deposit with reworked head beneath c20cm of podzolic horizons (texture unspecified). Although Tuckfield's detailed interpretation is hampered slightly by the possibility of post-depositional textural changes, such as clay translocation, there is a marked similarity between his findings and the evidence from Hive Garn Bottom.

All four sites for which relative dating is available (Hive Garn Bottom, Long Bottom, Long Slade Bottom and Stephill Bottom) show that the main phase of Flandrian colluvial deposition post-dates the expansion of *Alnus*. This event is known to be diachronous within the Forest (Clarke and Barber, 1987) and has been dated from 5170 $\pm$ 50 BP to 8590 $\pm$ 120 BP. Radiocarbon dating from the Hive Garn Bottom catchment and the Stephill Bottom section shows that the main period of deposition continued up to about 2500 BP and 3000 BP, respectively. This was followed by a phase of declining inorganic deposition until about 1500 BP. The earliest pollen assemblages from the colluvial and infill deposits show the presence of open habitats, including the probable establishment of heathland, at both these sites. Woodland composition already appears

modified and there are indicators of agricultural activity in the assemblages, as well as continuing clearance-regeneration episodes at Hive Garn Bottom.

There is, therefore, a strong case for an anthropogenic origin of Flandrian colluvium erosion and deposition in the New Forest. Dating suggests that the main phase occurred from the Middle Bronze Age (and probably earlier) to the early Iron Age (3000+ to 2500 BP). Prior to this the main periods of deposition probably took place during the Devensian and Late Devensian cold stages under periglacial conditions. This demonstrates an episodic development of New Forest slope deposits. Elsewhere in southern England, there has been increasing recognition of the role of Man in the formation of Flandrian colluvial, alluvial and infill deposits (e.g. Shotton, 1978; Limbrey, 1978; Brown, 1982). Burrin and Scaife (1984) attribute most of the valley sediments in the River Ouse, Sussex to increased sediment supply within the catchment as a result of anthropogenic deforestation since Neolithic times. They also suggest that early Flandrian sediments in southern Wealden rivers and the Medina, Isle of Wight (Scaife, 1982) are due to Mesolithic activity. In Buckinghamshire, charcoal flakes from a buried soil yielded a radiocarbon date of 3910 $\pm$ 220 BP beneath up to 3m of sediment, which Valentine and Dalrymple (1976) suggest is a combination of slopewash and ploughwash initiated by clearance and cultivation in the late Neolithic or early Bronze Age. Similarly, 0.5 - 1m of clay alluvium in the Windrush valley, Oxfordshire is thought to be due to local forest clearance and ploughing in the Late Bronze Age or early Iron Age, from buried tree roots dated to 2660 $\pm$ 85 BP (Hazelden and Jarvis, 1979). Brown and Barber (1985) estimate that in the Ripple Brook catchment, Worcestershire, there was a 500% increase in sediment yield due to deforestation, cultivation of slopes and resultant soil erosion during the late Bronze Age and early Iron Age (2900 - 2300 BP). Inorganic floodplain accumulation showed a dramatic increase during this period from very low levels earlier in the Flandrian, and declined more slowly to a level greater than the early Flandrian rates and continuing to present.

The anthropogenic origin of the upper colluvial deposits in the New

Forest is of significance not only because they indicate soil structure deterioration and erosion, but also because these sediments are an important component of the bisequel soil profiles which are responsible for the generation of lateral flow in the valley mire water budget.

3.3.2.4 Loess

Although a formerly widespread cover of loessic deposits over much of southern England is now generally accepted as a result of a growing body of research (Perrin *et al*, 1974; Catt 1977, 1978, Burrin, 1981), the presence of aeolian sediments was first recognised much earlier (Prestwick, 1864; Wooldridge and Linton, 1933; Kirkaldy and Bull, 1940) and was described in the south Hampshire area by Palmer and Cooke in 1923. Part of the failure to realise the full significance of loess in southern England was due to an overly-rigid definition of terms by some workers (see Lill and Smalley, 1978 for example, and Catt's 1979b response). However, many of the loessic deposits are thin and weathered, and are often mixed with other sediments by periglacial, colluvial and biological processes. This can lead to confusion over the provenance of some loessic-type deposits, particularly with regard to reworked floodplain sediments (see Burrin, 1981, 1982; Gallois, 1981; Burrin and Scaife, 1984).

The ecological consequences of loess deposition have received virtually no attention, except for brief discussions by Catt (1978) and Limbrey (1978). Loess and coversands have been recognised as important in the development of chalk heath in W. Sussex and East Anglia (Perrin, 1956; Perrin *et al*, 1974) and on serpentine soils in the Lizard, Cornwall (Coombe *et al*, 1956), but the wider implications for postglacial vegetation change have not been considered. On the basis of physical and chemical properties, three main features can be identified as important when predicting the possible ecological effects of a loessic component in soils:

1. Loess has a valuable moderating effect on the textural characteristics of extreme soils (Catt, 1978) and, on weathering, is a source of nutrients and clay particles in siliceous and clay soils. The loessic brickearths are highly fertile.

2. Silt is the most easily transported grain size because more energy is needed to entrain the higher mass of sand particles and to overcome the greater attractive force between clay particles. Hence, loess is highly susceptible to erosion.

3. When dry or slightly moist loess is highly porous, has a low bulk density and, mechanically, is relatively firm. However, flooding, temporary waterlogging and other processes rapidly cause structural breakdown, probably by disruption of clay bridges which space the silt particles apart (Catt, 1977). This leads, firstly, to a greater susceptibility to erosion and secondly, to the formation of a hard, non-fissured, impermeable and often laminated surface-capping which can cause waterlogging in otherwise well-drained soils (Catt, 1978). Down-profile translocation of silt can promote surface-waterlogging, particularly in pelostagnogleys (Thomasson and Bullock, 1975).

In South Hampshire the loessic brickearths, such as the original 'Hamble' soil series, extend from the West Sussex plain to the western shore of Southampton Water (Kay, 1939; Fisher, 1971; Catt, 1977; Fordham and Coleborne, 1984). Brickearth in the New Forest is widespread but locally restricted, and its mode of origin is enigmatic (Fisher, 1971; Keen, 1980). However, a loessic component in the upper horizons of soils is much more common in the New Forest, being most noticeable as a thin silty drift on the terraces (e.g. Fisher, 1975a).

The chronology of loess deposition and its subsequent fate is important in relation to its ecological effects in the New Forest but the available evidence is incomplete. Indeed, there is little direct evidence for the age of loess deposits in Britain - most are thought to be of Late Devensian age but four areas indicate at least two periods of deposition during the Pleistocene (Catt, 1978; Reynolds, 1987). In central Europe at least three phases of loess deposition during the Devensian are found:

1. early glacial : 46000 BP
2. Pleniglacial A : 28200 BP
3. Pleniglacial B : 12200 BP

Pollen and faunal evidence indicates that loess accumulated under relatively cold and dry conditions with steppe vegetation (Fink and Kukla, 1977). Similar divisions occur in central France, but in NW Belgium and NE France, closest to Britain, the older Wurm deposits are missing (Catt, 1978). Most of the British loess is thought to be the 'tail end' of the North European Pleniglacial B deposits (Perrin *et al*, 1974; Catt, 1977). A westward thinning and fining of aeolian sediments in England (Perrin, 1956; Harwood *et al*; Catt, 1978; Lee, 1979; Eide, 1982; Vincent and Lee, 1981; Catt and Staines, 1982; Roberts, 1985) accords well with the pattern of winds due to a stable anticyclone centred on Scandinavia proposed by Hill and Smalley (1978). The frequent incorporation of loess in solifluction deposits and periglacial soil structures has led Catt (1977, 1978) to conclude that the loess was laid down just before or during the last cold stage, and he points out that loess underlies Older Dryas deposits in Kent. This interpretation is consistent with the evidence from Hive Garn Bottom (see previous section). Here, loess is thought to occur as a thin drift and silt component in the upper horizons of terrace soils in the Plateau Gravels, but is also present on the valley slope as inclusions in the lower, periglacial colluvium and in disturbed layers of the underlying solid geology. However, an older date for loess deposition in the New Forest is suggested by Wintle (1981) using thermoluminescent dating (see Wintle and Catt, 1985 for a review of methods). In an early application of this technique, Wintle estimated loess deposits at Sturtmoor Pond (SU274180) to have been buried at 14500 BP, or possibly earlier (17200 BP).

If loess deposition is regarded as almost ubiquitous south of the Devensian glacial ice-limit (Catt, 1978; Jones, 1981), then there must have been considerable erosion. This is because there are few, if any, areas of unweathered loess left in Britain and elsewhere loess survives as a reworked silty drift. Catt (1978) identifies three categories of erosion controlling the present-day distribution of a once continuous sheet of loess. Firstly, removal by Late Devensian solifluction and mixing with head and parent material by cryoturbation. Secondly, stream, sheet and wind erosion in the Late Devensian and early Flandrian. Catt speculates that higher precipita-

tion than the continent during this period may account for the sparser loess deposits in Britain. Thirdly, loessial topsoil was removed in late Flandrian colluvium as a result of the influence of man on soils.

Both Catt (1977) and Jones (1981) suggest that, in addition to coastal sediments, loess is present in southern England as Flandrian alluvial and colluvial storage. Recent research on floodplain alluvium and valley fill in the Weald has supported this view (Burrin, 1981, 1982; Burrin and Scaife, 1982). However, much of this interpretation is based on particle-size characteristics of these sediments, and this may not be sufficient to discriminate loessial-material from silt-sized sediments derived from the catchment parent lithology (Gallois, 1981). Definitive identification of loess can be made on the basis of a suite of physical and chemical properties (Pye, 1984), comprising grain size and shape, surface texture, chemistry and mineralogy.

This problem is also encountered in the New Forest and is particularly well-illustrated by the sedimentary analysis of the Stephill Bottom section (see Chapter 2). The solid geology exposed in this area comprises a well-sorted fine sand, with 97% of the unaltered parent material in pits 1 and 2 occurring in the range 63 - 250 μm. This feature allows both the within-profile and down-slope distributions of silty drift to be readily identified (Figures 2.16 - 2.22). Detailed particle size analysis is highly suggestive of a loessic origin for the silt component. The range of modal size classes is 18 - 40μm which is in close agreement with values for silty drift recorded by Fisher (1975a) and Reynolds and Catt (in press). The particle size distributions within the silt fraction are also similar to those reported from loess deposits by Lewis *et al* (1984). However, mineralogical analysis has failed to confirm a continental loessic origin for the Flandrian infill sediments at Stephill Bottom (Catt 1985, pers. comm.). This suggests that a large element of the aeolian drift may be of local origin (see Reynolds, 1987), as is suspected in the Thames basin (Gibbard, pers. comm. 1987).

From an ecological viewpoint the provenance of these silt deposits is

largely irrelevant, although the widespread survival of loess into the Flandrian would be of great significance to vegetation change. However, the evidence from Hive Garn Bottom, Stephill Bottom and elsewhere (Allen and Staines, 1984; Eide, 1982) shows that two ecologically important processes involving loessic-type sediments have occurred in the Forest. First, there has been down-profile translocation of silt during the Flandrian, often in association with clay. Soils at Hive Garn Bottom contain silt which coats and cements sand grains, and forms bridges between coarser particles. This is another factor which has affected the development of the present soil water regimes. Second, the Flandrian valley infill and colluvial sediments have a high silt content. For example, the sediments comprising macrofossil assemblage zone 1 at Stephill Bottom (dated at 3080 $\pm$ 210 BP) contain 34% silt. This suggests that considerable topsoil erosion took place during the late Bronze Age and early Iron Age following alteration of the vegetation by Man.

3.3.2.5 Podzolisation

The formation and translocation of iron and aluminium sesquioxides (podzolisation) is associated with the accumulation of acidic organic matter residues in mor humus and their peaty horizons. In many parts of the Forest, podzolic soils and peat deposits form part of the same catena. Podzolisation and peat formation are therefore linked, and the age and causes of podzolisation are important to the understanding of valley mire origins. However, the interpretation of evidence provided by podzols is complicated by the nature of the podzolisation process.

Direct dating of podzol formation normally involves obtaining a radiocarbon date for the age of organic matter in a podzol Bh horizon, a buried Ah horizon, or in the overlying sediment of a buried podzol (usually peat). The carbon cycling of buried soils is normally assumed to be frozen, whereas active soils may suffer from incorporation of fresh ^{14}C into the Bh horizon, although most of the organic matter is thought to be stabilized in the Bh horizon at the start of podzolisation. Farmer and his co-workers have recently questioned

Table 3.2 Age estimates of buried and active podzols in Western Europe

SOURCE	VEGETATION	SOIL HORIZON	APPARENT MRT (ye)	INDEPENDENT DATING (yr BP)	NO. OF SOILS
		BURIED			
Proudfoot 1958	Developing peatland	Peat		2 - 3000	
Smith *et al*, 1971	"	"		2600	
Jaumiainen 1971	"	bBh	1880	2400	
Valentine and Dalrymple 1975	Broadleaved woodland	Peat		4000+	
Matthews 1980	-	bAh		3000+	
Scaife and Macphail 1983	-	bBh	3770±150		
Hassko *et al* 1969	-	bBh	4520±210	-	
		ACTIVE			
Cruickshank and Cruickshank, 1981	Broadleaved woodland to heathland	Bh	1100-1200	1440	
Hurst and Burgess, 1967	(Woodland	Bh	360-370	-	2
	(Heathland	Bh	1580±2860	-	
Perrin *et al*, 1964	Heathland	Bh	1580±200 to 2860±200	-	5
Hassko *et al*, 1969, 1974	(Mixed woodland	Bh	180±150 to	-	2
	(		800±170	-	
	(Heathland	Bh	430±60 to	-	12
			2260±120	-	
Andersen, 1979	Broadleaved woodland			130	

Table 3.3 Age, type and environment of buried soils associated with archaeological sites in present-day heathlands of S.E.England. (Data sources: Tubbs, 1968; Scaife and MacPhail, 1983)

PERIOD	NUMBER OF SITES	BURIED SOIL			ENVIRONMENT				
		BROWN EARTH	IMMATURE PODZOL	PODZOL	WOOD	WOOD - HEATH	HEATH	GRASS - HEATH	ARABLE
Mesolithic	3						3		
Neolithic	1	1				1			
Bronze Age	15		4	10	1	4	4	1	
Iron Age	2			2	1		1		
Medieval	5	1		4			2	2	1

the traditional role of complexing organic compounds (fulvic acids) in transporting iron and aluminium sesquioxides from the e luvial to illuvial horizons (Anderson *et al*, 1982; Farmer *et al*, 1984). Instead, they attribute a crucial function to allophane, which is normally regarded as a by-product in the transport process, and the organic matter is viewed as a secondary precipitate in the illuvial horizon. This model of podzolisation has been strongly criticised by Buurman and van Reeuwijk (1984; see also Farmer's, 1984 reply). While the necessary conditions for podzolisation are not in question, the debate casts doubt on the exact interpretation of dated podzol profiles. Part of the controversy centres on the stability of organo-metallic complexes and carbon turnover (the mean residence time) in the Bh horizon. The issues are such that radiocarbon dating of a Bh horizon can be regarded as a minimum estimate of its real age.

Table 3.2 shows a range of age estimates and environmental information for podzols studied in north-west Europe. The first point to note is that the mean residence time is lower than independent age estimates in both active and buried soils (Cruickshank and Cruickshank, 1981; Jaumiainen, 1972). Secondly, most active podzols yield a much younger range of dates. These two points suggest that carbon cycling in the Bh horizon is resulting in the underestimation of podzol age based on mean residence time. Dates from Bh horizons in podzols under woodland are younger, suggesting a shorter mean residence time compared to heathland. In a study of French podzols, based on 54 radiocarbon dates, Hassko *et al*, (1969, 1974) conclude that organic polymers in the Bh derived from *Calluna* litter have a much slower turnover time. From other evidence (Guillet, 1970, 1971a and b), they suggest that the radiocarbon age is about half the real age of the heathland podzols. Radiocarbon dating of humic acids in the Bh horizon yields older dates than fulvic acids (Hassko *et al*, 1969, 1974; Matthews, 1980) but the age obtained also depends on the method of extraction (see also Goh and Molloy, 1978).

It is generally now accepted that podzols form the latter stages of a genetic sequence starting with acid brown earths, and that podzolisation has begun before morphological differentiation of soil profile horizons leads to its detection. This means that the causes of podzol-

isation cannot be equated simply with environmental changes that are correlated in time with the occurrence (by morphological criteria) of podzols, since the process had begun before the physical appearance of podzolic soils. Herbauts (1982) carried out chemical and mineralogical analysis of the following evolutionary sequence of forest soils: acid brown earth - ochreous brown earth - brown podzolic soil - podzolic soil - ferric podzol. He found that the chemical process of podzolisation was already active in ochreous brown earths well before such incipient podzolisation is detectable by direct morphological observations, i.e. it is active before the profile develops 'immature podzol' features.

Podzolisation is regarded as a natural interglacial process which may be accelerated by various environmental changes (i.e. Iversen, 1958; Duchafour, 1982; Miles, 1985). Podzol development in the absence of Man is widely recognised in the high altitude and latitude zones of Europe (e.g. Ball, 1975; Ellis, 1980). However, this process has also taken place under broad-leaved woodland in lowland Britain (Valentine and Dalrymple, 1975), and also may have occurred in the New Forest (Dimbleby and Gill, 1955; Allen and Staines, 1984). However, podzolisation can be rapidly accelerated when it is associated with deforestation. For example, Cruickshank and Cruickshank (1981) concluded that the main phase of Bh development took only 200 - 300 years, following forest clearance, in a podzol dated to 1440 BP. The first visible signs of podzolic horizons in recently created primary substrates can take only a few decades to appear in extreme conditions (Paton *et al*, 1976; Miles, 1985).

Soils buried under archaeological sites have been used as evidence of the timing of-and environments associated with podzolisation (see reviews by Tubbs, 1968; Dimbleby, 1976, 1985). Table 3.3 summarises much of the data available from the heathlands of south-east England including the New Forest. The high proportion of Bronze Age sites reflects the frequency of structures from this period on the heathlands. Podzolic horizons were visible in all these soils and it is clear that acidification (reflected by pollen preservation) and podzolisation had begun much earlier than the Bronze Age. The evidence before the Bronze

Age is, however, sparse; the Neolithic site from Norfolk (Dimbleby and Evans, 1972) showed a brown soil but the three Mesolithic sites do not indicate brown earth conditions (although the soil descriptions are brief). Dimbleby (1976; Case *et al*, 1969) suggests the following sequence of events for the Neolithic site under more oceanic conditions in Ireland:

(i) clearance of forest associated with a brown podzolic soil,
(ii) cultivation of a soil in which earthworms are active,
(iii) conversion to pasture, the soil progressively acidifying,
(iv) the disappearance of earthworms and the development of a leached soil with a thin iron pan,
(v) the development of surface wetness, probably due to the deterioration of soil structure,
(vi) the onset of peat formation at a date still within the Neolithic.

More detailed soil analysis of seven buried profiles has been carried out recently by Eide (1982) in the New Forest. Apart from one site, the soils were already podzols of various types before burial, or showed incipient podzolisation in the form of iron and aluminium transformation and partial redistribution in the profile. At Dark Hat, soils were investigated under two banks. One was described as a palaeoargillic podzol while the other, thought to be younger, was a palaeoargillic brown earth. The soils outside the banks are now palaeoargillic brown podzols and surface water gleys. Chemical analysis suggests that the change from brown earth to podzol took place mainly after the construction of the banks and cultivation of the enclosures. However, the evidence from the buried soils suggests that the upper soil horizons were already strongly weathered and leached when the banks were built. The effects of cultivation included subsoil compaction attributed to ploughing and the addition of phosphorous-rich material (manure) to the enclosures. Eide concluded from pollen analysis that agricultural activity took place during the Middle Bronze Age to Late Iron Age, though initial clearance of the site began earlier, possibly in the Early Bronze Age.

The buried Ah horizons of two soils examined by Eide (1982) were dated radiometrically. The first, a cambic stagnogley at Long Slade Bottom was

dated to 3265 ± 90 BP, while the other was a sandy argillic gley at Burley Moor and was placed at 2235 ± 80 BP. The interpretation of these dates is problematic. Due to carbon cycling they may be regarded as minimum estimates for the date of profile development, particularly in both cases the formation of a distinct topsoil and a high water table. However, in order to determine the age of burial (when they are assumed to be no longer active) it is necessary to subtract the mean residence time (mrt) of carbon from the radiocarbon age. The problems associated with the determination of the m.r.t. are discussed by Eide (1982), but the application of a correction factor of 1450 years based on an arable soil at Rothamsted seems inappropriate. Other studies from semi-natural soils in lowland heath suggest a figure of a few hundred years, in the range 150-800 yr, may be more applicable to these New Forest soils (e.g. Hassko *et al*, 1969, 1974; Keatinge, 1983). The buried soils at both sites are little different to those at the present surface, although there is evidence of podzolisation in the bank itself at Burley Moor.

Overall, the seven sites examined by Eide (1982) show that many features of present soil profiles had probably developed in a period encompassing the latter Bronze Age and Iron Age. Reynolds (née Eide) and Catt (in press) conclude that podzolisation began during the Iron Age or earlier in many parts of the New Forest and is attributable to earlier deforestation and agriculture or to progressive natural acidification of base-deficient parent materials during the mid-Flandrian. They also concluded that difference in parent material is one factor responsible for the variation in the rate of podzolisation across the Forest.

3.3.2.6 Summary

The sequence of soil development deduced from the evidence from Hive Garn Bottom is summarised in Figure 3.8. The soils preserved on the plateau show that deep weathering and clay illuviation took place during one or more interglacial periods. The upper horizons of these soils were subsequently eroded, probably during the Devensian. They have many features in common with the Plateau Drift in Oxfordshire (Bullock and Murphy, 1979). A number of important soil forming processes operated during this period. Cryoturbation features - e.g. disrupted argillans

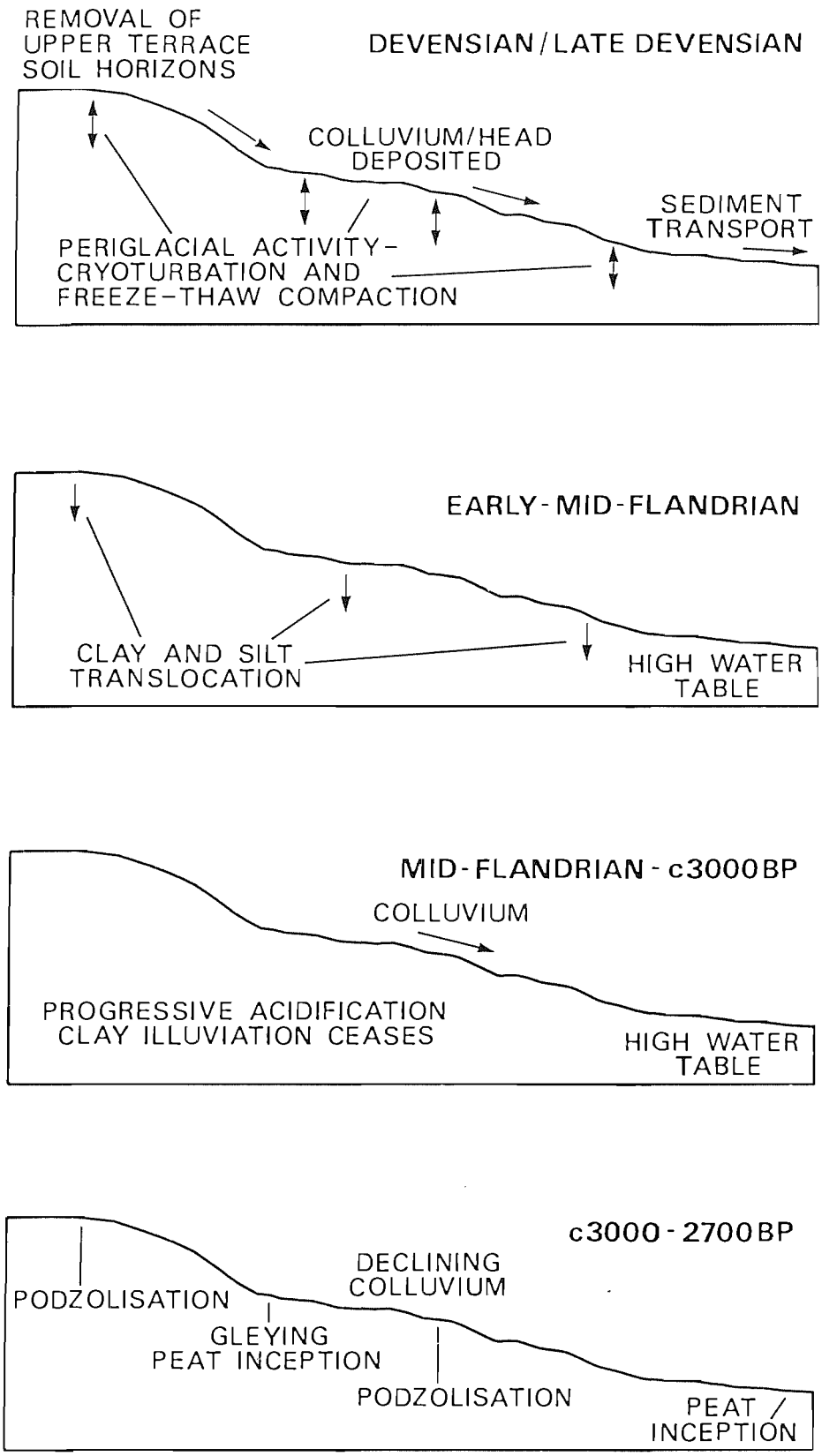


FIGURE 3.7 : Devensian and Flandrian soil development at Hive Garn Bottom.

and the alignment of stones - are prominent in the terrace soils, while colluvium or head formed under periglacial conditions was deposited on the valley-sides. Tuckfield (1986) suggests that it may be possible to distinguish two phases of head deposition, from nearby at Hampton Ridge, which are separated by a phase of stability possibly during the Late Devensian Interstadial. Loessic inclusions are present within the head deposits and disturbed Tertiary deposits at Hive Garn Bottom. This suggests that loess deposition may have been contemporaneous with head deposition and cryoturbation, possibly during the latter part of the Devensian (Wintle, 1981). Evans (1975) reports loessic drift in cryoturbation structures from the chalk in Wiltshire, with a snail fauna indicating open, treeless tundra and similar to the assemblage in solifluction deposits in Kent (Kerney, 1963). In all, the erosion of upper soil horizons, the absence of relict interglacial features on the valley-side, the formation of head, and the deposition and reworking (including removal) of loess suggest that there was considerable erosion and sediment transport out of the valley at Hive Garn Bottom during the Devensian. The present bisequel soil profiles on the valley side may have been formed only towards the end of this period. Periglacial activity may have also resulted in the compaction of sub-soil horizons through freeze-thaw cycles.

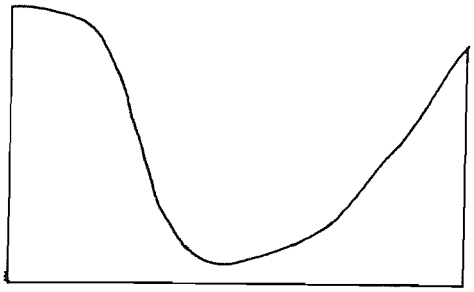
The main physical controls of soil hydraulic conductivity and the present valley mire water regime were in place, therefore, by the beginning of the Flandrian. The poorly consolidated sediments beneath the peat in the valley bottom are unweathered and intensely gleyed, sometimes with bluish hues. These features suggest that the valley bottom has remained waterlogged since these sediments were deposited (Avery, 1980), and that there has been constant surface saturation throughout the Flandrian. Apart from the valley bottom, illuviation of clay has taken place during the Flandrian in both the valley and terrace soils, including the seepage step. This is a relict feature and is indicative of less acid soils than those present today. The pH range from soil profiles varies from 3.5 - 4.2 on the terrace to 4.1 - 5.0 on the valley side. This suggests that the acidity of these soils has increased by at least 1 - 1.5 pH units (a ten to thirty-fold increase) during the late Flandrian. The period of clay illuviation is unknown but macrofossil analysis and radio-

carbon dating suggest that it must have ceased well before 3000 BP, a conclusion which is supported by the work of Eide (1982). Illuviated clay within gleyed horizons beneath peat on the seepage step suggests that the water table was lower earlier in the Flandrian, in contrast to the valley bottom. However, the water table has been observed to fall below at least the upper illuviated horizons during drought conditions, and so it is not possible to conclude with certainty that there has been a significant change in hydrological conditions on the seepage step, given our present understanding of clay translocation mechanisms. Clay translocation and leaching down-profile are both expressions of the same soil processes. For soils such as those in the New Forest, a phase of clay translocation during the early stages of natural and progressive acidification is to be expected. The cation exchange capacity will decline with acidity increasing in the elluviated horizons until the chemical environment no longer favours movement of clay. Thus, the phase of clay translocation during the early Flandrian may be due to internal changes in soil chemistry rather than to the climatic conditions particular to that period of the postglacial.

A series of soil changes, resulting in the present soil pattern, occurred around 3000 BP or somewhat earlier. Firstly, there was a phase of erosion resulting in the deposition of colluvium within the valley. This included preserved organic remains, due to waterlogging, which indicate that mire and heathland vegetation had already developed. They also show that the formation of colluvium was contemporaneous with the modification of woodland composition by Man, including at least one local clearance episode. By 2700 BP, colluvium inputs were declining and the accumulation of peat began in the valley bottom and on the seepage step, in association with gleying and podzolisation. Eide (1982) estimates by pollen analysis that podzolisation of Plateau Gravel soils took place around 2500 BP, nearby at Dark Hat. However, the evidence also shows that the soils at Dark Hat were already strongly weathered and leached by this time, and were acidic enough to preserve pollen. A rapid resurgence in colluvium deposition took place within the valley between about 2600 - 2700 BP, this is correlated with a clearance event within the basal pollen spectra preserved at the seepage step (Willis, 1985).

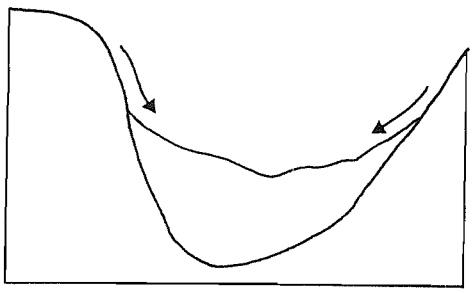
Inorganic sediment inputs declined slowly over a period ending between 1400 - 1700 BP. Significantly, Sumner (1927) estimates, from archaeological evidence, that the Roman pottery kiln close to Hive Garn Bottom gradually declined and ceased activity between 1640 BP and about 1500 BP, with Sumner favouring an earlier date within this period. Subsequently, colluvial inputs have continued at very low levels to the present day (see Chapter 5.5) and show no relationship to changes in the pollen spectra described by Willis (1985), which therefore probably reflect more regional rather than local changes in vegetation.

Additional evidence of Flandrian soil and environmental change, from Stephill Bottom, is summarised in Figure 3.8. Almost all the valley infill (at least 85% of the total volume) was deposited after the local expansion of *Alnus*, probably between 8600 and 5200 BP. Earlier in the Flandrian there was little colluvial or alluvial sediment storage and erosion was either greater than or equal to sediment supply. No sediments were found which could be attributable to the Devensian. Mire and heathland plant species were present from the earliest phases of sedimentation. Colluvium deposition in the valley bottom continued until about 3100 BP, when it began to decline with the onset of peat formation. The earliest available pollen spectra came from the uppermost colluvial sediments (Dodd, 1985). They show that local deforestation had occurred during an earlier period, and that heathland was already established. There is also evidence of agricultural activity. These deposits are fine-grained, predominently silt sediments and the evidence suggests the erosion of topsoil and textural deterioration of soils in the surrounding catchment due to agriculture. This pattern is consistent with the observation of Burrin and Scaife (1984) from the southern Weald, where they suggest that the upper reaches of the River Ouse exhibited erosion, possibly of earlier stored sediment, during the first part of the Flandrian which was subsequently replaced by sedimentation due to anthropogenic causes during the post-Neolithic era. Following the switch from predominently inorganic to organic sediment deposition, the accumulation of peat (c 17.5cm/1000yr) has continued relatively constantly until the present, allowing for the thick acrotelm (see Chapter 5.4). Peat stratigraphy and macrofossil assemblages show



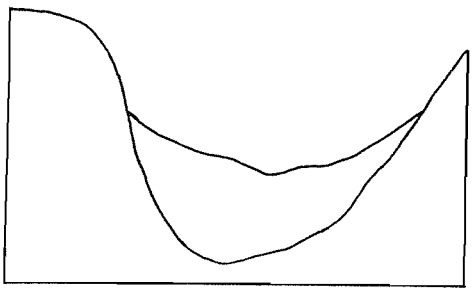
EARLY - MID-FLANDRIAN
(10000 - c 5000 BP)

Little sediment deposition: transport = supply. (Low sediment yield in catchment?)



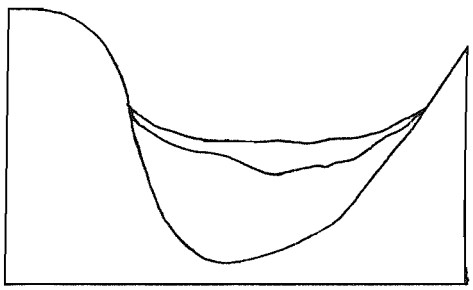
MID - FLANDRIAN - 3100 BP

Colluvial infill deposited
Mire vegetation present
(and heathland?)



3100 BP

Peat accumulation starts as inorganic inputs decline. Deforestation already taken place, heathland established. Water track present (replacing channel flow?)



3100 BP - PRESENT

Peat accumulation (17.5cm/1000yr) beneath water track.

FIGURE 3.8 Flandrian development of the valley at Stephill Bottom. (note exaggerated vertical scale).

that peat accumulation has taken place beneath a water track with no significant change in the mire communities at the site, which suggests that environmental conditions within the mire have remained relatively constant.

3.4 Discussion

Four principle postulates provide the basis of the approach taken in this chapter:

1. The most simple explanation of peat formation is that peat develops at points where the potential profile of the groundwater table is higher than the earth's surface. The groundwater profile depends upon the water budget, the drainage network density, and soil permeability.
2. A causal explanation of peat inception may be obtained in terms of how processes have operated over time to produce the present situation (the valley mire water regime).
3. Peat formation and other soil processes are linked through the relationships between the water regimes and topographic positions of soils.
4. The appropriate null model for the ultimate cause of peat inception is based on the hypothesis that peat development is a natural consequence of pedogenesis under the environmental conditions of the present interglacial, and its timing is a function of the relaxation time of the system (the time needed to reach equilibrium). This has logical primacy over other causal hypotheses of peat inception.

The proximate cause of valley mire formation in the New Forest is the collection of groundwater and throughflow in breaks of slope, hollows and valley bottoms, especially by lateral water flow in upper soil horizons. Lateral flow has been generated by the development of soil profiles with depth variation in hydraulic conductivity, particularly the presence of relatively permeable material over slowly permeable subsoils. This has occurred through (i) the formation of colluvium and other drift deposits during the postglacial and the last glacial, (ii)

interglacial and post-glacial clay illuviation, and (iii) the development (under periglacial conditions?) of relatively compact subsoils with high bulk density. Peat inception in valley mires can only be understood by reference to soil development, as a whole, at the level of the catena. This is due to a suite of related processes governed principally by the movement of water. Many of the features found in the New Forest are found in soils of similar areas elsewhere in southern England (Table 3.4). This suggests that the model of pedogenesis developed here for the New Forest may have more general applicability, allowing for some regional variation in detail.

It is clear that many of the physical factors governing the present water regimes of the valley mires were in existence by the end of the Devensian - much of the present topography and drainage network defining interfluvial regions is a relict of the Devensian and earlier periods, also most drift deposits and seepage zones (due to parent lithology) were in place by that time. The most significant development in the physical structure of many soils during the Flandrian has been the translocation of clay and, perhaps silt.

Macrofossil analysis shows that valley mire plant communities were present before the start of peat accumulation. The plant communities are a function of population dynamics and the ecological response of species to the environment, whereas peat is a physical expression of the production to decomposition ratio and the amount of energy in the sedimentary environment (cf Bellamy, 1972). Valley mire development has been accompanied by a switch in sedimentary regime from one dominated by inorganic deposition to one in which processes favouring organic sedimentation are dominant. The preservation of peat at all sites is preceded by a phase of predominantly inorganic deposition in which plant remains are preserved. This is a ubiquitous feature of mire development in the New Forest, from Late Devensian and early Flandrian sites, such as Church Moor and Cranes Moor, to the more recent sites. This suggests that a threshold change in the sedimentary environment occurs at peat inception, with the basal sediments representing a transitional phase between the two states of the system. The unripened valley bottom soils and buried plant remains, such as at

Table 3.4 Heathland soil characteristics related to peat development and waterlogging recorded in southern England and north-east France

REGION	PODZOLISATION	FLANDRIAN CLAY ILLUVIATION	INTERGLACIAL CLAY ILLUVIATION	SLOPE DEPOSITS	COMPACT SUBSOILS	LOESS	LATERAL WATER FLOW	SOURCE
New Forest	+	+	+	+	+	+	+	See text
N & E Hampshire	+	+	+	+			+	Gibbard 1981 Jarvis *et al* 1984
Surrey	+	+		+			+	Macphail 1983 Jarvis *et al* 1984
W Sussex	+	+		+		+	+	Scaife and Macphail 1983 Kirkaldy and Bull 1940
E Sussex	+	+	+	+	+		+	Abbas, 1979, Abbas and Burnham 1983 Jarvis *et al* 1984
Kent	+			+		+	+	Burnham 1975 Burnham and McRae 1975
Dorset	+	+	+	+		+	+	Findlay *et al* 1984
Plateau Lorraine, France	+	+	+		+			Guillet, 1970

Stephill Bottom, indicate that the mire communities have been present at many sites much longer than is suggested by the peats which have been preserved. The stratigraphic record is, therefore, much simpler than the real history of mire communities in the New Forest. This is because the valleys and seepage steps are relatively sensitive landforms which respond to small changes in environmental conditions (see Brunsden and Thornes, 1979). Earlier peat deposits may have been removed by subsequent erosional events, and present peat accumulation represents a persistent (i.e. more or less unidirectional), response of the system to the controlling variables in the environment.

The presence of mire communities before peat preservation, the evidence of continuous waterlogging in valley bottoms throughout the post-glacial, and the existence of mires in the New Forest since at least 12500 BP all suggest that mire communities - including open habitats - may have been more widespread during the first half of the Flandrian than is often assumed. Indeed, the widespread assumption (see Simmons and Tooley, 1981 for a review) of closed forest conditions in lowland England during the Boreal and Atlantic, with relatively late establishment of heathland, is questionable. There is direct and indirect evidence for the persistence of heathland throughout the post-glacial in the New Forest. The main problem is the low relative representation of heather pollen in sub-fossil assemblages and the absence of early Flandrian polleniferous sites from the large plateaux areas in the Forest. Firstly, the macrofossil and pollen data discussed in Chapter 5 show there to be a continuous record of at least *Calluna* in the New Forest since the Late Devensian. Scaife (1980; Scaife and MacPhail, 1983) has made similar observations from the Isle of Wight and elsewhere. Secondly, there is biogeographical evidence that many heathland species were established before the breaching of the land links with the continent, which occurred by 7800 BP in the North Sea (Simmons and Tooley, 1981) and probably earlier in southern England. For example, in the case of the heathland spider community, there is a group of at least 16 species which are now restricted to lowland heath in England and Wales; of these species, only 30% also occur in Ireland (data from Ratcliffe, 1977a; Locket *et al*, 1974). This suggests that the other species were prevented from colonising Ireland by the breaching of the

land link with the British mainland around 9200 BP (Simmons and Tooley, 1981) and, hence, that the English Channel would also be an effective barrier to immigration. Palaeoecological analysis of invertebrate sub-fossil assemblages shows a gradual decrease in the total number of species after the breaching of the continental land-bridge, including relatively mobile species such as the Coleoptera (Coope, 1981). Immigration of Coleoptera species has been very low during this period (Osborne, 1978). The silver-studded blue butterfly (*Plejebus argus*) is another heathland specialist thought to have been present in Britain since about 10000 BP (Dennis, 1977). The earliest heathland in southern England which is known to be associated with the activity of Man are the Mesolithic sites from Iping (Keef *et al*, 1965) and Oakhanger (Dimbleby, 1962), both dated to about 6300 BP. Comparison with the present day ecology of these invertebrates indicates that they are unlikely to have survived the Boreal and early Atlantic periods in marginal habitats, such as sand-dunes and heathland above the altitudinal tree-line. Such evidence favours the existence of significant open habitats during the early Flandrian, rather than the survival of heather under a sparse tree canopy (see Scaife and MacPhail, 1983). These considerations of mire and heathland communities suggest that the status of these habitats in southern England during the earlier Flandrian may need to be re-examined.

Pedogenesis in the New Forest during the Flandrian has been marked by a natural acidification of soil profiles. Clay illuviation suggests a reduction in pH of 1 - 1.5 units since the early to mid-Flandrian (see previous section), and the preservation of only late Flandrian soil pollen suggests an even greater decrease in acidity (Dimbleby and Evans, 1974; Dimbleby and Speight, 1969; Brady 1974). The presence of an apparent Ipswichian podzolic soil profile at Stone Point to the south of the Forest (Brown *et al*, 1975) suggests that this trend is not restricted to the Flandrian interglacial alone. The progressive acidification will have increased the probability of peat accumulation, not only because the increased acidity will have reduced the activity of decomposer organisms, but also because it will have favoured plant species whose litter is of low resource quality with, consequently, a low intrinsic rate of decomposition (Swift *et al*, 1979).

Radiocarbon dating and pollen analysis have shown that the process of peat inception has operated throughout the post-glacial (see Chapter 2), and acidification has continued into the historical period (Eide, 1982). However, there is evidence for the widespread development of present-day catenas during the Bronze Age and Iron Age (Table 3.5). This is accompanied by evidence for a deterioration in soil structure and topsoil erosion, but Man may have done no more than accelerate the process of acidification, if at all (Reynolds and Catt, in press). The hydrologic effects of deforestation on soil development and peat preservation are still highly conjectural. It is also important to note that none of the deposits in Table 3.5 are synchronous with primary deforestation. This implies that the possible impact of Man was either due mainly to subsequent cultivation of soils, or that there was a delayed response of the system to the initial clearance. Moreover, topsoil erosion may also be coupled with the changes in climate during these periods (Lamb, 1977; Simmons and Tooley, 1981), either through an increase or changes in the pattern of precipitation. The importance of Man as a causal agent is also weakened by evidence from two late Flandrian mires located within mainly woodland catchments. The basal peats at Barrow Moor (dated to c2200 BP) contain a total pollen assemblage comprising more than 70% tree pollen (Dawson, 1978). The data from this site and also from Church Moor, nearby, suggest that this area has had a long and sustained history of woodland cover (Barber, 1975, 1981a; Clarke and Barber, 1987), possibly throughout the Flandrian (see also Chapter 5.2). At Gritnam, there is a continuous representation of more than 90% tree and shrub pollen in the lowest 50cm of peat (Puzey, 1982), with open habitats absent apart from local conditions on the mire. Thus, even in later prehistory, peat has developed in the New Forest without deforestation in the catchment.

The importance of climatic change is also unclear. The main line of evidence in favour of a climatic influence on peat inception is the correlation between the radiocarbon age of the humus and basal peat layers in Table 3.5 and periods of climatic deterioration. The latter have been deduced mainly from their effects on peat development in ombrotrophic mires (Barber, 1982), where there is more direct coupling between bog growth and effective precipitation. The evidence from peat

Table 3.5 The development of organic surface horizons in present catenas - radiocarbon age determinations from the later prehistoric period. Not included here is the submerged seepage mire at Fawley (Hodson and West, 1972) which also falls within this era, having been dated to 3689 BP (Godwin and Switsur, 1966)

Note 1 From ^{14}C dates of 2700 ± 70 and 2630 ± 50 BP (see Chapter 5.4)

2 From ^{14}C date of 1455 ± 70 BP (see Chapter 2)

SITE	DATE (yr BP)	MATERIAL DATED	SOIL TYPE	
Hive Garn Bottom	2370 ± 60	Basal Peat	Argillic stagnohumic gley	(Seepage Step)
Hive Garn Bottom	c3000[1]	Basal Peat	Humic gley	(Valley bottom)
Stephill Bottom	3080 ± 210	Basal Peat	Valley Bottom Mire	
Barrow Moor	c2200[2]	Peat	Valley Bottom Mire	(Barber, 1981a)
Burley Moor	2235 ± 80	bAh	Sandy argillic gley	(Eide, 1982)
Long Slade Bottom	3265 ± 80	bAh	Cambic stagnogley	(Eide, 1982)

stratigraphy has also been supported by recent investigations of isotope ratios in hydrogen and oxygen preserved in the peat (Brenninkmeijer, 1983; Dupont, 1986). The period encompassed in Table 3.5 is characterised by a fluctuating climate with an underlying trend towards increasing wetness. An increase in effective precipitation is thought to have occurred between 4 - 3000 BP, possibly in two phases centred on 3900 and 3400 BP (Barber, 1982). This was followed by an even greater increase between 3 - 2000 BP, probably due to the combined action of increased rainfall around 2500 BP, or somewhat earlier (Barber, 1982), and a pronounced decline in average annual temperature through this period (Dupont, 1986). Unfortunately, the spatial variation evident in this data (Barber, 1982) prevents greater temporal resolution of climatic change inferred for the New Forest. Peat stratigraphy from the valley mires provides only limited evidence of climatic change during the Late Devensian and early Flandrian (Chapter 5). This is significant in itself, because it demonstrates that valley mire development has been less sensitive to these climatic events. Although this is seen most clearly in the macrofossils of Stephill Bottom (Chapter 5.4), which indicate continuity of wet conditions over the last 3000 years, analysis of other sites (Church Moor and Hive Garn Bottom I and II) also shows little evidence of change in the local mire environment during this period. Furthermore, the presence of mire communities before the formation of these peat deposits, at least at Stephill Bottom, suggests that surface waterlogging predates these climatic events, as does the presence of unripened soil profiles in the valleys (see above). A theoretical explanation of these observations may be found in the relationship between the groundwater profile and its determinants (Ivanov, 1981), discussed at the beginning of this chapter. Apart from the spatial dimensions of the area under study (i.e. topography), the height of the groundwater table (h) is proportional to the average effective precipitation ($\bar{w}$) and the hydraulic conductivity of the substrate (k) such that:

$$h \propto \sqrt{\frac{\bar{w}}{k}}$$

This means that a change in the water table is proportional to only the <u>square-root</u> of any change in effective precipitation. Thus, the direct effect of climatic change is damped down and the variation in climate

may not have greatly altered the potential for peat development during the post-glacial (see Chapter 5.3 for further discussion). There are two reasons for the greater sensitivity of ombrotrophic mires. Firstly, there is a direct coupling between the effective precipitation and bog plant growth, without any intermediate catchment effects. Secondly, the other determinant of water table height, hydraulic conductivity (k), shows covariation with effective precipitation in ombrotrophic mires, such as the differences in permeability of hummock and hollow peats and the effect of humification (see Chapter 5.3). However, the evidence from the New Forest shows that there has been little change in the hydraulic conductivity of the groundwater (inorganic) substrates in catchments since the early Flandrian.

A final, general point is that peat development has been favoured by three positive-feedback mechanisms. (1) Soil acidification reduces the decomposition to production ratio which favours peat accumulation and the growth of mire species. This in turn favours progressive acidification. (2) Mire development tends to produce a diffuse flow within a water track rather than a well-defined channel. This favours the deposition and preservation of peat sediments. (3) Peat development increases throughflow which increases surface wetness. These mechanisms provide the means of initiating change without any change in external variables.

3.5 Conclusions

It has been possible, from a theoretical base, to explain the proximate cause of peat inception (the valley mire water regime), but the ultimate causes have been explained less successfully. The null model developed in this chapter does, however, provide a framework for the investigation of this problem. Valley mire formation is a natural interglacial process, and it has been inferred that no formative event is required for peat development. This is a necessary condition of such a model. The fact that mire communities have predated peat accumulation in some cases suggests that it may be a sufficient explanation of mire development in terms of vegetation. However, peat formation <u>and preservation</u> is a function of sedimentary environment as well as soil wetness.

The apparent increase in the rate of peat formation (and preservation) during the Bronze and Iron Ages may be either an artefact of the relaxation time of the system, or it may represent a real shift in controlling variables to produce a new equilibrium state with an increased probability of peat formation. However, it has been shown that two causal factors of the groundwater table have remained relatively static during the Flandrian, that is substrate permeability and topography. There is more evidence for a change in the average annual effective precipitation, the third state variable. This is the difference between total precipitation and evapotranspiration. Both anthropogenic deforestation and climatic change may have altered this balance in favour of peat formation during the Bronze Age - Iron Age period. However, from the sites investigated here, the evidence may be regarded as sufficient to falsify the hypothesis that Man is a causal agent of peat formation. It has been shown that peat formation is not a result of a change in water budget due directly to forest clearance by Man. The data presented here do not falsify the climatic change hypothesis, but also do not corroborate this hypothesis apart from a broad temporal correlation. There is also theoretical and empirical evidence that the magnitude of climatic events has not been sufficient to significantly alter valley mire inception and development, because of the indirect coupling between valley mire development and effective precipitation through the groundwater supply. This hypothesis can only be tested rigorously with independent evidence of change in the local water budget.

Both the climatic change and deforestation hypotheses are faced with the problem that the processes leading to the development of present catenas in the New Forest have been operating over a much longer period of the Flandrian than the last 2 - 3000 years. There is also the difficulty that mires, as plant assemblages, may have existed much longer at particular sites than the period of peat accumulation and preservation. The observation that peat development in the valley mires is a function of the preservation potential of the sedimentary environment - in addition to the height of the water table - is highly significant. The preservation of peat may reflect a change in the magnitude and frequency of erosive events, or 'energy levels', in the

environment. The smooth boundary between inorganic and organic deposition shows the change to have been a gradual one, which has occurred at all sites investigated in the New Forest and at different times.

At the end of the last chapter it was stated that a formal explanation of peat inception cannot be achieved, since we are unable to define all the initial variables or characterise all the process laws. It is important not only to consider which alternative modes of causal explanation are acceptable, but also to recognise that with present methods the problem of mire origins cannot be answered fully. This should not prevent its investigation but investigators must frame their questions accordingly.

3.6 Summary

1. A causal explanation of mire origins is sought within a framework which describes the development of the factors which currently maintain the valley mire ecosystem, i.e. the valley mire water regime.
2. The processes controlling the shape of the groundwater profile are central to the explanation of mires origins. Lateral flow is an important component of the valley mire water budget. Mire development must be viewed as a soil process and is linked to pedogenesis at the level of the catena, through topography and water movement.
3. Evidence of pedogenesis in the New Forest is reviewed. The main physical controls of soil hydraulic conductivity and the present valley mire water regime were in place by the beginning of the Flandrian.
4. The stratigraphic record may be much simpler than the real history of mire communities in the New Forest and peat preservation is a function of sedimentary environment as well as soil wetness.
5. The proximate cause of valley mire formation in the New Forest is the collection of groundwater and throughflow in breaks of slope, hollows and valley bottoms, especially by lateral flow in upper soil horizons

6. A null model is developed for the ultimate cause of peat inception which, it is argued, has logical primacy over other causal hypotheses of mire origins and provides a framework for investigation.

SECTION TWO: VALLEY MIRE DEVELOPMENT

CHAPTER FOUR: MACROFOSSIL METHODS OF RECONSTRUCTING FORMER COMMUNITIES

4.2 Introduction

The object of utilizing palaeoecological techniques in this thesis is to add a fourth dimension, time, to the study of New Forest mire communities. Central to this conceptual framework is the principle of methodological uniformitarianism (Gould, 1965) - a working assumption accepted only while its consequencies help to interpret data. The operation of this principle is outlined by Rymer (1978)

> "As usually employed, the Methodological Principle of Uniformitarianism states only that the basic laws and types of processes remain the same, the leaves open the possibility that, given different values for the variables in these laws, rates or processes can change In other words, ... (it) is an epistemological principle... it may be thought of as an extension to the basic tenet of scientific methodology: that the universe is lawful and the basic laws of science remain constant through both space and time."

This is an important point. It is embodied in the approach taken to explain the sub-fossil assemblages found in peat - from the use of indicator species to the application of complex pollen calibration functions. In this way, analogy is the interpretative argument of palaeoecology, and analogy is successful only in so far as the analogues themselves are understood.

Before the techniques applied to this study are discussed, it is necessary to consider the nature of the data available to palaeoecological research, the contemporary analogues and the processes leading to the formation of these assemblages. Studies of community development *in situ* (at the sample site) are chiefly concerned with macrofossil data. The attention of the following critique is turned towards the two types of data which may be analysed, since the approach adopted determines the subsequent sampling strategy and techniques utilised.

4.2 A critique of macrofossil analysis

In the analysis of peat several types of evidence may be used - these

are, broadly, microfossils, comprising pollen, spores, diatoms etc, and macrofossils. The latter are not easily defined; Birks and Birks (1980) state that macrofossils are those remains visible to the naked eye. Frequently, however, the term is a default category, containing material larger than pollen grains, say over 125μm, so that macrofossils range in size from small *Juncus* seeds to tree trunks and buried men. As will be seen later, this range of macroremains creates problems for analysis.

For a site of given area, the microfossils in a peat sample are derived from a much larger source area. In telmatic or terrestrial peats most macrofossil material is deposited close to its point of origin, so that they provide a more accurate representation of the immediate community. In other studies of mire development, microfossils have been used to provide a framework for stratigraphic correlation (Barber, 1981b) and to provide information on host-specific fungal parasites (van Geel, 1978). In order to maximise the number of mires to be investigated, it was decided not to undertake microfossil analysis but to utilise existing pollen and spore studies of key sites in the New Forest (Barber, 1985; Barber, 1981a; Clarke and Barber, 1987; Barber and Clarke, 1987) and a number of undergraduate investigations.

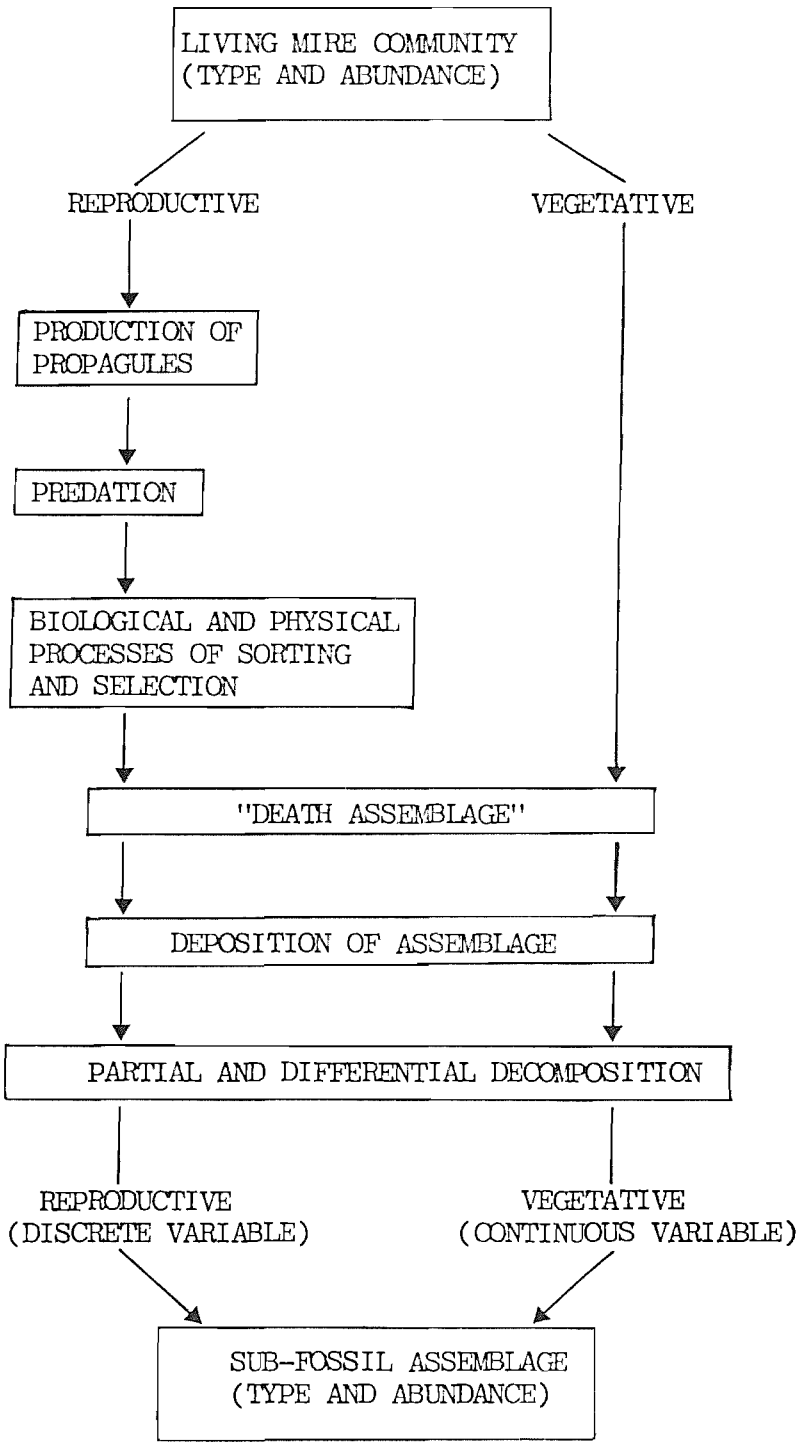
It is useful to state, explicitly, the objectives of macrofossil analysis. These are usually to obtain some estimate from the sub-fossil assemblage of the important parameters of former communities (normally relating to the type of organisms and their amount). For both contemporary and past communities, types are conventionally taxonomic units (but see Harper, 1982; Moore, 1980 for a consideration of ecotypic or intraspecific variation). Amount is most frequently described in terms of relative abundance, measured as numbers, cover or biomass. The plant sub-fossils of these assemblages are derived from reproductive (i.e. seeds, fruit) or vegetative material (structural/photosynthetic tissue). This is a division of great biological significance and is central to the argument of this critique.

For many studies, particularly in Britain and North American, 'macrofossil' is synonymous with 'seed', and the emphasis has been, implicitly, on the analysis of seed and fruit remains - often to the virtual

exclusion of any vegetative material. In part, this is because seeds and fruits form a well-defined set of readily quantifiable subfossils, and are relatively easy to assign to specific, or at least generic, level on the basis of morphological features. The fossil assemblage of seeds and fruits differs from the parent plant community in several respects (spatial and numerical), due to processes affecting reproductive production, or fecundity, and seed deposition. The pathways taken by macrofossils, from the living, parent mire community to the subfossil assemblage in peat, are shown in Figure 4.1. The death assemblage is a concept representing the material derived from the parent community which, on death, enters the acrotelm. From Figure 4.1 it can be seen that there is a direct link between the vegetative death assemblage and the parent community, but the pathway for reproductive remains is more complex due to a suite of processes which modify the representation of reproduction bodies in the death assemblage. Moreover, living plant communities are almost always described on the basis of vegetative material (i.e. the 'vegetation'), so that the reproductive death assemblage inevitably provides only an indirect reflection of the parent community. The argument to be presented here is that the estimation of former community parameters cannot be achieved using reproductive macrofossil data alone and that, conversely, vegetative material provides more direct evidence for *in situ* mire community development. Both types of macrofossil are subject to the problem of differential rates of decomposition between species (see below), but comparative data for reproductive and vegetative material are not available - ironically from the palaeoecological viewpoint, most decomposition studies have concentrated on vegetative material despite the emphasis on reproductive macrofossils. Reproductive macrofossil assemblages are not without information content; it is merely that emphasis on seeds and fruit with relative ease of identification is at the expense of power of interpretation.

The difficulty with reproductive macrofossil interpretation lies, particularly, in the processes of production, dispersal, sorting and selection (Figure 4.1). In contrast to palynology, little has been done to understand these processes - the most noticeable exception being Birks' (1973) pioneering work on "modern macrofossil" assemblages,

Figure 4.1 Preservation pathways for reproductive and vegetative macrofossils (see text)



which will be discussed below. There are, however, several fields of contemporary ecology which are concerned with the same processes - these have been neglected by palaeoecology, despite the perceptive comments of Watts (1978). The ecological evidence comes from studies of (i) life history characteristics, (ii) seed bank dynamics, and (iii) the biology of seed dispersal.

Many of these studies have been stimulated by the demographic approach to plant ecology (Harper, 1967; Harper and White 1974) and the concept of r- and K- selection (MacArthur and Wilson, 1967), particularly the investigation of life history characteristics and the partitioning of resources by plants (see Stearns, 1977). This work has shown that there is considerable inter- and intraspecific variation in the production of seeds and fruits - for a review of the abiotic and biotic factors involved, see Abrahamson (1980). In 1942, Salisbury published a survey of the seed size of many British plant species in relation to habitat, and demonstrated that species whose seeds germinate in shaded conditions and species found in the later stages of succession have larger seeds. This was related to the greater provision of food reserves for species growing at lower light levels in the face of competition. Harper *et al* (1970) suggested, further, that all species not found in climax vegetation are continually doomed to local extinction and therefore must be able to colonize new terrain. Consequently, selection will favour large-seed number, small-seed size and high dispersal among such fugitive ('r species'), while favouring fewer, larger seeds (and consequently, lower dispersibility) among species of shaded and climax vegetation ('K species'). Subsequent studies of populations have also tested the hypothesis that in early successional stages, when more resources are available, natural selection will favour allocating proportionately more of these resources to reproduction (e.g. Newell and Tramer, 1978), so that there is decreasing seed production with increasing maturity of secondary succession (e.g. Gadgil and Solbrig, 1972). Such biological processes will result in differential representation of species in a reproductive macrofossil assemblage. For example, Birks (1973) found that 3 seeds per $100cm^3$ sample of *Brasenia schreberi* indicated moderate abundance of the plant in the vegetation, whereas the same concentration of seeds for *Najas*

flexilis indicated that the plant was rare (or was some distance away from the sampling site).

The variation of reproductive effort with different ecological situations has been studied within a single species and between species of the same genus. Werner and Platt (1976) examined the seed characteristics of five species of *Solidago*, the goldenrod. Seeds from populations in less disturbed sites were, on average, three times heavier, 80% fewer in number and had a 30% reduced dispersal ability. Werner (1976) states that there is a trade-off in individual seed weight (w) and number per basal stem (N), in *Solidago*, such that NW = k, where k is a constant. There is little direct data from wetland or mire species - McNaughton (1975) showed that species of reed mace, *Typha*, living in the most stable habitats had the highest fecundities although the reasons for the variability of seed production within *Typha* are now open to re-interpretation (Grace and Wetzel, 1981).

In the New Forest mires, *Molinia caerulea* was observed to make a greater allocation to sexual reproduction at higher grazing levels, resulting in a 2-3 times higher number of flowering spikes at high grazing levels, relative to control plots (Section 7.3.2.2). A complex spatial pattern of flower production results from the interplay of *Molinia* abundance and grazing pressure. Most obligate aquatic plants are perennial and have well-developed mechanisms of vegetative reproduction (Arber, 1972), for example *Ceratophyllum demersum* rarely fruits but relies on vegetative propagation (Birks, 1973). Annuals must produce large numbers of seeds for survival, such as *Najas* spp., where data suggest that dispersal and transportation are important elements of the reproductive strategy (Birks, 1973).

The true contemporary analogue of the reproductive macrofossil assemblage is the seed bank, thus seed bank dynamics and the biology of seeds in the soil have the greatest implications for such macrofossil data. Yet, little attempt has been made to understand the seed bank in a palaeoecological context, even though at least 95% of all plant mortality occurs at the seed stage (Hickman, 1979). Useful reviews of seed population studies may be found in Pavone and Reader (1982) and Cavers (1983),

while Janzen (1984) provides an interesting perspective on the role of vegetative material in seed dispersal by herbivores. A general result of this research is that soils of climax habitats tend to contain predominantly seeds of species characteristic of disturbance and early succession, while the seeds of species growing at the surface are found in small proportions or are lacking altogether. Cook (1980) has reviewed this field and gives a summary of data on the numerical variation of seed numbers in the soil. In a recent study, Donelan and Thompson (1980) found that the density of buried seeds declined during succession on Magnesium Limestone and seeds of the dominant species were virtually absent from the seed bank. The underlying ecological and physical reasons are discussed elsewhere (Thompson and Grime, 1979). Haag (1983) found that the three most common species in Lake Wabamun, Ontario were rare in the seed bank, with the commonest *Myriophyllum exalbescens* absent. He concluded that the dominant aquatic macrophytes used seeds as only a secondary reproductive strategy, relying mainly on vegetative propagation.

To date, there are few studies, indeed, of present day seed banks carried out in order to aid palaeoecological data (Birks, 1973; GreatRex 1983; Hill and Gibson, 1986). Two of these relate to lake deposits (Birks, 1973; Hill and Gibson, 1986) and are therefore limited in the degree to which they can be applied to terrestrial peats. Only one study, Hill and Gibson (1986), critically compares vegetative and reproductive macrofossils.

Birks (1973) investigated "modern macrofossils" and vegetation in small lakes in Minnesota. The vegetation was recorded on a five point cover scale and seeds expressed as concentrations. Both data sets at the vegetation formation level reflected lake chemistry, possibly regional nutrient status. However, interpretation of the ordinations of the two data sets is not easy, since the sample points are not comparable.

Birks' results demonstrate the effects of differential fruiting behaviour, both within and between species, on representation in the seed bank. Increasing temperature and nutrients (from coniferous forest to prairie) caused increasing representation of *Utricularia* and decreasing represen-

tation of *Scutellaria*. And, in *Typha*-dominated communities, the degree of representation of *Typha*, was an order of magnitude greater than that of *Carex lasiocarpa* in *C. lasiocarpa*-dominated sedge mats.

From her data, Birks emphasizes the caution required before interpreting reproductive macrofossil assemblages in terms of communities, and she stresses the importance of the seed bank as the correct palaeoecological analogue. However, there is not a generally straightforward relationship, as Birks asserts, between a species' cover value and the number of seeds - there is little sign of a strong statistical relationship. Table 4.1 shows an analysis by the author of the data for seed numbers against species cover presented by Birks (1973). The number of seeds was correlated against cover value using Spearman's correlation coefficient corrected for ties (Siegel, 1956). The complexity of the processes operating is reflected by the high irregularity of representation, with most outcomes statistically non-significant.

Table 4.1: The relationship between number of seeds and species' cover value, taken from Birks' (1973) data

Species	N	r_s	t	p
Najas flexilis	59	0.093	0.712	N.S.
Brasseria schreberi	17	0.051	0.013	N.S.
Nuphar variegatum	37	0.354	2.24	$p<0.025$
Typha	13	0.260	0.892	N.S.
Carex lasiocarpa	6	0.814	-	N.S.

GreatRex (1983) has examined the relationships between vegetation and seed and fruit macrofossils in surface peat from fen and fen-carr communities. She found that on average 70% of the species within 1m of the sample were represented in the reproductive macrofossil assemblage. Unfortunately, she provides no quantitative comparison between the two assemblages but, in general, her data show only a poor relationship between species abundance in the vegetation and macrofossil density. Furthermore, some species were present as seeds or fruit but were absent

in the vegetation. Thompson (1986) found very clumped species distributions in the seed bank of an acidic grassland. More significantly, the spatial pattern of the seed bank could not be explained by reference to the vegetation pattern.

The problem of dispersal in the interpretation of fossil seed assemblages is well recognised. This is compounded by the physical processes of sorting and selection (Birks and Birks, 1980) resulting in differential concentration of particular seed types, and also by the role of biological factors in determining how seeds are distributed around the parent plant. Despite, theoretical considerations of fugitive species in space and time, there is little direct evidence from the mapping of seed 'shadows' of species (Cook, 1980). Ryvarden (1971, 1975) has investigated reproductive dispersal on deglaciated terrain and McQueen (1969) has examined the transport of macrofossils into lake sediments. Most work indicates that most seeds do not disperse very far (for aerodynamic considerations, see Burrows 1973, 1975). Contemporary studies show that most distributions are skewed away from the parent plant, although Werner (1979) and Bullock (1976) have suggested that a negative exponential function can provide a reasonably simple description of such distributions: $N = C \exp(-dX)$,
where N is number of seeds, C a constant, X is the distance from the parent plant and d is a measure of dispersibility under field conditions. The work of Sheldon and Burrows (1973) indicates that values of d probably differ even between closely related species.

The final distribution of seeds, prior to possible inclusion in a macrofossil assemblage, will also be determined by biological processes, particularly predation. The impact of birds in this respect has been most intensively studied, not only in terms of predation (see Cramp and Simmons, 1977, as a source of references), but also in relation to seed distribution and germination (McAtee, 1947; Chettleburgh, 1952; Cruden, 1966; Agami and Waisel, 1986). Janzen (1970) has modelled theoretically the interaction of seed dispersal and seed predation but field data have proved difficult to obtain without complicating factors (Janzen, 1975).

In addition to the processes of production, dispersal, etc outlined above

Rybniček (1973) has pointed out that macrofossil seed abundance is confused, finally, by germination - unripe, sterile seeds being well represented in assemblages, and ripe, germinated seeds are under represented. This also can be related to studies in contemporary ecology, that is the 'safe site concept' of Harper *et al* (1970). The safe site is the set of habitat conditions that favour the establishment of seedlings of a given species, and the number of seedlings of a species is therefore determined by the number of safe sites in a habitat. There is also intraspecific variation in seed germination (see Silvertown, 1984).

Clearly, many of the concepts of demographic plant ecology are relevant to palaeoecological interpretation of macrofossil assemblages. It is important to emphasise that this discussion is aimed at the study of immediate, peat-forming communities and not the local, or regional, basin. The argument put forward here is that sub-fossil seed and fruit assemblages present serious difficulties for interpretation in addition to those present in the interpretation of vegetative macrofossils. These arise, particularly, from the biological processes leading to the formation of seed assemblages, summarised in Figure 4.1. Most of our understanding of these processes comes from plant demography and community organization studies - but even here much is in flux. It is ironic, as Harper (1967) pointed out, that the development of plant demography is hindered by the very plasticity of seed production (e.g. *Chenopodium album* may produce from 4 to 100,000 seeds per individual). Watts (1978) has indicated that vegetative macrofossils overcome the representativeness of the "seed rain" - abundance, in plant communities, is in terms of vegetative material. Many palaeoecologists, such as Birks and Birks (1980), still place the emphasis on the analysis of seeds and fruits, but this represents a trade-off between identification and interpretation. Biologists, studying seed ecology, have begun to question the interpretation of palaeoecological data (Cook, 1980), such as the distribution of weeds and ruderals in the middle Flandrian inferred by Godwin (1975). Of all peat remains, vegetative macrofossils originate from the source most local to the sample point. Thus, vegetative macrofossils most accurately reflect the former assemblages of mire communities (Barber, 1981b). Despite differential decomposition,

the quantified relative abundances of vegetation macrofossils can provide an index of each taxon's biomass in the past. This is a central assumption of much palaeoecological research and enables the description of former plant community parameters. Vegetative remains are difficult to identify - and will always need to be qualified by evidence from seeds and fruits - but they are the best estimator of immediate populations given the current state of knowledge.

4.3 Interpreting macrofossil assemblages

Both reproductive and vegetative macrofossil assemblages are subject to differential rates of decomposition, resulting in an important information loss compared to the community's death assemblage. This has profound implications for the methods of interpretation used in macrofossil analysis. Substantial differences in the rate of decay have been observed between mire species. For example, leaves of *Narthecium ossifragum* have a decay rate double that of *Calluna* or *Eriophorum vaginatum* (Heal *et al* 1978) while *Sphagnum*, in particular, decays very slowly so that it tends to become over-represented in the macrofossil assemblage even after only a few years (Coulson and Butterfield, 1978). The decay rate varies not only between species but also in different parts of the plant. The roots of *E.vaginatum* for instance, decay over an order of magnitude more slowly than its leaves (Heal *et al*, 1978). Moreover, root material is more likely to be incorporated into the sub-fossil assemblage since it is closer to the permanently waterlogged zone, where the decay rate drops markedly (Clymo, 1965; Heal *et al*, 1978). Hence, a species normal growing position within the acrotelm is also important to the interpretation of macrofossil assemblages. In *Sphagnum*, the capitula decay more rapidly than stems and branches (Clymo, 1965), and are poorly represented in even *Sphagnum*-rich assemblages in New Forest peats. There are also cellular differences in the rate of decay within *Sphagnum* leaves (Dickinson and Maggs, 1974).

In general, the rate of decay is related to the resource quality of the plant material concerned, especially nitrogen and phosphorous content (Heal *et al*, 1978; Coulson and Butterfield, 1978; Malmer and Holm, 1984) although plant architecture such as surface area (Gallagher and Pfeiffer,

1977), and lignin content (Schwintzer, 1984) are also important. No investigation of seeds has been made, as was remarked earlier, but all these factors vary and widely differing preservation of seeds has been found in this and other studies (e.g. GreatRex, 1983).

The fact that the macrofossil assemblage provides degraded information relative to the original plant community, means that both vegetative and reproductive data should be utilized to minimise this problem. Moreover, it is also necessary to integrate the occurrence of macrofossils across different sampling horizons. This is because of the differences in the position of parts of the growing plant relative to the water table and the likelihood of their preservation. As a consequence different parts of the same plant may be preserved at different depths in the peat column, and with a differing degree of probability. This is illustrated in Figure 4.2 which shows an idealised sequence for the distribution of vascular plant remains, such as those from *Molinia caerulea* or *Calluna vulgaris*, based on the results of this study and those of most notably van Geel (1978) and Middeldorp (1984). Many vascular plants are preserved mainly as roots and this means that it is often not possible to define assemblages on the basis of a sample from a single depth, as is done for pollen or seeds and fruit. The need for depth integration is particularly important when defining macrofossil assemblage zones in a peat column.

The differential representation of species in sub-fossil assemblages is a major problem in palaeoecology because it prevents the reconstruction of complete community composition. Interpretation is based, therefore, firstly on the ecology of particular species, such as dominants or those with exacting habitat requirements ('indicator species'), and secondly at the level of whole communities or plant associations. This method of explanation is used in both pollen and macrofossil analysis. Methodological uniformitarianism in palaeoecology proceeds by using analogous phenomena to explain processes. This requires care in the choice of appropriate analogues, since errors of interpretation may be made by the use of analogous arguments which are incorrect. For example, plant associations have not remained constant over time and no species has yet to have its fundamental niche fully defined. Nevertheless, this does not invalidate such methods of interpretation, as Rymer (1978) has pointed

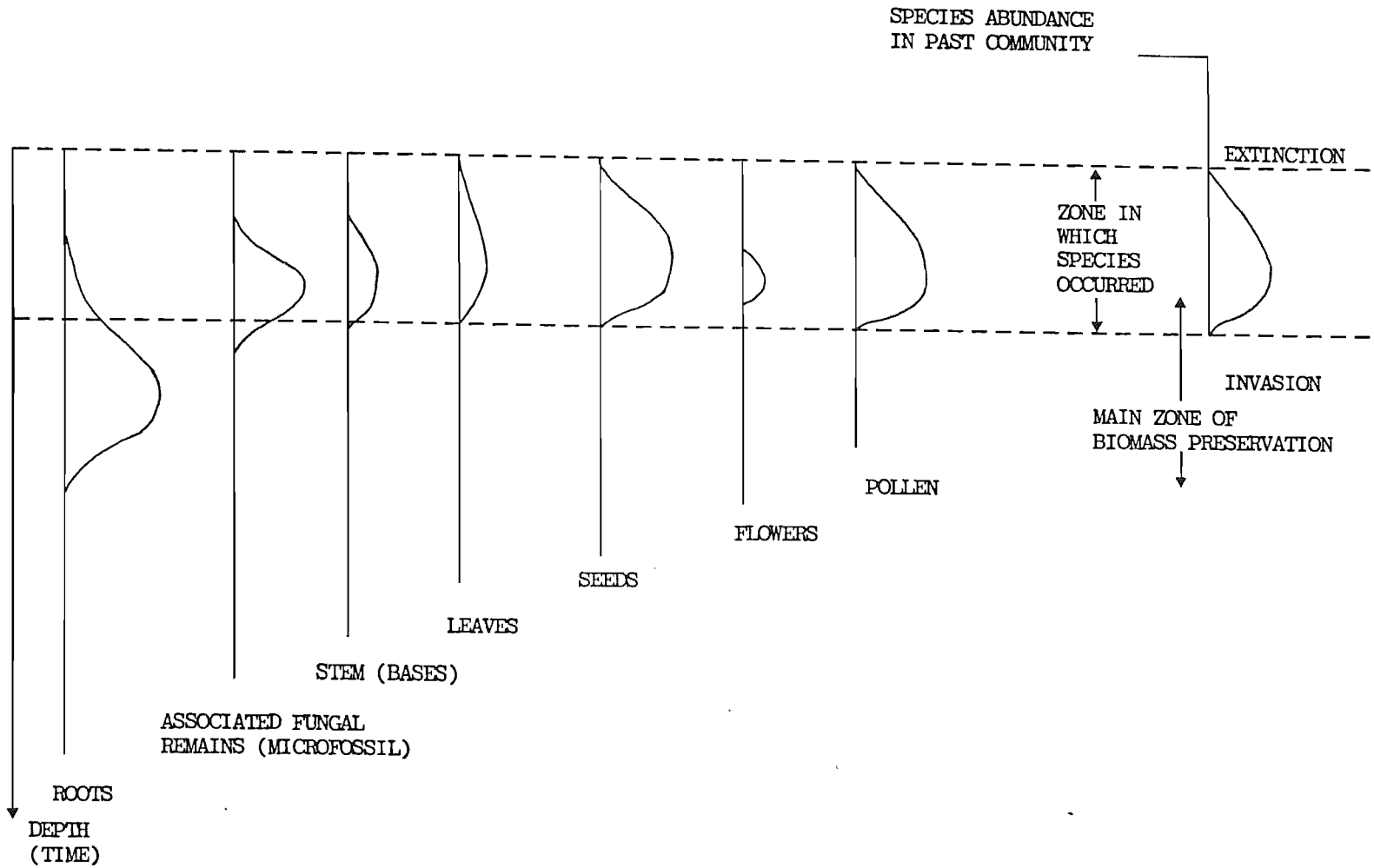


FIGURE 4.2: Idealised distribution of plant remains preserved in the peat column relative to the species' occurrence in the past mire community (see text).

out, but it is essential that these assumptions are acknowledged, in order to avoid accepting a false hypothesis or rejecting one that is true.

4.4 Field methods and laboratory preparation

4.4.1 The selection of sites

The degree of variation exhibited by the mires, and other habitats, of the New Forest is one of the main features of their conservation value. It is an objective of this study to cover the between-site variation of mires found in the Forest, but at the same time it is constrained by the degree of analysis required for a detailed description of community change at a given site. An excellent example of the resources required for small scale study is Middledorp's (1982) rigorous work on a 0.5m core from Engbertsdijksveen, The Netherlands.

In order to approach an optimum balance between the range and detail of study, a varied sampling strategy was used, with primary and secondary sites.

4.4.2 Procedure at a sample point

All peat samples were taken from boreholes. Distortion and contamination of peat was minimised using the version of the Russian sampler modified by Barber (1976). The shortened nose-cone of the Russian sampler enables basals deposits to be obtained more easily. In order to sample the whole depth of peat, two adjacent boreholes were used with alternate, overlapping, sampling. The field procedure is described by Barber (1976). 50 x 5cm samples are obtained, and are transported from the field in halved plastic tubing of the same dimensions, sealed in aluminium foil. Samples for radiocarbon age determination were obtained using a larger 30 x 9cm Russian borer (Barber, 1984).

Peat was described in the field using the Troels-Smith system as adapted by Aaby (1979) for the IGCP project 158B. The components were estimated on a 0-4 scale with all elements included within the sum. For secondary sites, material was identified as far as possible in the field, and,

where necessary, confirmatory identification was made in the laboratory.

4.4.3 Laboratory preparation

The ultimate aim of all preparation was to extract the sub-fossil peat remains in a way which reduces the loss of information during treatment. Peat cores were stored frozen until used, when the core was sectioned sequentially whilst still frozen in order to obtain precise cutting planes. Two centimetre thick sections were taken giving a maximum sample volume of $13.2cm^3$. This was found to be the optimum sample volume, after some initial trials, since closer sectioning resulted in greater fragmentation of macro remains, reducing the possibility of identification. Traditionally, macrofossil analyses have used volumes of at least $50cm^3$ (Grosse-Brauckmann, 1964; Wasylikowa, 1979). However, it was found that samples in the order of $10cm^3$ contained sufficient material, as is the case for other studies of vegetative macrofossils (van Geel, 1978, Barber 1981b); Grosse-Brauckman (1982) has also pointed out the difficulties in using larger samples.

The sample was allowed to thaw before its physical features were described according to Troels-Smith (1955). The volume of the sample was then calculated by displacement in a known volume of water. The peat was gently teased apart in a petri dish in order to extract any fragile identifiable material which may disintegrate on further treatment. The peat was sieved in the manner described by Barber (1981b), except that 500 and 125μm sieves were used in order to aid initial visual inspection; it was not necessary to apply chemical treatment. A standard quantity of water, 3 litres, was used in order to assess the degree of humification on an ordinal five-point scale, after initial attempts to quantify the turbidity of the filtrate by light penetration had proven unsuccessful, on grounds of practicality.

4.5 Estimation of species abundance

Numbers of reproductive macrofossils are discrete variables and, as such, they have been treated in many studies in the same way as pollen counts. The bulk of the peat, however, is composed of vegetative macrofossils and

data of this kind are continuous variables. Most studies using the palynologically-based approach have met with difficulty when trying to quantify vegetative macrofossils - for instance equating counts of *Sphagnum* leaves with a twig - this arises directly from the nature of the data involved, a point all too often overlooked. Studies of this kind are usually restricted to *Sphagnum* (often the dominant peat component) and other bryophytes. Relative frequencies of *Sphagnum* have been estimated with random subsampling of leaves by Green and Pearson (1977), and other studies of this kind are critically discussed by Barber (1981b). More recently, Janssens (1983) has attempted to express amounts of bryophytes in terms of leaf concentrations, using an arbitrary weighting factor (10 and 100) for branches and plants.

Approaches which have attempted to quantify continuous data are more applicable to all the types of vegetative macrofossils. Barber (1981b) has estimated macrofossil amounts on an ordinal abundance scale, while measurement on a ratio scale has been carried out by van Geel (1978), who estimated percentage volume of components. Obidowicz (1978) has used percentage cover on microscope slides, and, finally, Middeldorp (1982, 1984) has developed a rigorous method of measuring peat constituents on a wet weight basis.

This kind of quantified approach to vegetative macrofossils has several advantages:-

1) Formal methods of experimentation: in terms of sampling, experimental design, data analysis and inference.
2) Precise and explicit formulation of the problem.
3) User uniformity and consistency in operational rules.
4) Data for which error can be estimated and is in a form suitable for multivariate analysis and statistical inference.

4.5.1 Methods used

After preparation, the material was placed in a glass trough, partially filled with water, for inspection under a zoom stereomicroscope. Analysis proceeded in three phases - search, identification, and estimation of abundance. Identification will be considered in the next section because of its importance, and because of the difficulties that are

encountered in vegetative macrofossil analysis, particularly in valley mire and fen peat dominated by vascular plants.

All reproductive remains were removed and placed aside for identification and counting, as were invertebrate skeletal remains; all these were expressed as concentrations. Small samples of vegetative remains were removed and placed in glycerol before mounting on slides for examination under a high-power microscope. Thirty leaves of *Sphagna* were randomly selected and stained with Gentian Violet. The relative abundances of different taxa were estimated as percentages of all leaves.

Once identification had been carried out as far as possible, the relative abundance of the different macro-remains was estimated. It was decided that the most cost-effective method of assessment was to estimate percentage volume of each macrofossil type. The procedure adopted was to estimate the percentage volume of each type in a standard field of view under the stereomicroscope. It was found that a standard glass trough effectively provided a monolayer of remains. Estimation was carried out using a 10 x 10 square grid graticule, containing 100 numbered squares. This provided a quick and robust method for estimation, since the field of view was divided into 1% units. The microscope was used at x10 magnification, which was found most suitable for separating material and estimating amount; at this magnification the area covered by the grid was $1cm^2$. This process was repeated in order to provide an estimate of the mean percentage volume of each macrofossil element and the standard error about the mean. The trough was moved randomly between estimates, using random number tables.

This type of sampling frame has several advantages and is formally analogous to quadrat sampling of present day communities. A pilot study was carried out to determine the number of trials required to provide a mean with a reasonable confidence interval. In order to do this, a computer program was developed by the author to calculate the running standard error of the mean (using Bessel's correction) with the number of trials. This program was used in all further analysis and could calculate the number of trials required for a given level of accuracy (a given standard error), at a specified confidence level. Figure 4.3 shows the decrease in 95%

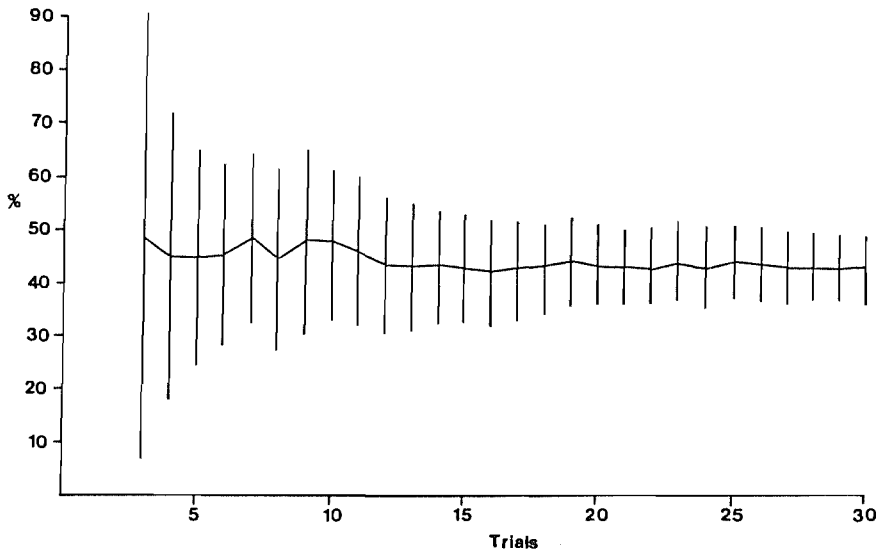


FIGURE 4.3 : Estimation of mean abundance and error for *Sphagnum* remains in a macrofossil sample (99cm) from Church Moor. Graph shows running mean and 0.05 confidence limits with increasing number of sub-samples (trials).

confidence limits for percentage volume of *Sphagnum* in a sample from the Church Moor pilot study. The number of trials necessary was determined to be fifteen. This appeared to give the best return in accuracy, in relation to effort expended, based on several graphs of this kind. It represents a 8% subsample of the total macrofossil sample. It should be noted that it is important to include the proportion of field that is empty in these calculations. Wasylikowa (1979), quoting Obidowicz, recommends that all fragments of tissue in one field should sum to 100%. However, the result is that each trial is not comparable, since the average proportions will be biased by the different densities of material in each field of view.

4.5 Identification

The identification of sub-fossil seeds and fruits is well developed in Britain and North America, but this is not true for vegetative remains - except, perhaps, for *Sphagnum*. This contrasts with continental Europe and Russia, where there has been extensive work on this subject (see Grosse-Brauckmann, 1982, for a review). The identification of these remains does, still, present a most difficult problem - any piece of plant can be preserved, there are no keys and a comprehensive reference collection is needed. These problems are greatest in fen and valley mire peats, where there are lower proportions of *Sphagnum* (usually 40% or less in New Forest mires) and significant amounts of difficult remains, such as monocotyledon roots, and a greater range of types encountered (Grosse-Brauckmann, 1980). This is in contrast to ombrotrophic peats, where there is a far greater proportion of a few characteristic *Sphagnum* species (often 90%).

The importance of identification cannot be over-emphasised, because it imposes a constraint on interpretation. Successful identification depends on the build-up within a laboratory of both published material and reference collections. Information used here is given below, along with additional data built-up during this study.

4.6.1 Seeds and fruit

No British seed atlas exists but atlases have been compiled for parts of

Table 4.2 Seed and fruit literature

GENERAL TEXTS	
Beijerinck (1947) with dutch key	Berggren (1969, 1982) with keys
Bertsch (1941) with german key	Brouwer and Stählin (1955)
Katz, Katz and Kipiani (1965)	Mason (1957)
Martin and Barkley (1961)	
SPECIFIC TAXA	
Betula:	
Mamakowa,(1968)	Białobrzeska and Truchanowiczówna (1960) (Polish with English summary)
Carex:	
Nilsson and Hjelmquist (1967) with key	
Cereals:	
Helfaek (1969)	
Juncus and Graminae:	
Korber - Grohne (1964) with keys	Farragher (1974) Poaceae
Ericaceae:	
Huckerby *et al* (1972) electron microscopy	
Potamogeton:	
Jessen (1949) with key	Aalto (1970) with key
GENERAL METHODS	
Barber (1976)	Overbeck (1975)
Rybniček and Rybničkova (1977)	Watts and Winter (1966), treatment of results
Wasylikowa (1979)	West (1968)

Table 4.3 Wood literature

GENERAL TEXTS	
Barber (1976) methods	Brazier and Franklin (1961)
Grosser (1977)	Jane (1956)
Sen (1963) X-ray (epidermis)	Reidl (1937) roots
Wilcox (1964) preparation	Schweingruber (1978) including sub-fossil wood and keys

the western Palearctic and the Nearctic floras. Palearctic studies are most relevant, but many mire species have a distribution across much of the Holarctic, so that works from both regions are of use to British palaeoecologists.

The following were found to be particularly useful: Beijerinck's (1947) atlas of the Dutch flora, the published volumes of the northwest Europe atlas (Berggren 1969, 1982); Katz, Katz and Kipiani (1965), and the North American manual by Martin and Barkley (1961) which contains some useful identification notes. Some keys of particular groups have been produced with the palaeoecologist in mind, but it is necessary, however, to use several sources of information since most works are necessarily limited. For example, the *Carex* keys of Nillson and Helmquist (1967) and Bergrren (1969), of nutlet and utricle morphology respectively, are largely complementary; but each omits certain species (absent from collecting areas) - in section *Dioicae*, for example, a different pair of the three European species are treated in each key. Korber-Grohne (1964) provides a key for *Juncus* seeds based on the sculpturing of the cell surface normally only visible with oil immersion. These features are often difficult to determine in sub-fossil seeds and the discovery of fertile hybrids between *J.articulatus* and *J.acutiflorus* (Blackstock and Roberts, 1986) sheds doubt on their reliability. Consequently, seeds of the latter species are referred to here as *J.acutiflorus*-type where they were encountered in samples.

4.6.2 Wood

The identification of sub-fossil wood on the basis of cellular structure is, as Barber (1976) cautions, a complicated problem. Root wood is more commonly preserved than trunk wood, structure varies with growth conditions, and preservation can cause distortion (such as the collapse of the characteristic large vessels of *Alnus* on compaction). Most of the literature is aimed at forestry, but several works are applicable for palaeoecologists, especially Schweingruber (1978) on identification and Wilcox's (1964) account of preparation techniques.

4.5.3 Bryophytes

The mosses are a particularly important group of plants in mire ecology, especially the *Sphagnum* genus (see Dickson, 1982; Barber, 1982). The significance of *Sphagnum* to palaeoecology is due to three factors. Firstly, they are dominant in many mire communities, and hence are the main constituents of peat. Also the main peat-forming species fall within the section *Sphagnum*, a small group of relatively easily identified species (see the key in Grosse-Brauckmann, 1974, and Barber, 1981b, pp. 62-66). Secondly, *Sphagna* have great value as indicator species, since they have relatively well understood ecological requirements, so that the presence of a taxon has inferential value concerning the reconstruction of communities. The potential of sub-fossil moss assemblages in delimiting microhabitats is recognised (e.g. Dickson, 1973 and Miller, 1980). The third feature of *Sphagnum* is that identification is based largely on characters which require microscopic identification, and hence are suitable to palaeoecological study, with enough remains present even in small samples.

Even with *Sphagna*, however, the situation is far from ideal, since most of the keys and other identification literature (Table 4.4) are based on whole, living plants. In mesotrophic mires, as in the New Forest, there is a diverse *Sphagnum* flora with many species difficult to determine on the basis of fragmented remains.

In order to exploit the information provided by *Sphagnum* remains to the full, it was necessary to develop a key as far as possible for branch leaves only (Appendix 3). The key is based largely on the data and criteria given by Hill (1978), but also draws on information from Daniels and Eddy (1985). It has been tested on fossil remains and material from three reference collections at Southampton Geography Department. The key is dichotomously branched, using the characters shown in Table 4.5, and keys down to section level. Where possible each section is keyed out separately - for section *Sphagnum*, *Rigida*, *Squarrosa*, and *Cuspidata*. The first three are given in Hill (1978), and the tentative *Cuspidata* key has been devised by Klinger (1976) and for which stain is essential. An English translation of this key is given

in Appendix 4. Gentian Violet is quick and easy to use and was included routinely in the macrofossil analysis procedure. The varied treatments of the genus by different authors, the plasticity of taxa, and leaf differentiation within a single plant all require caution in the identification of *Sphagnum* remains. However, identification to at least section level is often possible, and this approach is valid as long as the features used are clear so that revision is possible with further developments in the taxonomy of *Sphagnum*.

As discussed above, specimens from the section *Sphagnum* are readily assigned to species, although the characteristic of cuccullate (boat-shaped) leaves is not diagnostic of all branch leaves, and it is not uncommon to encounter lanceolate immature or pendent leaves. Leaves of this Section are frequently found attached to fragments of branch and the spiral fibrils are readily seen, even under a stereozoom microscope at high magnifications (75x).

The branch leaves of section *Rigida* show some similarities to Section *Sphagnum*, such as the resorbed branch leaf margin, but they are placed more closely to section *Subsecunda* by Hill (1978), due to structural features such as the abundant and prominent commisural pores of pendent branches. The phylogenetic dendrogram in Daniels and Eddy (1985) indicates similar affinities between these groups but places section *Rigida* more distantly from section *Subsecunda*. However, the authors do not give any details as to the basis or methods of their classification. Specimens of section *Acutifolia*, except *S.molle*, cannot be assigned to species level unless whole plants are available. This is probably the most problematic section for palaeoecologists, since it includes species from a wide range of environmental conditions. Section *Subsecunda* is also impossible to split without intact specimens or branch and stem fragments in monospecific peat, but most of its members indicate mesotrophic or even eutrophic conditions (Dickson, 1982; Daniels and Eddy, 1985). Both species of section *Squarrosum* are indicative of base-rich flushing and usually can be separated on branch leaf characters. The final section, *Cuspidata*, is variable in terms of microhabitat and is normally classified using stem characters, but a tentative key (in German) has been designed by Klinger (1976).

Table 4.4 Bryophyte literature

GENERAL TEXTS

MacVicar (1926) includes hepatics
Smith (1978)
Dickson (1982) macrofossil remains
Nyholm (1969) Fennoscandinavian Musci
Watson (1981) includes hepatics

SPHAGNUM

Daniels and Eddy (1985) European *Sphagna* with keys
Duncan (1962) with key
Barber (1981b) ombrotrophic species
Grosse-Brauckmann (1974) with key to peat-forming species
Isoviita (1966) revision of nomenclature
Hill (1976) macroscopic key
Proctor (1955) with key
Fearnsides (1938) with key
Klinger (1976) *Cuspidata* key
Lange (1982) key to northern species
Hill (1978) with keys
Cöster and Pankow (1968) Central European species

Table 4.6 Vegetative macrofossil literature

GENERAL TEXTS

Grosse-Brauckmann (1972, 1974)
Katz, Katz and Skobeeva (1977)
Bhadresa (1981) limited key for heathland species
Palmer (1976)

ANATOMY OF LIVING PLANTS

Metcalfe (1960)
Ross - Craigs (1974)
Metcalfe and Chalk (1960)

METHODS

Dilcher (1974)
Wasylikowa (1979)
Grosse-Brauckmann (1982)

Table 4.5 Important Section characters of *Sphagnum* branch leaves
Notes: (i) absent in *S.magellanicum*, (ii) not in *S.molle*, (iii) may be isodiametric in *S. tenellum*, (iv) larger in *S.tenellum*
Ventral = adaxial = convex surface
Dorsal = abaxial = concave surface

SECTION	SHAPE	MARGIN AND NO. OF CELL LAYERS	GREEN CELL EXPOSURE (MID-LEAF) VENTRAL	GREEN CELL EXPOSURE (MID-LEAF) DORSAL	HYALINE CELLS AT APEX	PORES (MID-LEAF UNLESS OTHERWISE) VENTRAL	PORES (MID-LEAF UNLESS OTHERWISE) DORSAL
Sphagnum	± cucculate Pendent lvs elongate	Denticulate 1 (Resorbed)	Broad Equal to wider	Equal to narrower (i)	Broader than long (Apex scabrous)	(Absent)	Usually triplets
Squarrosa	Weakly to strongly reflexed	Intact 1-3 narrow	Broader	Narrower	Longer than broad (Larger near base)	Along commisures Triplets at apex	Large (12-40μm) Not triplets
Acutifolia	Not cucculate	Intact 1-3(4) (ii)	Wider (or absent)	Narrow	Longer than broad (Larger near base)	Centrally placed when present	Triplets at apex, often ringed
Rigida	Variable with squarrose acumen	Denticulate 1-3 (Resorbed) Slight in pendent lvs	Absent	Absent (to narrow)	Longer than broad (Care at apex)	Cell wall junctions May be absent	Angles and commisures
Subsecunda	Variable	Intact 2-4 Narrow	Equal to narrower	Equal to broader	Narrow Longer than broad	Absent	Commisures Small (2-6μm)
Cuspidata	Ovate - Lanceolate	Intact 2-6	Narrowoto absent	Broader	Narrow Longer than broad (iii)	Faint Cell angles	Not at commisures small (2-9μm) (iv)

4.6.4 Other vegetative macrofossils

The major published works on vegetative macrofossil identification (Grosse-Brauckmann, 1972, 1974; Katz *et al*, 1977) are both difficult to obtain and have been largely ignored in Britain and America. The recent IGCP contribution of Grosse-Brauckmann (1982) provides a valuable English supplement to his earlier publications, and summarises the 'state of the art' for most European peats. Katz *et al* (1977) have produced a comprehensive guide, based on a long history of Soviet peat research, which was found indispensable for its hundreds of illustrations of plant tissues alone. Despite this information, identification remains a difficult problem which varies with region and mire type. A great deal also remains to be learnt about the variation in micro-morphology on a single plant of even common mire species. Vegetative macrofossil analysis has not previously been carried out on lowland valley mire peats in Britain and, because of the importance of identification, some information is given below based on New Forest peats and the reference collection at the Hugo De Vries-Laboratorium, Amsterdam.

Pteridophytes

The dominant fen species in central European peats is *Thelypteris palustris* Figure 4.4, but its limited distribution in Britain suggests that remains of this type cannot be readily assigned to species, even in the New Forest where it is a relatively frequent carr species. Leaf remains are characterised by dichotomous branching of nerves - a general feature of ferns.

Equisetum - Figure 4.5 The dark red epidermis is very characteristic (van Geel's "red epidermis"), with crenulated cells on the rhizome seen at high power (x300).

Monocotyledons

The only members of the Graminae to have relatively well understood morphology are *Molinia caerulea* and *Phragmites australis* (see, for example, Grosse-Brauckmann, 1982). It should be noted, however, that *Molinia* roots are not distinctive, being typical monocot roots with a central bundle and long columnar cells, but wherever roots of this type are found, then epidermal fragments must be looked for. The overwintering terminal

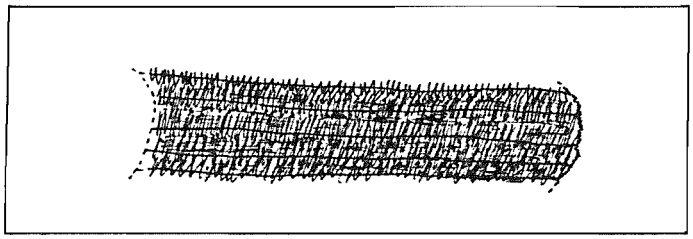


FIGURE 4.4 : *Thelypteris palustris* tracheid (x 125).

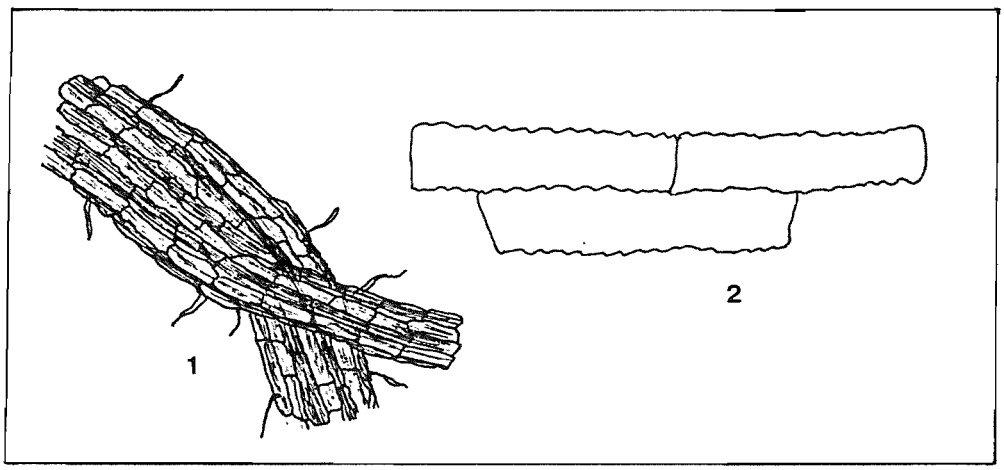


FIGURE 4.5 : *Equisetum* 1. Rootlet (x 125),
2. Epidermis (x 325).

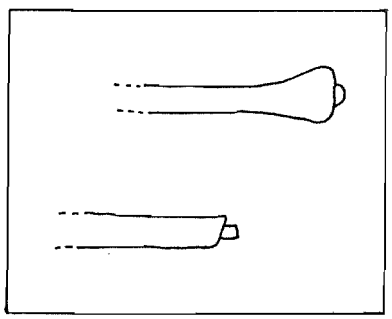


FIGURE 4.6 : *Molinia* basal node (x 25).

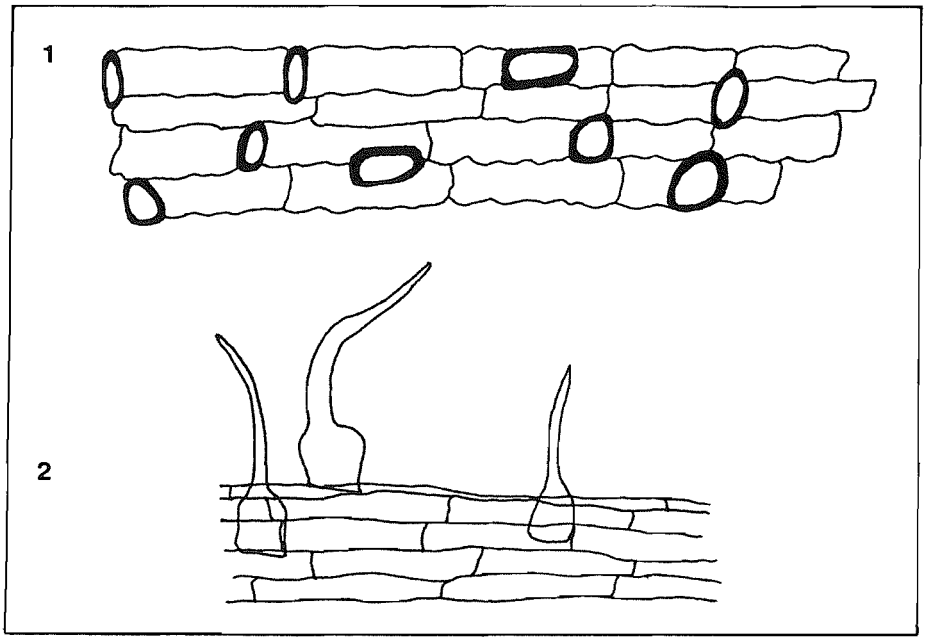
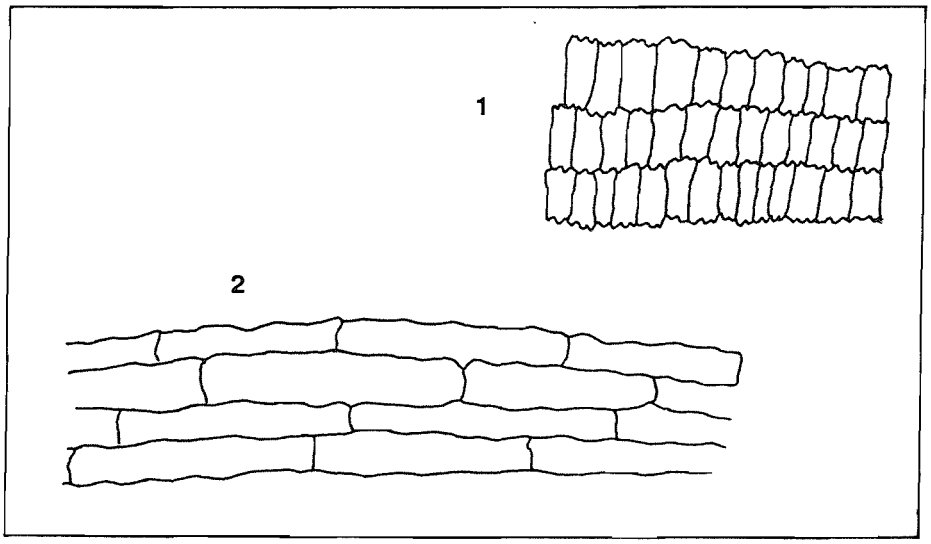


FIGURE 4.7 : *Carex* rootlet epidermis 1. Undet (x 325)
2. *Carex limosa* (x 500).



FGIURE 4.8 : *Rhynchospora alba* stem sheath epidermis
1. Marginal (x 300).
2. Central (x 350).

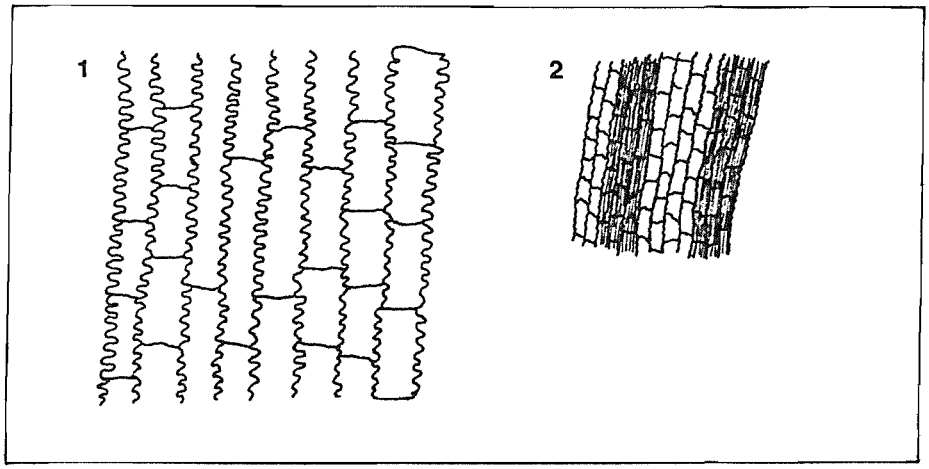


FIGURE 4.9 : *Trichophorum cespitosum* epidermis
1. (x 325)
2. (x 125)

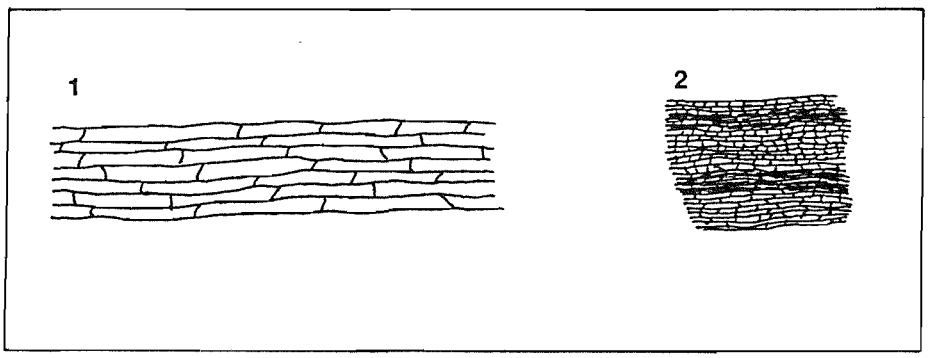


FIGURE 4.10 : *Scheuchzeria palustris* rhizome
1. Epidermis (x 325)
2. Epidermis and hypodermis (x 125)

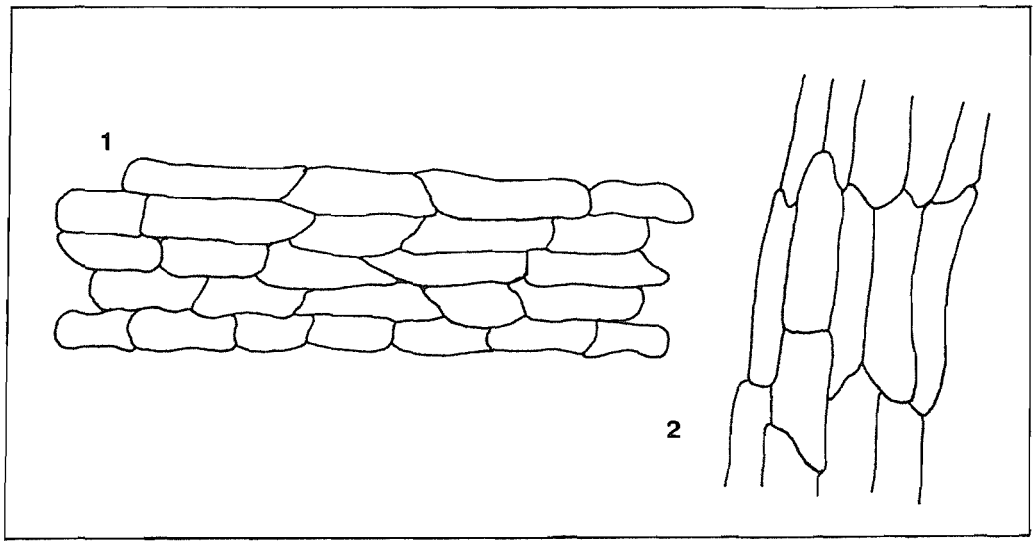


FIGURE 4.11 : *Menyanthes trifoliata* epidermis
1. Rootlet (x 400)
2. Leaf base (x 400)

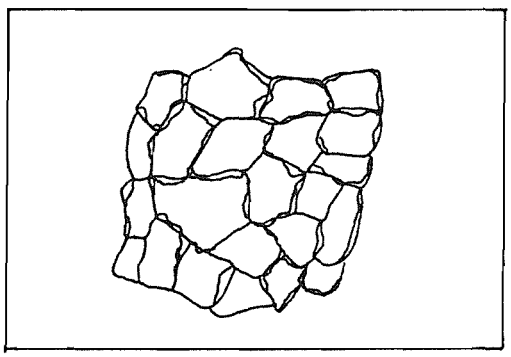


FIGURE 4.12 : *Vaccinium oxycoccus* leaf epidermis (x 325)

node of *Molinia* stems (Figure 4.6) appears to be characteristic and is encountered in New Forest peats, in addition to stem-bases.

Cyperaceae - The fine rootlets of *Carex* species have superficial, isolated incrassate cells (Figure 4.7) - the 'Pustel-Radizellan' of Grosse-Brauckmann. Katz *et al.* (1977) have used these to make specific identifications, but Grosse-Brauckmann (1982) doubts their usefulness. Their size and distribution are probably determined by mainly environmental factors, and they also occur in other Cyperaceae (e.g. *Cladium* and *Eleocharis* and Graminae (e.g. *Phragmites*). As Grosse-Brauckmann (1982) points out, this problem needs re-examination and re-evaluation. The stem sheaths of *Rhynchospora alba* have a distinctive cellular arrangement (Figure 4.8) - at the edges the cells are longer than broad whereas towards the centre the situation is reversed. The epidermis in *Trichophorum cespitosum* may be distinguished by short cells interspersed by rows of larger cells (Figure 4.9).

Scheuchzeria palustris

The epidermis of the rhizomes is characterised by long, rectangular cells (up to 10 times as long as broad), with slanting cross-walls (Figure 4.10). It can be confused with *Menyanthes*, but the latter has squatter, less rectangular cells. The above ground epidermis is similar but the cells are shorter and 'dumpier'. The presence of hydathodes is definitive of above-ground material

Menyanthes trifoliata

Thin membranous tissue with ill-defined vascular bundles covers the leaf bases - at higher magnification, the characteristic epidermal pattern is visible (Figure 4.11).

Ericaceae

The leaves and stems of *Empetrum nigrum* can be readily confused with *Erica tetralix*, however the leaves of the former species are virtually completely inrolled producing more globose leaves. The presence of *Empetrum* is often indicated by the resistant stones of the fruits. The stem bears some resemblance to *Erica tetralix* but lacks the spiral four leaf scars. The leaf epidermis of *Vaccinium oxycoccus* consists of irregular rounded/polygonal cells with overlapping edges. They can be more rounded than illustrated, particularly on the dorsal surface (Figure 4.12).

Table 4.7 Animal macrofossils identification and methods literature

GENERAL

Frey (1964)

SPECIFIC TAXA

Cladocera:
Freyer (1963
Rossolimo (1927)
Frey (1979)

Coleoptera: Coope (1979) and therein

Oribatid mites:
Sellnick (1929)
Michael (1884-1888)

Ostracods: Loffler (1979) and therein

Testate rhizopods:
Corbet (1973)
Tolonen (1966, 1979)

4.6.5 Fauna

A number of animal groups are frequently encountered in macrofossil samples, particularly Cladocera, Coleoptera, Oribatid mites, Chironomids, ants and testate amoebae. Mites were by far the commonest taxa found in this study, although a noticeably richer assemblage of sub-fossil invertebrates was present at Church Moor, a valley mire surrounded by ancient woodland. The identification of all these groups is time-consuming and requires additional expertise. Several specimens of mites from Church Moor were kindly examined by Dr. P.Vink of the Hugo de Vries-Laboratorium, Amsterdam. He identified three species, using Sellnick (1929/1960): *Hydrozetes lacustris* (Michael, 1882), *Limnozetes sphagni* (Michael, 1884) and *Punctoribates sellnicki* Willmann, 1928. All indicated wet or moist conditions associated with *Sphagnum* - which was already apparent from the plant remains. This illustrates a general problem in the use of many invertebrate groups in the analysis of peat deposits, in that there is insufficient ecological information as to species habitat requirements. Thus, the return in terms of additional information may not be worth the effort expended to obtain it, unless it is intended to answer specific objectives. The density of mites in peat samples was calculated in this study but further identification was not attempted. Other identification guides are given in Table 4.7

4.6.6 Reference collections

The difficulty of constructing keys for much of the remains in peat means that the basic identification process is one of trial-and-error comparison with present day material and illustrations. Identification may be based on gross morphology, such as the characteristic tubercles on the roots of *Myrica gale*, or fine cellular details. This means that a whole range of material is required in a reference collection. The power of identification is directly dependent on the size of the available reference collection. Both microscope slide and larger specimens are necessary and it is also useful to keep dry material of intact specimens. Southampton Geography Department also has extensive reference material of *Sphagnum* and other bryophytes.

Whole specimens may be kept in glycerol, but a standard formalin-acetic-

alcohol (FAA) solution is better (see Corrington, 1941). This is a standard biological preservative, achieving minimum distortion, and has the advantage of fixing the material. Glycerol is not recommended for arthropod exoskeletons since it dissolves skeletal structures, such as fine hairs, essential in the identification of groups like the Acari.

CHAPTER FIVE: MACROFOSSIL ANALYSIS AND FIELD STRATIGRAPHY

5.1 Introduction

This chapter examines valley mire development and plant community succession, based on evidence from macrofossil analysis and field stratigraphy. Palaeoecological information of this kind is important for two reasons. Firstly, it provides evidence which is both of theoretical interest and of practical relevance to mire conservation. For example, it allows questions to be examined such as, 'What is the relationship between valley mire and raised bog development?', and 'What are the current successional trends in valley mire vegetation?'. Secondly, mires are one of very few ecosystems which contain information on the way they have developed. This is of general significance to ecology, in relation to issues such as ecological stability, species turnover and the role of historical factors in community structure.

Macrofossil analysis is laborious and time-consuming, and this places an over-riding constraint on sampling in most studies. Five macrofossil cores will be described in this chapter. Two were taken from Church Moor and Cranes Moor, which are regionally important sites for palaeoecology, and for which pollen data and radiocarbon dates were already available. The significance of these sites is due mainly to the depth of peat (time span and resolution), and to the presence of Devensian Lateglacial and early Flandrian deposits which are rare in southern England. The two other sites investigated, Stephill Bottom and Hive Garn Bottom, are both more typical valley mires with shallower peat deposits. Stephill Bottom is a structurally simple, narrow valley bottom mire (part of the Denny Bog system). Hive Garn Bottom is a complex of seepage step and valley bottom mire communities, and cores were taken from both mire types. In addition, field stratigraphy from a further nine sites is discussed.

5.2 CHURCH MOOR

5.2.1 Introduction

Church Moor is located, some 50m OD, in a shallow valley within the Dark Water catchment on the south-western flank of a prominent ridge which

forms the watershed with the Highland Water catchment. Northwards the ridge is steeper and is capped by a belt of Plateau Gravels which protect an outlier of the Headon Beds. Church Moor lies on Barton Sand and further down the valley Barton Clay outcrops about 300m below the mire, although the precise position of geological boundaries is uncertain in this area. Some 400m east of Church Moor, a more recent valley mire system occurs at Barrow Moor on the other side of the watershed. The Barton Sand here is a fine sand, but drift deposits contain some fine-medium angular gravel, possibly frost-shattered, with traces of silt and clay, derived from the Pleistocene gravels.

Church Moor is surrounded on three sides by Mark Ash Wood which comprises predominently mature and senile *Fagus sylvatica*, but an oak (*Quercus robur*) - beech mix is frequent in the vicinity of the mire with occasional stands of mature *Pinus sylvestris* and younger *Betula pendula*. The mire is truncated to the south by the *P.sylvestris* plantation of Knightwood Inclosure. This site contrasts with the other mires used in this macro-fossil investigation in being surrounded by woodland. The main structural feature of the mire itself is the *Alnus* carr along the western side of the mire (see Barber, 1975; Alcock, 1985). The major part of the carr is dominated by multiple-stemmed and larger, single-stemmed *Alnus* with occasional *Betula pendula* and *Pinus sylvestris*. On the eastern side, the carr comprises of thicket of *Salix cinerea*, *Alnus*, sometimes tall bushes of *Myrica gale*, *B.pendula* and *Frangula alnus*. Tussocks of *Carex paniculata* are a major structural element in the carr groundflora as are the *Sphagnum recurvum/S.palustre* dominated areas. In places the fringing shrubs and trees extend across the mire at a lower density but their growth appears less vigorous. The majority of the larger *B.pendula* and *P.sylvestris* (2-3m high) in particular are dead or dying, suggesting a toxicity factor operates once the root system grows beyond the most biologically active layers in this part of the mire.

The upper part of the mire is typical of many mire communities occurring in light-gaps within a dense woodland canopy in the New Forest, and is dominated by tussocky *Juncus acutiflorus* with a ground layer of *Sphagnum recurvum*. *Hypericum elodes* is also locally prominent along lines of ground-water flow which occasionally generate significant overland flow

during periods of high rainfall. Southeastwards, the mire becomes dominated by *Molinia* tussocks with *Myrica gale* which grades into a wider area where *Molinia* is less abundant although still an important dominant. Here, *Sphagna* are more significant especially *S.papillosum* but also *S.recurvum*, *S.capillifolium*, *S.tenellum*, *S.palustre* and *S.cuspidatum*. Other infrequent species are *Erica tetralix*, *Eriophorum angustifolium*, *Juncus acutiflorus* and *Drosera rotundifolia* with less abundant *Myrica gale*. This area overlies the region of deepest peat (3m) in Church Moor, from which the cores were taken (see Figures 5.1 and 5.2). Further southwards still, *Molinia* increases in abundance with *Phragmites australis* and *Myrica gale*. For additional floristic data see Alcock, 1985.

The mire forms the head waters of a small tributary of the Dark Water which, under normal conditions of base flow, emerges within a channel in the lower part of the carr. During wetter conditions, the stream may extend above the mire when the groundwater table is very high. The ground surface upslope of the mire is less well vegetated and provides a sediment supply during these events, although most sedimentation is confined to the channel. Earlier inorganic sediment deposition in Church Moor is probably related to erosion in this source area as well as lateral slope-wash. The *Hypericum elodes* areas are clearly related to this surface- and groundwater movement, as is the carr which is displaced to the western side of the mire along the line of maximum movement. A second significant environmental factor is the grazing of commoners' ponies. This occurs mainly in the upper *Juncus*-dominated zone but also occurs further down the mire where tree and shrub cover is sparse or absent. The carr appears to be inpenetrable to the stock.

The first palaeoecological investigations at Church Moor concentrated on a core some 250cm deep taken within the carr (see Figure 5.1) and dating back to the Boreal chronozone, approximately 8000BP (Barber, 1975). Following the discovery of deeper peat, the field stratigraphy was investigated by the Mires Research Group (see Figure 5.2), and a core designated ChMI was taken for pollen investigation from the deepest part of the mire (see Clarke and Barber, 1987). The core used in this macrofossil investigation (designated ChMII) was taken from the same

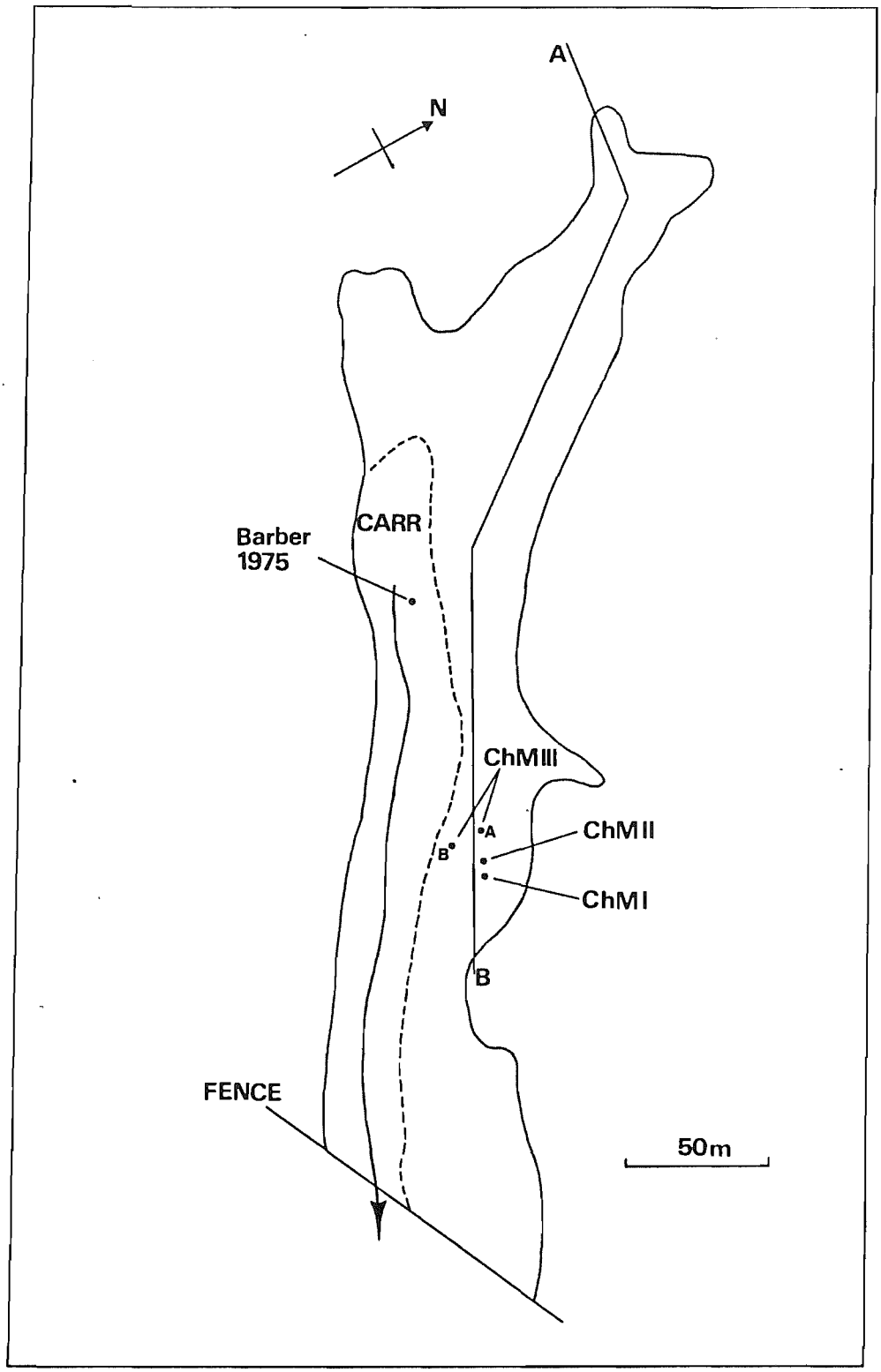


FIGURE 5.1 : Map of Church Moor showing location of cores and transect.

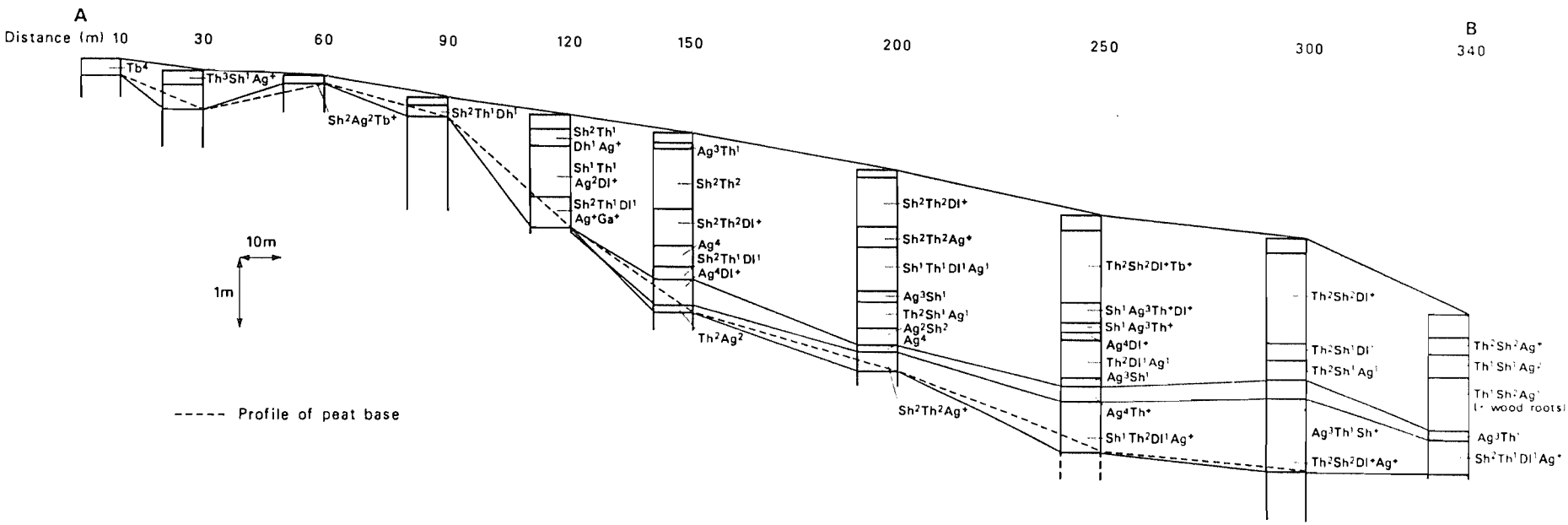


FIGURE 5.2 : Stratigraphic long-section of Church Moor showing correlation of a sediment layer attributable to the Loch Lomond Stadial. Symbols denote Troels-Smith (1955) sediment types. (Based on Mires Research Group data, 1979).

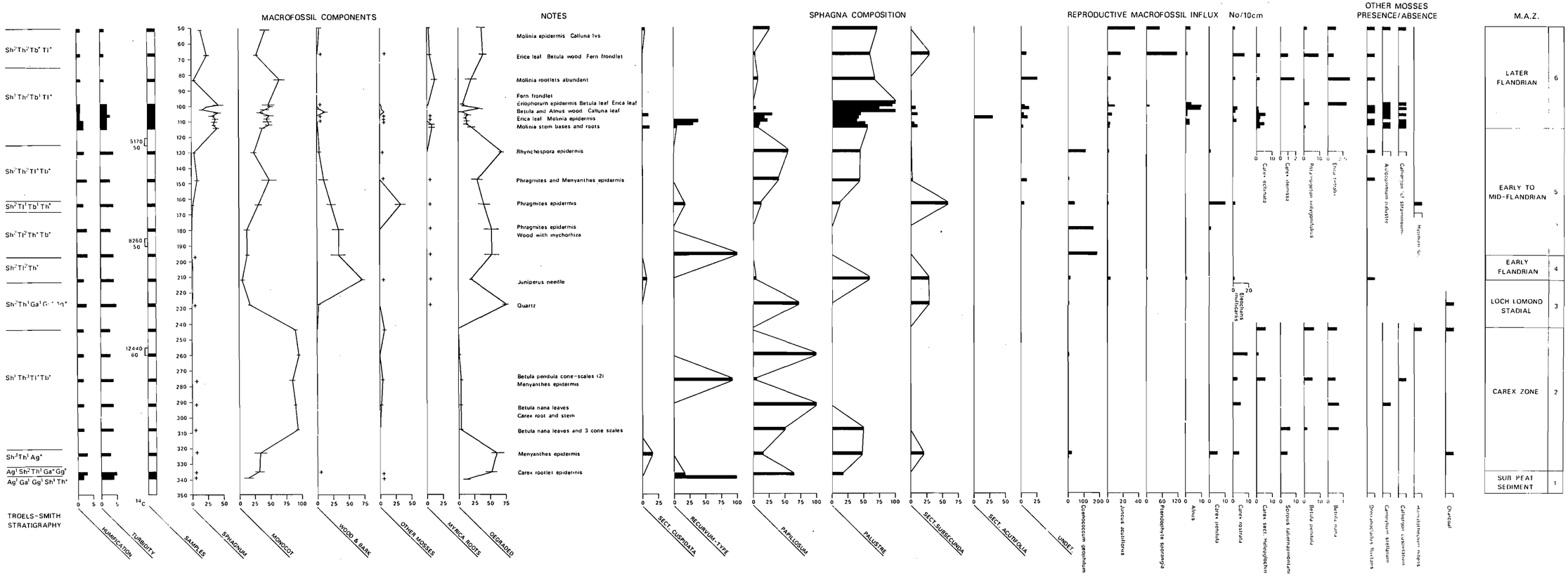


Fig 5.3 Macrofossil Diagram from Church Moor (ChMII)

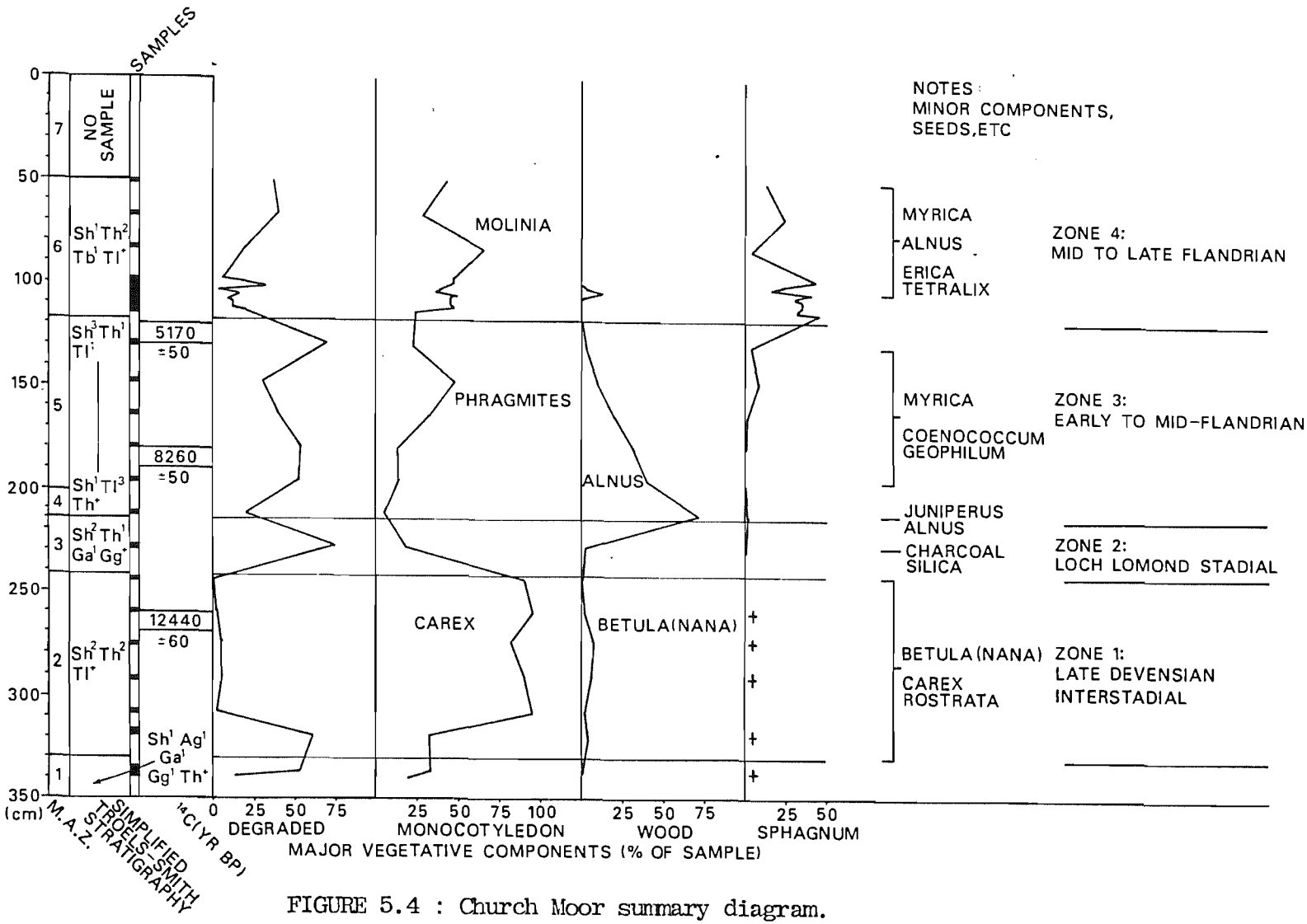


FIGURE 5.4 : Church Moor summary diagram.

area and was estimated to be within 2-3m of ChMI (A.R.Tilley, pers. comm, 1982). In both cases, the very wet and unconsolidated nature of the peat prevented sampling of the top 50cm by the Russian borer, although the field stratigraphy for ChMII was described (see later). Radiocarbon dates were obtained from three samples in ChMI (New Forest series 1); 260-270cm: 12440 ± 60BP, 180-190cm: 8260 ± 50BP, 120-130cm: 5170 ± 50BP (see Appendix 2).

The results of macrofossil analysis from ChMII are shown in Figure 5.3 and in the summary diagram, Figure 5.4. For descriptive purposes the core has been divided into seven macrofossil assemblage zones:

1 : 340 - 335cm : the sub-peat sediment
2 : 335 - 243cm : the *Carex* zone (2a and 2b)
3 : 243 - 213cm : the Loch Lomond Stadial
4 : 213 - 197cm : the early Flandrian
5 : 197 - 115cm : early to mid-Flandrian
6 : 115 - 50cm : the later Flandrian
7 : 50 - 0cm : recent

The macrofossils at Church Moor are particularly significant to the interpretation of the Late Devensian Lateglacial and this site is of importance in relation to vegetation and environmental history of southern England, despite the absence of pollen during the Loch Lomond Stadial in ChMI. For this reason, the discussion of results from ChMII will be divided into two parts to facilitate an overview of the Devensian Lateglacial at Church Moor.

5.2.2 Macrofossil zones 1 - 3 : the Late Devensian Lateglacial at Church Moor

There are few Lateglacial sites in southern England and Church Moor is particularly important in this respect, since this period is well represented, in contrast to most sites. Before discussing the results from Church Moor it is useful to set out what is known about the Devensian Lateglacial in southern Britain. However, our present understanding of this period is far from straightforward and it is helpful to examine the reasons for the complexity and uncertainty, since it allows more tenable conclusions to be drawn from the Church Moor data.

Early ideas concerning the Devensian Lateglacial were based upon a simple tripartite division of this period (see Godwin, 1975), who reviews most of the evidence up to 1970). Since then, research has stemmed particularly from more sophisticated pollen analysis and the study of fossil Coleoptera assemblages. In a review of this more recent evidence, Lowe and Gray (1980) were unable to extend their view of the present consensus on the Devensian Lateglacial further than an initial period during which warm conditions developed, followed by a period of cold - the Loch Lomond Stadial - which preceded the start of the Flandrian. The evidence is equivocal for a climatic oscillation equivalent in time to the Allerød (Zone II) of continental Europe, and the most consistent evidence comes from northern Britain (see Coope, 1977; Watts, 1980; Lowe and Gray, 1980). The Loch Lomond Stadial, in contrast, was very marked in Britain compared to the rest of Europe and this may be due partly to much greater snowfall, at least initially, compared to more continental regions of Europe (Rose *et al*, 1979).

A number of workers (e.g. Godwin, 1968, 1975; van Geel and Kolstrup, 1977; Watts, 1980) have made the point that a model based principally on the mean July temperature is simplistic and misleading; many climatic parameters are involved in shaping plant distributions as well as other factors. But even today the controls on a species' distribution are poorly understood (Perring and Walters, 1962). Moore (1980) urges great caution in the use of "indicator" plants to interpret the Late Devensian environment. Two assumptions are implicit in this approach. Firstly that the physiology, and its genetic basis, of Lateglacial populations is equivalent to present-day plants of the same species, despite the widespread existence of differing ecotypes and the rapidity of genetic response to selective pressures. Secondly, that an adequate understanding of the environmental control of present-day species distributions is available. As Moore (1980, p.153) says, "The first assumption is tenuous and the second requirement is naively optimistic".

A more fundamental difficulty is that Devensian Lateglacial communities are <u>not</u> analogous to those of the present day, a common feature of most

Late Devensian sites is the co-existence of species which display contrasting present-day ecological characteristics (e.g. the presence of both "calcicoles" and "calcifuges") and the simultaneous occurrence of arctic, montane, boreal and atlantic species (Smith, 1970; Pennington, 1977). This is a major obstacle to environmental interpretation of the Devensian Lateglacial using ecological data. This is because palaeecology seeks to explain by way of analogy - as was discussed in the previous chapter - yet there are clearly no present-day analogues of the Late Devensian vegetation. In other words, the evidence demonstrates that the principle of methodological uniformitarianism cannot be applied at the community level to the Devensian Lateglacial. Given the acknowledged complexity of this period, recognition of this problem is an important step in the development of a more rigorous interpretation of Devensian Lateglacial ecology.

A related factor (and possibly the cause) to the non-analogous nature of Devensian Lateglacial communities is the difference in interspecific competition between then and now. Much of the Devensian Lateglacial flora exhibits a more restricted present-day range compared to its former widespread distribution. Many of these species may be regarded more or less as "stress tolerators" rather than "competitors" in the sense of Grime (1977), e.g. *Betula nana, Hippophae rhamnoides* and *Juniperus communis*. Indeed, there is nothing new in this line of thought - Iversen (1954) invoked the absence of competitors as the explanation for the abundance of heliophytes (light-loving plants) during the Devensian Lateglacial. Thus, although species may have retained their fundamental niches throughout (i.e. no evolution has occurred), their realised niches have changed due to variations in interspecific competition and, perhaps, also in the processes that maintain co-existence. Vegetation change during this and previous interglacials has been shaped by competition as communities were invaded by newly immigrating species.

The discrepancy between the composition of past plant communities and present analogs is particularly pronounced during the Devensian Lateglacial. The rapidity of climatic change during this period is seen as having introduced a marked lag effect in vegetation due to the time required for species to migrate from refugia (see Ruddiman *et al*, 1977).

The disequilibrium between vegetation and climate creates a situation whereby vegetation change may be internal, driven solely by the time taken for species migration (see Davis, 1981 and Webb, 1986 for reviews). This may be regarded as a biological null hypothesis and the burden of proof lies upon other (environmental) hypotheses of vegetation change. During the Lateglacial, vegetation change therefore must be interpreted in terms of a complex of internal, climatic and edaphic factors (Prentice, 1986; Pennington, 1986; Webb, 1986). Moreover, the lag effect of the Lateglacial resulted in the absence of numerous members of the present species complement of southern England. Many of these may be described as "competitive" species, *sensu* Grime (1977), and the Lateglacial plant community may, in a sense, have been "released" from certain competitive interactions of the present day. This allows for differing ecological distributions of species compared to the present, and provides an alternative hypothesis explaining the composition of Lateglacial assemblages. Other workers have also touched on these ideas in relation to the Devensian Lateglacial and early-mid Flandrian (Davis, 1978; 1981; Bennett, 1986).

It is ironic that most organic deposits derived from the Devensian Lateglacial are found within the limits of the Devensian glacial ice. Indeed records are so sparse in southern England that there is nothing like the correlated framework constructed for upland Britain, described by Pennington (1977). We know that exceedingly cold temperatures were prevalent during the mid-Devensian in southern England, from fossil ice wedges and other features associated with frozen ground (Watson, 1977). At the same time, the available evidence points towards the survival of a significant per-glacial flora (Dickson, 1973; Godwin, 1975) and the existence of refugia for more thermophilous species, such as *Corylus avellana* (Deacon, 1974) and *Alnus glutinosa* (Chambers and Price, 1985, see also Heyworth *et al*, 1985), not far from the present south and west coasts of Britain. It may be noted, in passing, that central southern England was the most distant area from the Devensian ice limit within the present land surface of Britain. Moore (1980) has argued that the climate may have been more alpine rather than arctic in nature, due to the effect of lower latitude. While West (1977) suggests that a comparable situation may exist where a cold ocean borders a continental mass;

cold westerlies may have prevailed in the summer, possibly with low air humidity, and very cold anticyclonic conditions during the winter. Such a hypothesis is in accord with the frequent records of Asiatic Coleoptera found even in the Late Devensian of Britain (Coope, 1977). However, the presence of a significant oceanic component in the Late Devensian flora (Smith, 1970), including species such as *Erica tetralix* from the earliest part of this period (Godwin, 1975), suggests that the climate was not entirely continental in nature.

The available evidence indicates a warming in climate somewhere between 14000 and 13000 BP, at the beginning of the Devensian Lateglacial. The coleopteran evidence is indicative of a relatively rapid rise in temperature sometime after 14000 BP, which approached modern summer temperatures (Coope, 1977). Some pollen analytical studies suggest an earlier date for the beginning of warmer conditions (Pennington, 1977), and the bulk of the evidence supports a marked vegetational response by about 12800 BP (see Burrows, 1975 for a review). The issue of a Bolling-Older Dryas - Allerod climatic oscillation in Britain (and continental Europe!) has still yet to be resolved (see Watts, 1980 and Lowe and Gray, 1980 for a review of this problem). The Coleoptera indicate that a cooling of the climate began at about 12200 BP (Coope, 1977; Bishop and Coope, 1977), and a date of 11800 BP has been derived from Cladocera studies (Harmsworth, 1968). Glacier initiation may have begun again by about 11500 BP (Sissons, 1979) and there is geomorphological evidence from lowland Britain of a temperate but cooling climate between 12200 and 11300 BP (Rose *et al*, 1979). The evidence from the Coleoptera indicates a period of sustained cooler conditions before the more pronounced climatic deterioration of the Loch Lomond Stadial (Zone III). However, the evidence based on vegetation suggests that the second part of this cool phase may have been warmer to some extent (e.g. Heyworth *et al*, 1985), but the pollen analytical evidence is not consistent in this respect.

Yet, within this general picture of the Devensian Lateglacial there is very little evidence from southern and lowland sites. Furthermore, much of the interpretation of the data from this area relies on an environmental scenario which has been developed for other northern and upland

areas of Britain. There is a pronounced regional differentiation in the vegetation of the Devensian Lateglacial (Pennington, 1977; Watts, 1980) as well as non-synchronous change in vegetation, for which no simple climatic explanation is available. In addition to the altitude gradient which has been demonstrated in the Devensian Lateglacial (Birks and Deacon, 1973), a more distinct north-south gradient is to be expected with more detailed studies (Pennington, 1977). Although, southern species were poorly represented in the numerical analysis of Birks and Deacon (1973), this group was centred on East Anglia and southern England and Wales. Table 5.1 lists most of the available studies on the Devensian Lateglacial of southern England. Despite the limitations discussed by Godwin (1968), the early pollen diagrams (1940-1963) from East Anglia do not exhibit the "usual" pattern of vegetation change during the Lateglacial, derived from the northern sites. A series of herb-rich communities is evident, but a variety of shrubs and tree birches are also prominent. The pollen percentages of *Pinus* may be ascribed to long distance transport, but they indicate that populations of this species were relatively close. The East Anglian evidence is similar to the assemblage derived from peat blocks at Colney Heath, which occur as fluvial erratics and have been dated to 13560 $\pm$ 210 (Godwin, 1964). However, the data from Colney Heath is difficult to interpret in environmental terms. Although the plant assemblage is one of mainly open conditions with many present-day "calcicoles", there is nothing to indicate a particularly cold climate. It is true that the bryophyte community shares species in common with mid-Devensian sites (Dickson, 1973), but many of these species can also be found today in lowland mires. Also, the Coleoptera from this site include both northern and southern species (Coope, 1977)

The Lateglacial site from Hawks Tor (Brown, 1977) is particularly important since it is often quoted as strong evidence for climatic severity in Britain far outside the limits of recent glaciation. Certainly there is evidence for a climatic regression in the Loch Lomond Stadial, albeit under a marked oceanic influence. However, these deposits deserve to be interpreted independently of the usual model for northern Britain. Taken alone, the data presented by Brown (1977) suggest predominantly open, but not necessarily cold conditions. For example, there is an essentially

TABLE 5.1 Devensian Lateglacial sites in southern England

SITE	AGE/CHRONOZONE	SOURCE
Colney Heath, Hertfordshire (peat erratic)	13560 ± 210	Godwin, 1964
Hawks Tor, Cornwall	c13000	Brown, 1977
East Anglian early pollen diagrams	Zones I - III	see Godwin, 1968
Nursling, Hampshire, early pollen diagram	Zone III	Seagrief, 1959
Munsley, Isle of Wight	Late Zone II, Zone III	Scaife, 1982
Croydon, Kent, artic beetle assemblage	10130 ± 120	Osborne, 1971
St. Aubin's Bay, Jersey		Coope *et al*, 1985
Elstead, Surrey		Seagrief and Godwin, 1960

temperate diatom flora in the basal muds, estimated to be pre-13000 BP. Indeed, there is no independent geomorphological evidence to indicate that these basal silts are periglacial in origin. However, several cold 'indicator' species are associated with the first phase at this site, such as *Astralagus alpinus* and *Saxifraga stellaris*. Other such species, for example *Artemisia norvegica* and *Salix herbacea* are not free of identication problems (Moore, 1980). The sparse records of *Betula nana* are, in fact, restricted to the second phase at Hawks Tor, during which Brown (1977) estimates the mean maximum summer temperature to have been only 2.5^{o}C less than today, using phytogeographical data. This method requires an accuracy of estimation to less than 5% for this difference to be meaningful. It may also be noteworthy to observe that Coope (1977) describes the beetle fauna of Hawks Tor as "boreal" rather than "arctic". An argument based on indicator plants is a dangerous course here, since the Hawks Tor flora also includes *Lycopus europaeus* which now does not occur north of 62°N in Scandinavia (Brown, 1977).

The point is that the available evidence from the southern and unglaciated regions of Britain does not fit the pattern of Lateglacial vegetation change in northern Britain very closely. Nor should it be expected to do so. Much more evidence will be required before a regional and comparative scheme can be constructed for southern England. The need for Late Devensian sites in southern England, other than peat erratics and upland granitic masses, is one of the most important areas of future research for the study of palaeoecology in Britain. In this respect, Scaife's (1982) study of the Isle of Wight is particularly valuable for the Loch Lomond Stadial and the early Flandrian (see later).

5.2.2.1 Macrofossil zone 1 : the sub-peat sediment : 335 - 340cm

Only small samples (7cm^{3}) were available at the limit of sampling at 340cm using a Russian corer. The basal material immediately beneath the peat consisted of a strongly gleyed silty clay with some gravel, and is typical of the colluvial sediments which mantle most of the slopes and valleys in the New Forest. The sparse macrofossil assemblage was dominated by monocot rootlets, most of which were unidentifiable but some *Carex* epidermis with "pustelradizellan" (see section 4.6) was

present. Although the rootlets may have penetrated from above, the presence of *Sphagnum* shows that contemporary above-ground plant material was incorporated during deposition of the inorganic sediments. Furthermore, the moderate preservation of the *Sphagna* suggests that they are derived from plants growing *in situ* or nearby, since mechanical damage due to transport would be high given the nature of the sediment. The nearby ChMI core is dated to 12440 ± 60 BP at 260 - 270cm. Thus allowing for some variation in depth, the basal samples from ChMII occur some 45cm or more below the date of 12440 BP, suggesting a date from the earliest Devensian Lateglacial. As will be seen, the pollen evidence from ChMI is consistent with an age of some 13000 BP for Church Moor. It is interesting to note that the *Sphagna* present, - *S.palustre* *S.papillosum* and *S.recurvum* - type (the commonest species) - are some of the most frequent species in the New Forest under present-day conditions, including Church Moor. These are some of the oldest Late Devensian records, for *Sphagna* from a radiocarbon-dated site in Britain, according to Dickson (1973). This is not the kind of cold-climate assemblage that one would predict from the present day *Sphagna* of the high, and even low, arctic (Dickson, 1973). Indeed, *Sphagnum palustre* is absent from northern Norway today (although it occurs in southern Scandinavia) and *S.papillosum* is restricted to the west coast where it occurs in about 20 - 25% of sites according to Lange (1969). In the "*S.recurvum* group," *S.flexuosum* and *S.fallax* are even scarcer in the west coast area but *S.angustifolium* is more widespread throughout the Troms and Finnmark regions (Lange, 1969). There is, therefore, no evidence to suggest that the upper colluvial sediments beneath the peat contact are due to solifluction. This is not to discount the role of such periglacial processes in the New Forest prior to the preservation of organic remains at Church Moor. Colluvial sediments may often attain some 40 - 50cm in thickness in the New Forest, but the significance of snow-melt in low latitude periglacial conditions should not be discounted (Worsley, 1977).

5.2.2.2 Macrofossil zone 2 : the *Carex* zone : 243 - 325cm

This zone is characterised principally by abundant, well-preserved monocotyledon remains, forming on average 90% of the total macrofossil assemblage. The *Carex*-dominated zone 2 correlates with the *Betula* phase

in the ChMI pollen diagram. The low level of decomposition is illustrated by the virtual absence (2-3%) of degraded material, which formed some 25 - 30% of the total assemblage in other parts of the ChMII core. Most of the material was composed of fine rootlets, which in places gave the peat a "felted" texture, but some stem and leaf fragments were also present. Microscopic examination suggested that most of this material was derived from *Carex*; the distinctive "pustel-radizellan" of *Carex* were especially frequent. The problems involved in the identification of *Carex* species from epidermal tissue have been discussed already (section 4.6) and identification below generic level was not possible. However, the associated *Carex* utricles and nuts provide evidence as to the species present. The utricles of *Carex rostrata* were the commonest type found. *Carex rostrata* remains are frequent throughout the Devensian Lateglacial and Flandrian, and this species may have survived in Britain from previous interglacials in per-glacial areas (Godwin, 1975). Holdgate (1955) describes *Carex rostrata* as a typical dominant in northern and western parts of Britain where the larger, "southern" sedges are infrequent. A similar distribution occurs in Sweden, where *Carex rostrata* is a frequent dominant of *Magnocaricetum* in areas where the larger species are absent (Holdgate, 1955).

The fruits of *Carex* section *Heleoglochin* (= *Paniculatae*) were also common in this zone, and often consisted of nuts in badly eroded utricles. The shape of the specimens was variable and it was considered that reliable identification to species level was not possible. The specimens most closely resembled *C.paniculata* and *C.diandra* according to Berggren (1969), but only *C.paniculata* (which still grows at Church Moor) was available for reference material. The data on these two species in Berggren (1969) contrasts somewhat with the illustrations in Jermy *et al* (1982). The nutlets were similar to *C.paniculata* reference material, and more closely resembled this species than *C.diandra* according to Nillson and Hjelmquist (1967). The only other reproductive remains from *Carex* in this zone were (i) one nut from the section *Phacocystis*, the "*Carex nigra* group". The nerves on the utricle are critical within the group and there is considerable intraspecific variation and fertile hybridisation, so that identification was not possible. (ii) Four achenes were

found in the sample from 323 - 325cm which were tentatively identified as *Carex pendula* (refer to macrofossil zone 5 where similar specimens were found). Lower horizons of zone 2 also contained seeds of *Scirpus tabernaemontani*, characterised by their size and very large downward-pointing barbules. This species is now very restricted in the New Forest but occurs at Crockford Bottom in association with the Headon Beds.

The second notable feature of this zone was the presence of *Betula nana*, the dwarf birch, in the macrofossil assemblage. Indeed, *Betula nana* is one of the few plants encountered in this study which is not found in the valley mires today. This is an interesting observation on the ecology of the mire communities, since it suggests that the species turnover in the valley mires has been much less than that of the surrounding dry land plant communities during the post-glacial. Two species of birch are present as macrofossils in this zone : *Betula nana* and *B.pendula*. Seeds and cone scales from both species were found, but only leaves of *B.nana* were present. The numerous leaves and leaf fragments of *B.nana* suggest that this species may have been growing on the mire. This conclusion is supported by the presence of *Betula* cf *nana* wood in the macrofossil assemblage. Examination of a squash of this thin rootlet material under high magnification revealed numerous pits and scalariform plates with up to 15 bars - the small size and abundance of the ray vessel pits is a distinctive feature of *B.nana* (Schweingruber, 1978). The distribution of the *Betula* cf *nana* wood in the core was 260 - 337cm, while the above-ground remains of both species occurred from 243 to 293cm. The peak of *Betula* pollen in ChMI spanned 260 to 290cm and was dated at 12440 $\pm$ 60 BP at 260 - 270cm. The potential separation of *Betula* species pollen on the basis of size has been the subject of considerable discussion in palynology (see Prentice, 1981 for a review) since, on size criteria alone, *B.nana* is only distinguishable from *B.pubescens tortuosa* and not *B.pendula* or *B.pubescens pubescens* (Birks, 1968). An analysis of size-frequency data carried out here for *Betula* pollen from ChMI, counted by A.R.Tilley, reveals the presence of *B.nana* and *B.pendula* in the pollen rain, and possibly a third species of *Betula* (Figure 5.5).

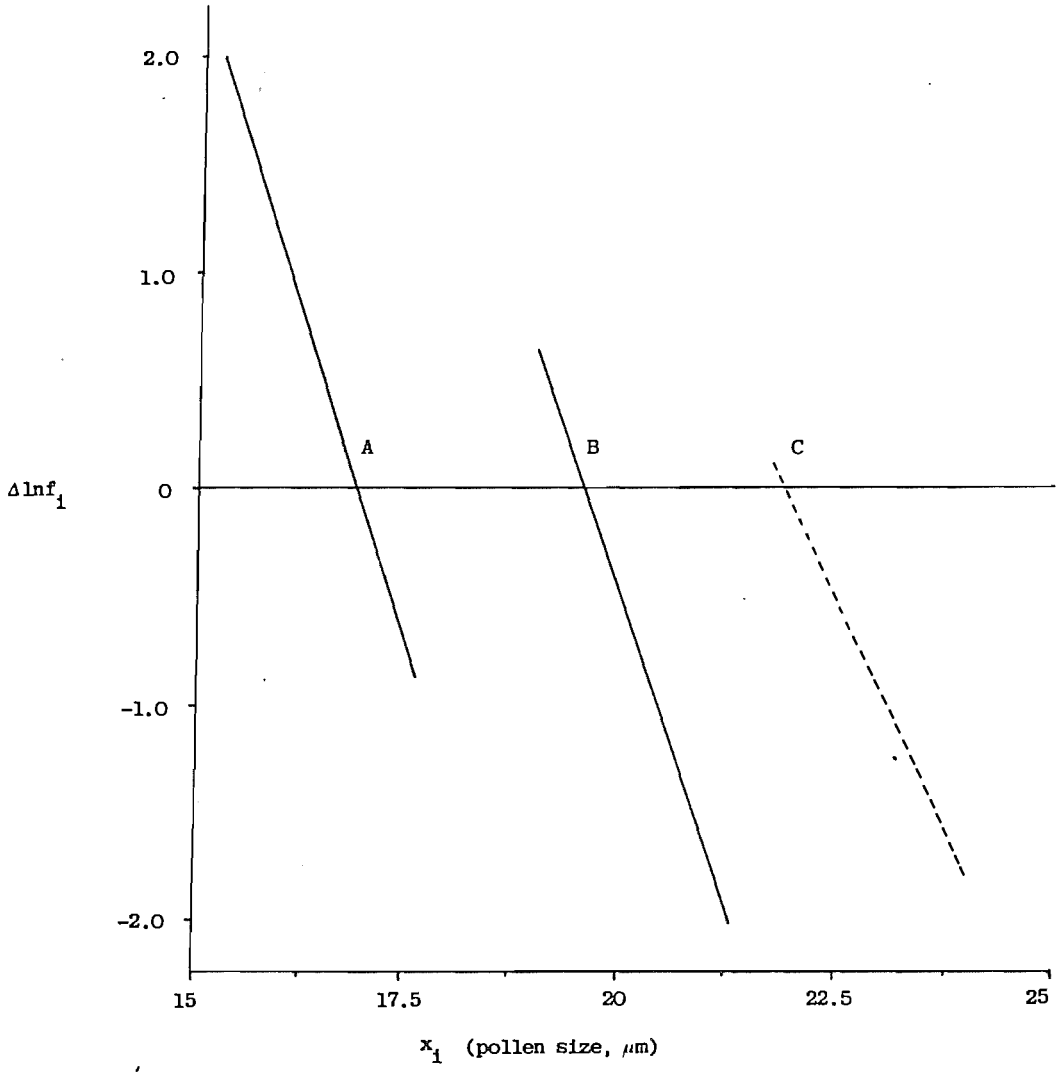


FIGURE 5.5 Bhattacharya plot for *Betula* pollen at Church Moor, 260 - 312cm (see text)

A: = 17.5μm, s.d. = 0.363μm = *B.nana*

B: = 20.1μm, s.d. = 0.389μm = *B.pendula*

(C: = 22.6μm, s.d. = 0.461μm = *B.pubescens*)

This analysis follows Prentice (1981) and is a simple graphical method to estimate the number of species in a mixture. The difference between the proportions of pollen grains in adjacent size classes ($\Delta \ln fi$) is plotted against pollen size (x_i) to produce a graph known as a Bhattacharya plot, after Bhattacharya (1967). Regions where the graph approximates a straight line with negative slope denote the number of different components (i.e. pollen taxa). It is then possible to calculate the parameters of each species' size - frequency distribution, assuming the underlying distribution to be normal. This assumption permits reliable separation of *Betula* species in northwest European pollen diagrams (Prentice, 1981). In the Bhattacharya plot for *Betula* in ChMI 260 - 312cm (Figure 5.2), a component attributable to *B.nana* can be identified (mean diameter = 17.5 m, st. dev. = 0.36 m), and another to *B.pendula* (mean diameter = 20.1 m, st. dev. = 0.39 m). A third component, representing approximately less than 5% of the total *Betula* pollen, can also be identified. Allowing for shrinkage due to HF treatment (Prentice, 1981), this minor component is probably due to *B.pubescens pubescens* rather than *B.p.tortuosa* on the basis of size data given by Birks (1968). The low frequency of this third component and the absence of identifiable *B.pubescens* macrofossils suggest that long distance transportation is responsible for the *B.pubescens* pollen (see GreatRex, 1983).

It is possible to extend this analysis further to calculate the percentage of each *Betula* species in the pollen rain (Prentice, 1981). Certainly, two phases can be identified in ChMI, in which different proportions of *B.nana* and *B.pendula* pollen are represented (Figure 5.6). There is an earlier phase from 284 - 312cm in which *B.nana* is much more abundant than *B.pendula*. This is followed by a second phase, at 260 - 276cm, in which *B.pendula* appears dominant. However, interpretation is difficult and may be confounded by virtue of the two species originating from different pollen sources. The macrofossil evidence strongly suggests that *B.nana* was growing *in situ* on the mire (fruits, cone scales, leaves and roots), while the absence of any vegetative remains from *B.pendula* (fruits and cone scales only) suggests that this species was more peripheral to the site. It is well known that *B.nana* is greatly over-represented in all modern pollen samples (Pennington, 1980). Thus, it

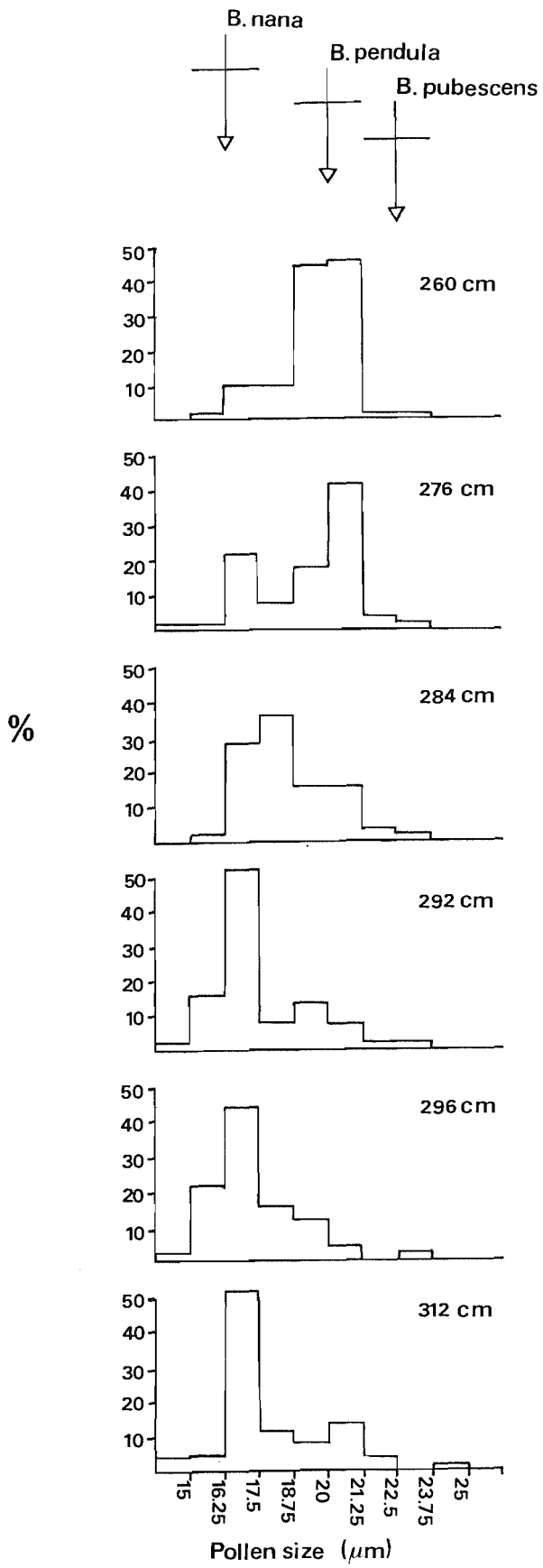


FIGURE 5.6 : *Betula* pollen size frequency data in Late Devensian deposits at Church Moor.

is not possible to know whether the changes in abundance of *B.pendula* pollen (Fig. 5.6) are due to variation in that species' population or to local pollen production by *B.nana*, since the pollen percentages are not independent. Pollen concentration/influx data and a radiocarbon-calibrated accumulation rate would overcome this problem.

The bryophyte assemblage in this zone is also noteworthy. In common with most other Lateglacial sites, the *Sphagna* are present at low levels (Dickson, 1973), although they are scarce throughout much of ChMII, while other mosses are present in significant quantities. Three species were identified, *Calliergon cuspidatum*, *Campylium stellatum* and *Homalothecium nitens*. The first two species are common in Lateglacial deposits (including Colney Heath see Table 5.1), and *Campylium stellatum* may have survived in Britain as a per-glacial species throughout the Devensian (Dickson, 1973). *Calliergon cuspidatum* is found in a variety of habitats and is present at Church Moor today, but *Campylium stellatum* is absent, although it is present in a number of base-enriched sites in the New Forest (see section 6.5.6). The third, *Homalothecium nitens*, is now restricted to basic flushes and fens in E.Anglia, North Wales, Shropshire and scattered localities northwards (Smith, 1978). However, this species exhibits a wider tolerance elsewhere in its range and is one of the commonest mosses of arctic and subarctic regions (Dickson, 1973). It is widely regarded as a relict species in Britain with a much more widespread and frequent former distribution which extends back at least to the Middle Devensian (Proctor, 1956; Rose, 1957; Pigott, 1963; Dickson, 1973). A well-known site in lowland England is at Swangey Fen, Norfolk where its associates include *Cladium mariscus*, *Juncus subnodulosus*, *Peucedanum palustre*, *Phragmites australis*, *Schoenus nigricans*, *Aulocomnium palustre*, *Campylium stellatum*, *Ctenidium molluscum*, *Fissidens adianthoides* and *Mnium punctatum* (Petch and Swann, 1968). It has also been recorded from Roydon Common, Norfolk in recent times, a site which has much closer affinities to the New Forest mires. At least part of its decline in southern England has been attributed to man where, for example, sub-Atlantic sites in Kent, Sussex and Somerset have been much modified (Dickson, 1973). A similar contraction appears to have occurred on the mainland of north-western Europe (Delvosalle *et al*, 1969 cited in Dickson, 1973). The position may be more complex since a survey of

Swangey Fen in 1980 failed to record this moss, and its absence was attributed, in part, to the cessation of peat cutting (Wheeler *et al*, 1982).

Comparison with the ChMI pollen data allows the macrofossil zone 2 to be subdivided on the basis of the representation of *Betula nana* and *B.pendula*. As would be expected, the two cores show a relatively close correlation by depth. Table 5.2 compares the assemblages present in ChMI and ChMII and includes a third phase, macrofossil zone 3, which approximates the Loch Lomond Stadial. The beginning of macrofossil zone 2a is marked by the presence of charcoal and a decline in inorganic inputs. Pollen preservation in ChMI improves with the accumulation of organics. At this stage, the *Betula* pollen curve is rising and is dominated by *B.nana* (Figure 5.6). *Betula nana* macrofossils were also most abundant in this sub-zone and were associated with wood which is probably also ascribed to this species. The pollen data indicate open conditions with Cyperaceae accounting for up to 54% of the pollen sum, although both *Betula pendula* and *Salix* were present. However, the Cyperaceae were the dominants of the mire community, particularly the *Carices*. In contrast, there is no macrofossil evidence for an pollen source for the Graminae pollen. The abundance of *Betula nana* in the pollen rain and the presence of *Saxifraga nivalis* pollen is suggestive of cold conditions. However, there are also a variety of species that are not normally associated with an arctic-alpine climate (such as *Saxifraga granulata*, *Chrysosplenium* and *Filipendula*). Furthermore, there were abundant Coleoptera remains at 307 - 309cm in ChMI identifiable to the *Donacia/Plateumaris* group of chrysomelid beetles, which is particularly abundant under present-day conditions in the New Forest valley mires, especially *Plateumaris discolor* (D. Sheppard, pers. comm. 1983). The evidence is most consistent, therefore, with a relatively warm climate under which several species now associated with colder climates were able to flourish, possible due to the absence of more competitive species. This sub-zone probably falls within the first part of the Bolling chronozone (see above).

Zone 2b is characterised by a greater representation of *Betula pendula* over *B.nana* in both the macrofossil and pollen assemblages. There is a

TABLE 5.2 Comparison of Late Devensian macrofossil and pollen assemblages at Church Moor

Depth (cm)		Assemblage	
ChMII (MACROFOSSIL)	ChMI (POLLEN)	MACROFOSSIL	POLLEN
243 - 213	251 - 203	*Betula* disappears from assemblage *Carex* declines and degraded material increases Charcoal and inorganic inputs	*Betula* rapidly declines but *B.pendula* still dominant *Juniperus* more frequent Cyperaceae 71% NAP Followed by no pollen
293 - 243	285 - 251	*B.pendula* more abundant than *B.nana*, and *B.nana* wood disappears	*Betula* peak *(B.pendula)* 260 - 270cm = 12440 BP
325 - 293	312 - 284	*Betula nana* most abundant and present on mire Mire dominated by *Carex* *Donacia/Plateumaris* chrysomelid	*Betula* rising but mainly *B.nana* Cyperaceae accounts for 54% total pollen
340 - 326	-	Colluvium. *Carex* rootlets *Sphagna*	Pollen preservation poor/absent

peak in the birch pollen and a decrease in herbs, Graminae and Cyperaceae. However, although this suggests less open conditions than 2a, the evidence is not conclusive of a particularly closed tree birch environment. The fact that the Cyperaceae decline in the pollen rain but remain constant in the macrofossil assemblage suggests that the degree of tree birch dominance may be, in part, over-represented due to an increase in absolute influx of *Betula* pollen, so that, the relative percentages of other taxa are depressed as an artifact. The radiocarbon date of 12440 $\pm$ 60 for the peak in *Betula pendula* pollen corresponds to the middle of the Bölling chronozone. Similar peaks in tree birch pollen at Hawks Tor (Brown, 1977) and in northern sites (Pennington, 1977) are thought to have occurred somewhat later, closer to 12000 BP, but this event has been shown to be diachronous (Pennington, 1977). It is also interesting to note that the dominant tree birch in E.Anglia (Godwin, 1968) and northern Britain (Pennington, 1977) was *B.pubescens*. However, in central southern England *Betula pendula* has been recorded in the Late Devensian from Surrey (Seagrief and Godwin, 1960) and Dorset (Haskins, 1978), while at Nursling, Hampshire *Betula nana* and *B.pubescens* were recorded from the latter part of the Lateglacial (Seagrief, 1959). At Church Moor, the pollen percentages of *B.pubescens* remain consistently low throughout this period, and are indicative of long distance transport.

The macrofossil and pollen assemblages of both zones 2a and 2b include a variety of "calcicolous" species. The mire community included several species associated today with more base-rich fens than the New Forest valley mires, such as *Campylium stellatum* and *Homalothecium nitens*. Similarly, the pollen assemblage includes *Helianthe um*, *Hippocrepis*, *Sanguisorba* and *Thalictrum*. The abundance of plants in the Late Devensian which are now restricted to mainly calcareous habitats has been widely documented - and widely interpreted as evidence for soils of higher base-status during the Late Devensian due to an absence of weathering (e.g. van der Hammen *et al*, 1971; Godwin, 1975; Pennington, 1977). Indeed, this phenomenon is regarded as almost ubiquitous on deglaciated terrain (Lowe and Gray, 1980). The main problem associated with this hypothesis in the New Forest is the potential source of the higher soil concentrations of calcium in the absence of glacial sediments.

Two processes may be invoked as possible sources of topsoil enrichment beyond the limits of glaciation in southern England. These are cryoturbation (periglacial disturbance of the soil) and loess-deposition but the evidence is equivocal for either of these processes causing markedly base-enriched conditions in the New Forest during the Devensian.

Weatherable minerals in loess may have had an appreciable effect on the soils of the Late Devensian and early Flandrian (Catt, 1978). However, the effect of loess is unlikely to have been of such a magnitude as to create calcareous conditions in the New Forest, since elsewhere loess-deposition has resulted in more acidic vegetation types, such as the chalk-heath (Perrin *et al*, 1974). Furthermore, most loess was probably rapidly eroded after deposition in the Late Glacial and may have been locally-derived, as was discussed in section 3.3.2.4.

There is strong evidence for cryoturbation throughout southern England during the Devensian (Watson, 1977; Worsley, 1977). But, despite wide-spread soil disturbance in the New Forest, the exposure of unweathered substrates and recycling of "relict soils" may not have led to nutrient-enrichment at the scale inferred from the Lateglacial plant communities. An important ecological feature of the New Forest is the predominantly nutrient-poor lithology. Apart from localised exceptions, the soils are unlikely to have ever been particularly calcareous, because the parent material is intrinsically base-poor. Chemical analyses of New Forest soils are sparse, but the available evidence supports this hypothesis. Unaltered parent material from a variety of lithologies contains less than 1mg/100g of calcium, and pH ranges from 4.5 - 5.0 compared to 7.7 - 8.4 for chalk deposits (Moffat and Cope, 1984; Allen and Staines, 1984).

Two hypotheses are available to explain the occurrence of plants in the New Forest during the Devensian Lateglacial that are now associated with more calcareous habitats. The first depends on the conventional interpretation of a base-rich environment due to raw, unleached immature soils. As has been shown, there is no data available which unequivocably supports this hypothesis. The alternative "competitive-release" hypothesis

outlined at the beginning of this section, requires an expansion in the realised niche of "calcicolous" species in the absence of species with more competitive life-history (*sensu* Grime, 1977). This is a more parsimonious interpretation of the environment during the Late Devensian and a certain amount of evidence supports the hypothesis. It is well established that during the Late Devensian species co-existed which now have contrasting ecological distributions (e.g. Smith, 1970; Pennington, 1977), for example species from extremes of soil acidity (and related factors such as iron and aluminium toxicity). The taxa present at Church Moor during this period also exhibit a wide range of contemporary edaphic distributions, such as *Betula nana*, *Calluna vulgaris*, several *Sphagna*, *Helianthenum*, *Sanguisorba* and *Hippocrepis*. The co-existence of these species at Church Moor indicates that they enjoyed a much greater niche breadth during the Late Devensian than today.

In conclusion, there is no evidence, as yet, for a more base enriched environment in the New Forest during the Late Devensian which is independent of observations based upon ecological distributions resulting from present-day interspecific competition. At the same time, evidence suggests many of the Late Devensian plants exhibited a broader niche than today. Thus, a more parsimonious interpretation of the Late Devensian involves the notion of competitive release, and is more tenable than the alternative base-enrichment hypothesis. This contrasts with the conventional interpretation of other Late Devensian sites mainly within the limits of glacial till. Further research is necessary before either of these hypotheses can be adequately tested in the New Forest. There is a need for a closer study of Pleistocene pedogenesis in the New Forest before the impact of man and a more detailed spatial analysis of the Late Devensian vegetation mosaic is also required. Thirdly, additional sources of data are necessary, such as diatoms which may provide further evidence concerning water chemistry.

5.2.2.3 Macrofossil zone 3 : the Loch Lomond Stadial: 243 - 213cm

A marked change occurs in the macrofossil assemblage at this zone; the amount of degraded material rises rapidly from previously very low levels,

while the proportion of identifiable *Carex* remains decreases. A number of species disappear from the macrofossil assemblage, probably denoting their extinction at Church Moor, including *Betula nana*, *Carex rostrata*, *Homalothecium nitens* and *Campylium stellatum*. This zone corresponds with the relatively abrupt decline of *Betula* pollen in ChMI followed by a zone in which pollen was absent from the core between 204 and 236cm. There is noticeable inorganic deposition in this zone, forming a silty peat with some fine sand (corresponding to the non-polleniferous layer in ChMI). This horizon may be traced across the area of deepest (Lateglacial) peat at Church Moor (see Fig. 5.2). It is suggestive of slope-wash or stream migration and is variable in composition, being almost pure silty clay in places. The increased inorganic sedimentation and the decline in *Betula* pollen (especially tree birch) from earlier high levels are often considered characteristic of the Loch Lomond Stadial, and this interpretation is entirely consistent with the dates above and below this zone at Church Moor, of 12440 and 8260 BP respectively.

Another feature associated with this zone is relatively abundant charcoal fragments, which at 227 - 229cm formed in the order of 1 - 2% of the sample. It is possible that the inorganic sediments are due to erosional events following fire in the surrounding catchment. Some additional support for this hypothesis comes from mineral magnetic data, which were collected from Church Moor in a pilot study at an early stage in this investigation. Two cores were taken close to ChMI and ChMII and both revealed a peak in bulk susceptibility between 215 and 240cm (Fig. 5.7), although the equipment available at the time produced a poor signal to noise ratio. Magnetic susceptibility has been used to study erosional events especially in lake catchments (e.g. Thompson *et al*, 1975, Dearing *et al*, 1981) and has proved useful in the study of climatic change during the Late Devensian (Björck *et al*, 1982). The susceptibility peaks in Figure 5.7 suggest enhanced magnetic properties of secondary iron minerals formed in soils affected by fire (Longworth *et al*, 1979). Further study of this phenomenon at Church Moor might include characterization of the magnetic properties of the catchment sediments, and investigation of remnant magnetism and particle-size distributions.

BULK SUSCEPTIBILITY MEASUREMENTS

FROM CHURCH MOOR [CMIII]

TWO CORES [A&B] 7·4m APART

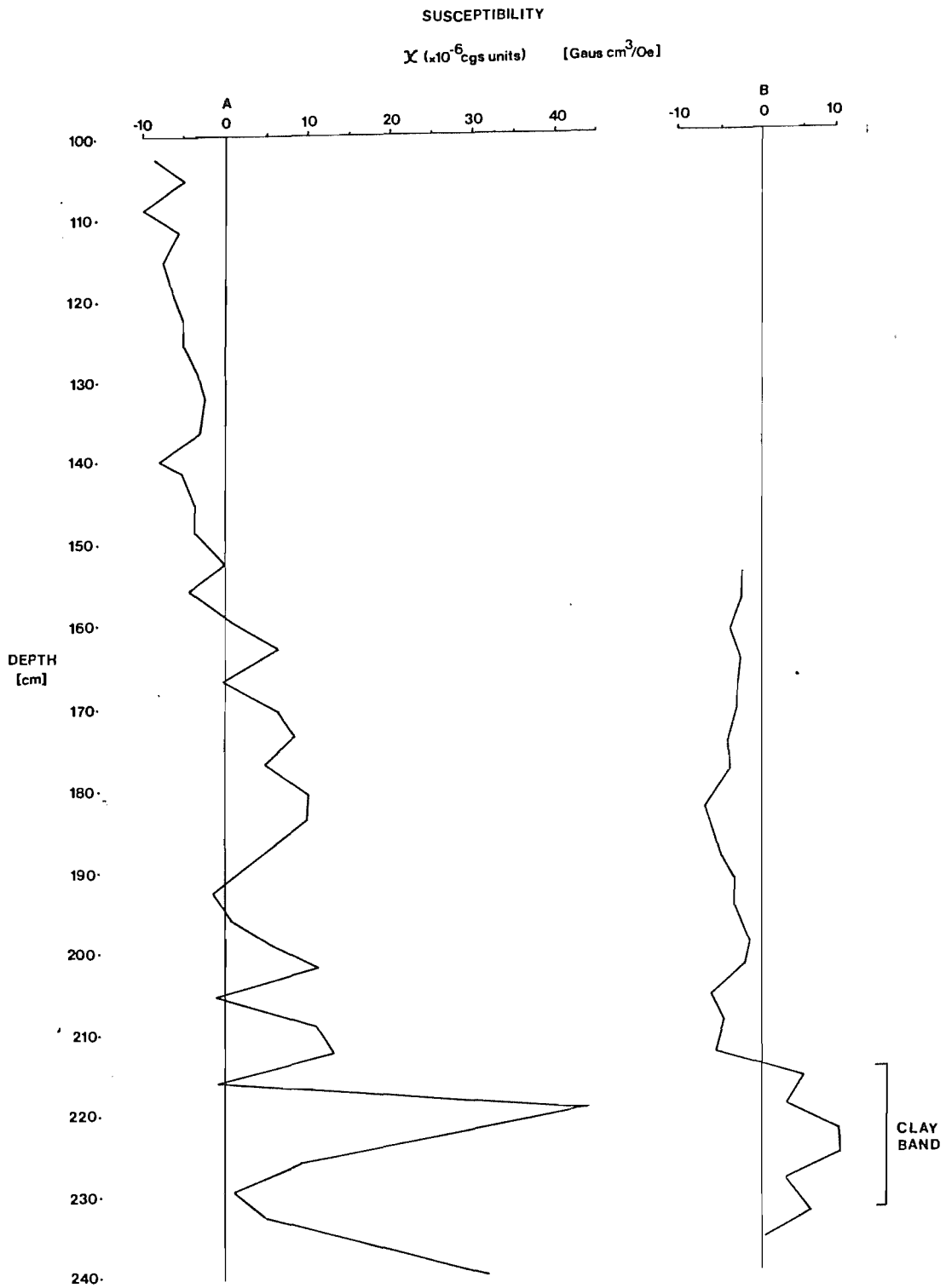


FIGURE 5.7

The presence of fire within the catchment and the high levels of decomposition (including the absence of pollen) in the mire indicate a seasonally dry climate. This is not inconsistent with the findings of Rose *et al*, (1979) from the River Gipping in Suffolk, where they postulate a more continental climate coupled with high peak discharges during the transition to the Loch Lomond Stadial. They attribute increased erosion to peak discharges caused by spring melt of winter snow and seasonally frozen ground, accompanied by restricted infiltration and high surface run off. Rose *et al* suggest a decline in total snowfall as the Stadial progressed due to reduced penetration from the west by Atlantic fronts. This led to increased sedimentation rates due to lower peak discharges and greater sediment supply from freeze-thaw processes on the hillslopes. Similar environmental interpretations demonstrating accelerated rates of weathering and erosion have been derived from other parts of south and east England (Sissons, 1979).

The extremely open conditions indicated by the pollen flora on the Isle of Wight have led Scaife (1982) to suggest that conditions were even more severe in southern England than has previously been supposed. The pollen assemblage in the transition to the non-polleniferous zone in ChMI also reflects the development of much more open conditions (although the effect of changes in total pollen influx are not known). Interestingly, the analysis of *Betula* pollen (Figure 5.6) indicates *B.pendula* to be the dominant species rather than *B.nana*. Furthermore, the presence of *Sphagnum papillosum* and section *Subsecunda* as macrofossils preclude a direct comparison with present-day high arctic environments (Lange, 1969). The seasonal, and diurnal fluctuations in the climate must be regarded as the more critical environmental factors during this period rather than mean temperatures. During the Loch Lomond Stadial, Church Moor was probably still dominated by *Carices* but with much poorer preservation of remains. Both *Carex* utricles and epidermal material are found in this zone, and the high proportion of Cyperaceae pollen in the transition to this period in ChMI also indicates that *Carices* were prominent in the local flora. The rootlets of *Myrica gale* which appear for the first time in ChMII at 227 - 229cm, may be ascribed to penetration from further up the core. The extinction of

Betula nana at Church Moor is, therefore, more attributable to the sequence of climatic and vegetation change during the Lateglacial, rather than to direct competition with *Myrica*, which shares its shrub habit.

5.2.3 Macrofossil zone 4 : The early Flandrian : 213 - 197cm

This zone is transitional in character between macrofossil zones 3 and 5, containing a large amount of degraded material, some inorganics and major root penetration from above by *Alnus*. *Eleocharis multicaulis* and *Drepanocladus* (undet.) appear and pteridophyte sporangia are recorded for the first time. Although still at low frequencies, there is slight increase in *Sphagna*. A relatively diverse flora was present, dominated by *S.palustre* and section *Subsecunda* and including *S.papillosum* and section *Cuspidata* (*S.recurvum*?). A needle of *Juniperus communis* was recorded and it is possible that this corresponds to the *Juniperus* expansion noted by Scaife (1982) from the Isle of Wight at about 9900 BP, but unfortunately the pollen is absent immediately below 204cm in ChMI. A single fruit of *Alnus glutinosa* was also recorded. There is no reason on stratigraphic grounds to suspect that this has been derived from later sediments so that, discounting sampling contamination, this demonstrates the presence of *Alnus* in the New Forest in the earliest Flandrian. This provides macrofossil evidence in support of a local origin for early Flandrian *Alnus* pollen on the Isle of Wight (Scaife, 1982), Dorset (Haskins, 1978) and the Thames estuary (Devoy, 1979). Chambers and Price (1985) have suggested a western refugium to explain the early dates for *Alnus* in Wales. However, there is now a growing body of evidence to show that *Alnus* was widely distributed at low levels throughout southern England, and Bennet (1983) has demonstrated that *Alnus* differed in its population growth compared to most other tree species in the post-glacial, with a long period of erratic low population densities before later expansion.

5.2.4 Macrofossil zone 5 : early to mid-Flandrian : 197 - 115cm

The amount of root penetration of *Alnus* declined in this zone and there was a proportionate increase in monocotyledon rootlets. The latter were

poorly preserved but *Phragmites australis* epidermal tissue was identified in several samples. A small amount of *Rhynchospera* material was recognised at 129 - 131cm and it is possible that some of the other fine rootlets were derived from *Molinia*. The better preservation of the *Alnus* roots was in strong contrast to the rest of the peat matrix. Overall, little above ground material was preserved at all. However, at 163-165cm much of the sample was composed of *Hypnum* in a poor state of preservation. Reproductive remains associated with this sample were *Rubus*, *Juncus acutiflorus*, *Eleocharis multicaulis*, *Carex echinata* and nutlets of another sedge which were assigned to *Carex pendula*. The latter were most abundant and were also recorded from 323 - 325cm, the base of macrofossil zone 2 in the Late Devensian, as well as from two other samples in zone 5. The papillose, three-sided achenes are most easily confused with *C. lepidocarpa* (Nilson and Hjelmquist, 1967), but they differed from this species in being ovate in shape. Comparison with reference material confirmed the identity of these achenes as *C. pendula*. *Carex pendula* is now relatively scarce in the New Forest, but is frequent in the *Alnus*-dominated wet valleys that have survived in the Southampton area. *Sphagnum* is more abundant in the upper part of this zone than previously, and *S. palustre* and *S. papillosum* are the most prominent species. *Myrica gale* rootlets occur frequently and it is probable that this species was also part of the mire community at Church Moor during this time. The age of the lower boundary to this zone is not readily determined by the pollen data from ChMI due to the absence of a typical *Pinus* dominated Boreal assemblage and the lack of pollen between 204cm and 236cm. However, the radiocarbon date of 8260 $\pm$ 50 BP from 180 - 190cm in ChMI is well within the conventional span of the Boreal chronozone. From this, it may be estimated that the lower boundary of macrofossil zone 5 is some 8500 - 9000 BP. The upper boundary is more clear cut and is readily correlated with the sudden increase in *Alnus* pollen dated to 5170 $\pm$ 50 BP.

This zone may also be correlated with the Boreal chronozone in the pollen core taken from the carr (Barber, 1975) between 250 and 170cm. Both the pollen diagram from ChMI (Clarke and Barber, 1987) and Barber (1975) indicate that *Corylus* and *Quercus* were important components of the woodland as well as *Pinus*.

The macrofossil assemblage from this zone in Church Moor is remarkably poor in recognisable remains. The poor degree of preservation is probably a major factor, but it may also reflect the extremely closed plant community indicated by the low values for non-arboreal pollen in ChMI at similar depths (Clarke and Barber, 1987). Only at 163 - 165cm is there an indication of a more open environment with *Eleocharis multicaulis* and *Carex echinata*. The mire surface was probably heavily shaded during this zone. The high pollen frequencies of *Salix* (c10% DLP) suggest that this species may have been present on the mire as willow thicket, despite the absence of recognisable macrofossils (Clarke and Barber, 1987). Other dominants in the vegetation may have been *Myrica* and *Phragmites*. The poor preservation shows that the local environment, at least, favoured decomposition processes for much of this time. Drier conditions are indicated by the abundance of sclerotia of *Coenococcum geophilum* between 129 and 197cm, which van Geel (1978) associates with only relatively dry mire surfaces.

5.2.5 Macrofossil zone 6 : mid to late Flandrian : 115 - 50cm

This zone is marked by the appearance of two valley mire dominants, *Alnus glutinosa* and *Molinia caerulea*. The occurrence of *Alnus* fruits from 113cm upwards correlates with a sudden increase in *Alnus* pollen in ChMI at 118cm and with a similar event at 170cm in the nearby core described by Barber (1975). The expansion of *Alnus* at Church Moor has been dated to 5170 $\pm$ 50 BP between 120cm and 130cm in ChMI. This is a relatively late date for the expansion of *Alnus* (Godwin, 1975; cf Huntley and Birks, 1983) which has been dated to 7000 and 7830 BP elsewhere in the Forest, and to 6385 BP at Gatcombe Withy Bed on the Isle of Wight (Scaife, 1982). Such diachroneity within a small region supports the suggestion that local factors were more important in controlling the marked expansion of *Alnus* in the mid-Flandrian (e.g. Scaife, 1982) than regional climatic change (e.g. Bennet, 1983).

Data from ChMI show that Gramineae pollen has been more abundant than Cyperaceae throughout the Flandrian in contrast to the Devensian Late-glacial. In this respect, it is interesting to note that *Molinia* was not positively identified in the macrofossil assemblages before this

zone. In many of its features, the start of zone 6 denotes the beginning of mire communities similar in composition to the present vegetation. The macrofossil assemblage includes *Eriophorum angustifolium, Rhynchospora, Eleocharis multicaulis, Carex echinata, Carex demissa, Juncus acutiflorus, Potamogeton polygonifolius, Drosera rotundifolia* and *Calluna vulgaris*. The assemblage suggests that the community present at ChMII was dominated by *Molinia* and *Erica tetralix*, with *Myrica gale* and *Sphagna* (principally *S.palustre)* as important components. The number of species associated with unshaded mire habitats suggests a relatively open environment in the immediate vicinity of the core, but the carr must have been nearby since frequent wood and bark of *Alnus* and *Betula* were found in this zone with relatively abundant pteridophyte sporangia and frond fragments. The absence of *Salix* is curious since the pollen data suggest that it was present at Church Moor, possibly at low abundance, in this and earlier zones. The lack of macrofossils may be an artefact of preservation and identification (see previous chapter). The moss flora in the assemblage comprised *Sphagnum palustre* with occasionally significant amounts of *S.papillosum* and less frequently *S.recurvum*-type, and sections *Subsecunda* and *Acutifolia*, other frequent mosses present at low abundance were *Drepanocladus fluitans, Aulocomnium palustre* and *Calliergon (*cf *stramineum)* while one sample also contained *Cratoneuron commutatum*. Such a diverse assemblage is consonant with the relatively rich bryophyte flora present at Church Moor today. The *Alnus* wood in zone 5 is clearly associated with the expansion of this species in zone 6. This is a good example (albeit at a larger scale) of the need to integrate, over depth, vegetative macrofossils (stems, leaves and roots), reproductive macrofossils and pollen (see Chapter 4). The soft and rotted nature of the *Alnus* wood discounts the possibility of modern root penetration, and suggests that the *Alnus* carr distribution has remained relatively static since its initial colonisation of the mire (with possibly a local contraction in the vicinity of ChMII). This suggestion is also supported by the stratigraphy of Church Moor which indicates that the stream has occupied its lateral position for much of the Flandrian (see Fig. 5.1 and section 5.2.1).

The beginning of this zone is marked by fluctuating but low levels of

decomposition with rising degradation of remains towards the upper part of the zone. The macrofossil assemblage shows little sign of changes in species composition that could be related to a change in hydrological conditions (note, for example, *Potamogeton* remains in the macrofossil diagram), and so it is difficult to draw conclusions as to the ultimate causes of the trend within the zone. However, the transition to zone 6 from zone 5 is more marked: from a poorly preserved macrofossil assemblage to one which is much more diverse and less degraded. It is unlikely that such a change in decomposition processes would be solely due to the accompanying development of more open mire communities. The change in mire communities, the expansion of *Alnus* and the reduction of decomposition may all be related to, at least, a local increase in surface wetness of the mire system and other changes in the water regime (this point will be discussed further in relation to the evidence from Cranes Moor). One other factor possibly relevant to the zone 5 - zone 6 transition is the peak in *Rumex* pollen in ChMI, immediately below the *Alnus* rise, along with other herbs and Filicales. This is mirrored by a drop in the relative abundance of tree pollen and a disproportionate reduction in *Corylus*. Whether this is the result of early Neolithic man's activity is not clear, but the data demonstrate that the transition to macrofossil zone 6 was a time of more rapid vegetation and local environmental change. The leaves of *Erica tetralix* and *Calluna vulgaris* appear shortly after the beginning of the zone, along with the first appearance in the Flandrian of Ericaceae pollen in ChMI. Given the relative isolation of Church Moor from other extant mires during this time (c 4500 - 5000 BP), this may also be indicative of environmental change, reflecting the progressive acidification of soils during the Flandrian (see Chapter 3).

An interesting find was encountered in the sample between 101 - 103cm. This was an intact specimen of a beetle identified as *Corynetes* Paykull 1798 (nom. emend) cf *caeruleus* (Deger 1775), a member of the Cleridae family and associated with old timber. No doubt the mid-Flandrian forests around Church Moor were rich in dead wood habitats. This specimen illustrates the long continuity of habitat in the Mark Ash Wood area, indicated by the epiphytic lichens assemblages present (Rose

and James, 1974) and the palaeoecological data (Clarke and Barber, 1987).

5.2.6 Macrofossil zone 7 : recent unconsolidated peat : 50 - 0cm

This zone is defined by default in that it was not possible to sample the wet, unconsolidated peat. The acrotelm, or biologically active layer, was the major element in this unconsolidated zone with much recent rootlet material in the upper 30cm. The two principal macrofossil components encountered when attempting to core this zone were monocotyledon roots (probably *Molinia*) and *Sphagnum* leaves from the section *Sphagnum*. The core was located in a *S.papillosum* cushion with *Molinia caerulea* dominant in the immediate vicinity of the core. Other species growing with 20cm were *Eriophorum angustifolium*, *Drosera rotundifolia* and *Erica tetralix* (see 5.2.1).

The acrotelm contains relatively recent material and exhibits a high depth: age ratio due to incomplete decomposition processes and low density. Thus, the top 25cm of the core in the carr described by Barber (1975) contains *Pinus sylvestris* which is referable to the planting of this species at Boldrewood in the beginning of the 19th century. This depth is similar to the occurrence of the stratigraphic marker with in other New Forest mires. From this it may be concluded that much of macrofossil zone 7 is referable to the historic period of the last 1000 years or so.

5.2.7 Summary

1. Peat accumulation early in the Devensian Lateglacial was preceded by a phase of inorganic sedimentation which incorporated mire species present at the site. Charcoal indicates that fire may have been an important environmental agent. The sediments developed a cover of, principally, large *Carex* species and inorganic inputs declined, possibly reflecting a more widespread reduction in sediment supply within the catchment.
2. For most of the Lateglacial, Church Moor was dominated by *Carex* species with *Betula nana* and a diverse moss assemblage, and was characterised

by particularly low decomposition rates. The evidence is most consistent with a relatively warm climate until at least 12400 BP and there is no independent evidence for a base-enriched environment. The co-existence of species with contrasting modern ecological characteristics is best explained by differing competitive interactions within the Late Devensian plant community compared to the present day, due to the migration lag-effect of species in southern refugia during the cold stage. The end of the macrofossil zone corresponds to rapidly declining tree birch pollen from an earlier peak dated to 12440 BP, and suggests a relatively early deterioration in climate.

3. A number of species extinctions at Church Moor occurred with the onset of the Younger Dryas chronozone, when a seasonally dry climate is indicated by relatively decomposed peat, the absence of preserved pollen and abundant charcoal. Significant inorganic inputs occurred and these may be related to the high peak discharge during spring snow-melt suggested for elsewhere in S.England during this period.
4. For most of the Flandrian until about 5200 BP, conditions favoured decomposition processes and the mire surface was probably relatively dry. The impoverished macrofossil assemblage probably also reflects the closed conditions thought to predominate within the vicinity of the mire. The surface of the mire may have been heavily shaded with *Salix*, *Myrica gale* and *Phragmites australis* as the dominant plant species. *Alnus glutinosa* is recorded early in the Flandrian but expansion of *Alnus* is relatively late at Church Moor compared to other dates available for the New Forest and the Isle of Wight.
5. An increase in local wetness at c5200 BP is indicated by increased organic preservation. This was associated with a diverse macrofossil assemblage reflecting both the development of a local mire community containing species intolerant of shading, and the establishment of *Alnus* carr nearby. Local environmental change is also indicated by a temporary increase in herb pollen associated with a disproportionate decrease in *Corylus* pollen. The appearance of *Erica tetralix* and *Calluna* may be related to progressive soil acidification during the Flandrian.

6. The macrofossils demonstrate the persistence of a *Molinia* - *Myrica* - *Erica tetralix* - *Sphagnum* community for the last 5000 years and indicate that the distribution of the *Alnus* carr rapidly reached an equilibrium with environmental factors. The persistence of this vegetation pattern within the vicinity of the core studied may be due to the stability of the valley mire drainage network for much of the Flandrian.

5.3 SPHAGNUM BOG (Cranes Moor)

5.3.1 Introduction

Cranes Moor is located at the head-waters of a tributary in the lower catchment of the River Avon and is the most extensive mire system in the New Forest. It occurs within an area of low relief Barton Sand flanked to the east by the prominent watershed of Burley Ridge, a gravel-capped synclinal outcrop of the Headon Beds, and to the north-east by a Plateau Gravel terrace. The Cranes Moor system is a mire-complex and is usually regarded as being divided into Bagnum Bog, Cranes Moor (Flush Bog, *Sphagnum* Bog, Little Bog), Strodgemoor Bottom, Vales Moor, and Broad Bottom. The floristic composition of the various side-arms of the system is determined largely by the amount and sources of water flow. Most of the mire system is surrounded by wet heath, rich in bryophytes and lichens, and dry heath communities (this zonation is related to a soil catena developed almost entirely in freely-permeable Barton Sand). The area around Cranes Moor itself is dominated by uneven-aged stands of self-sown pine and, despite the influence of man, the pine-mire association is reminiscent of the boreal forest formations. Together, this is one of the most outstanding heathland-mire complexes in the New Forest.

A map of Cranes Moor, the main area to be considered here, is shown in Figure 5.8 and includes the three mires used in previous palaeoecological investigations of this site. Flush Bog is dominated by tussocky *Molinia*, with *Myrica* and occasional *Schoenus nigricans* and *Carex rostrata* as the other main structural elements in the community. Other frequent species are *Erica tetralix*, *Cirsium dissectum*, *Eriophorum angustifolium*, *Sphagnum*

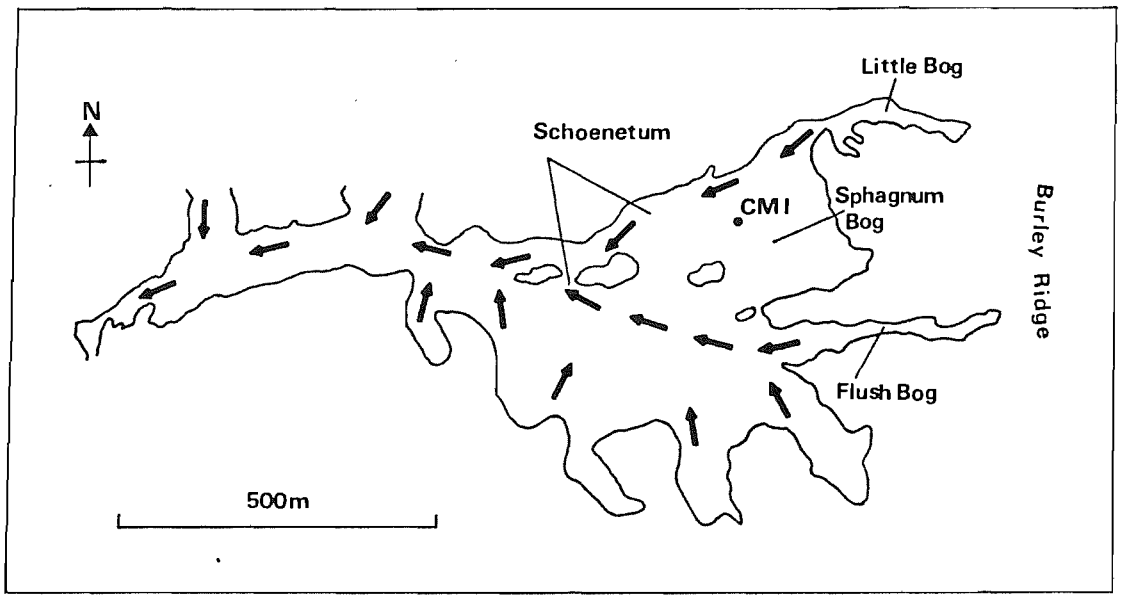


FIGURE 5.8 : Map of Cranes Moor showing main flush lines and location of core (CMI).

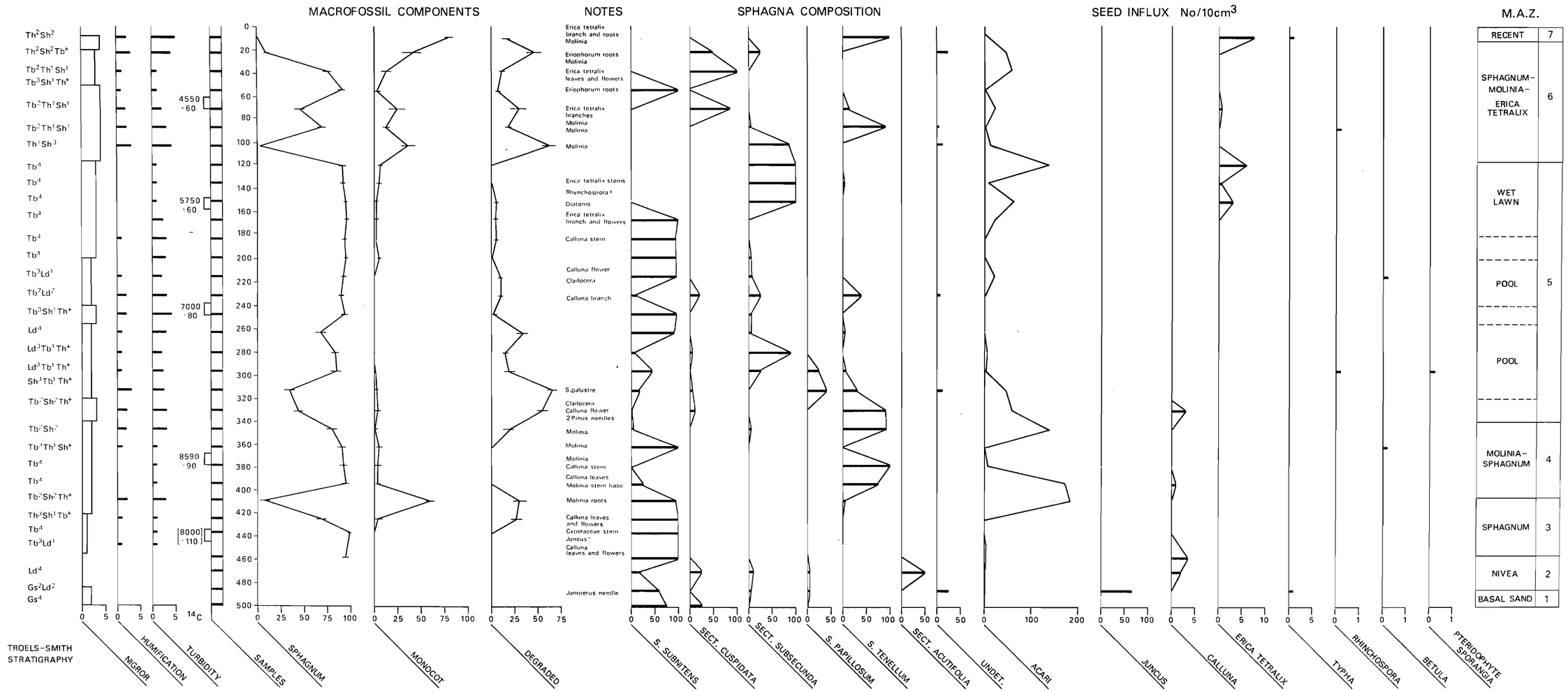


Fig 5.9 Macrofossil Diagram from Sphagnum Bog, Cranes Moor (CMI)

papillosum, *S.palustre* and *S.auriculatum* while *Narthecium* and *Rhynchospora alba* are less abundant. A mosaic of runnels supports abundant *Potamogeton polygonifolius* with *Eleocharis multicaulis*, *Menyanthes*, *Drosera rotundifolia*, *Sphagnum auriculatum*, *S.subnitens* and occasional *Utricularia minor*.

There are two main components to *Sphagnum* Bog. The northern part of the mire comprises a water track, dominated by *Schoenus*, which together with Flush Bog receives most of the water draining from the Headon Beds of Burley Ridge. Both *Rhynchospora alba* and *Narthecium* are more abundant than at Flush Bog while *Myrica* is less frequent. *Cirsium dissectum*, *Erica tetralix*, *Eriophorum augustifolium* and *Molinia* are all significant members of the community. The bryophyte assemblage of this area is particularly diverse with *Sphagnum auriculatum*, *S.palustre*, *S.papillosum* and in places *S.capillifolium* and *S.magellanicum*, other mosses include *Hypnum ericetorum* and *Aulocomnium palustre*. Hepatics are plentiful, such as *Cephalozia* spp., *Lepidozia setacea*, *Calypogeia fissa*, and *Riccardia multifida*.

The other component, south of the *Schoenetum*, is often termed the "shielded area" after Seagrief (1950) and Newbould (1960). This supports vegetation variably dominated by *Sphagna*, *Calluna* and *Erica tetralix*. The *Sphagnum* lawn is dominated by *S.papillosum* and *S.magellanicum*. The latter *S.magellanicum* community is particularly well represented at Cranes Moor, although other good examples occur at Warwickslade, Duckhole-Crabtree Bogs, Three Beech Bottom, the Denny Bog system, Fawley Bog and Fort Bog. This species is widely distributed in the Forest but is generally of restricted occurrence within the mires where it is found. Other species in the lawn areas are *S.auriculatum*, *S.cuspidatum*, *S.palustre* and *S.tenellum* with often abundant *Lepidozia* and *Odontoschisma sphagni*. Also present are *Eriophorum*, *Narthecium* and *Molinia* (mainly in non-tussock form). Drier parts of the mire surface are dominated by *Calluna* with *S.compactum* amongst the *Sphagna* and *Cladonia*. Almost all of this area appears to have been cut for peat, and the presence of causeways on the mire (Barber, 1981a) suggests that a significant resource must have been available to justify their construction. The present pool system of *Sphagnum* Bog is undoubtedly due to cutting.

Little Bog is effectively an outlier of *Sphagnum* Bog and is wetter than the shielded area with the main *Sphagna* being *S.papillosum*, *S.auriculatum*, *S.cuspidatum*, *S.magellanicum* and *S.subnitens*. The other main species present are *Molinia*, *Eriophorum*, *Narthecium* and *Erica tetralix*.

Grazing pressure is variable across the mire complex with ponies most often observed in the northern parts of the system. There is also a herd of red deer which frequents the Cranes Moor area. The grazing impact from this species is unknown but localised disturbance to the mire surface has been noted due to wallows in the rutting season, especially in the *Sphagnum* - Little Bog area.

Cranes Moor was first studied in detail by Newbould (1954, 1960; Newbould and Gorham, 1956) and Seagrief (1955; 1960). Their researches showed that the peat in *Sphagnum* Bog was exceptional both in terms of its depth and composition, and that the present mire surface is characterised by relatively low productivity and low nutrient status. With 5m of almost pure *Sphagnum* peat, this is the deepest valley mire in southern England (though Rimsmoor, Dorset is the deepest peat deposit with 18m (Waton, 1982). Seagrief (1960) carried out a pollen analytic investigation of all three sites at Cranes Moor. His results show the development of peat began in the early Boreal (zone V) at *Sphagnum* and Little Bogs - although Seagrief suspected that *Sphagnum* Bog may have originated in the Lateglacial - while pre-Boreal (zone IV) peat was identified at the base of Flush Bog. Peat growth appeared to cease in Atlantic times. Seagrief (1955) noted stratigraphic changes in the upper peat layers as well as a hiatus in the pollen diagram but, although the possibility of human disturbance was acknowledged, the extent of peat cutting was not recognised at that time (see Barber, 1981a). Stratigraphic investigations by both these authors have shown that the *Schoenetum* has migrated some 20m northwards with an expansion of *Sphagnum* bog. This is somewhat reminiscent of the lagg-zone of a growing raised mire. Little Bog, at the headwater of the *Schoenetum*, has a related developmental history (Seagrief, 1955) with monocot peat, from 340 - 140cm, subsequently replaced by *Sphagnum*-dominated deposits. By contrast, Flush Bog appears to have remained dominated by monocots

throughout its development.

Cranes Moor was the main site for Newbould's study into the relationship between mire vegetation and water quality (discussed further in Chapter 6). He showed that the highest pH and solute concentrations occurred in Flush Bog and the *Schoenetum*, with values decreasing from the headwaters to the exit. He also found that the shielded area was markedly oligotrophic and suggested that it received little lateral groundwater input due to the partially domed surface, although he was doubtful that fully ombrotrophic conditions could develop in southern England due to the summer water deficit (Newbould, 1960a). Studies into the production ecology of Cranes Moor have been continued by Clymo and colleagues, notably Giles (1977) whose research centred on the rooting ecology of *Eriophorum augustifolium*. Giles (1977) also found relatively low rates of primary production on the main expanse of the shielded area.

Cranes Moor cannot be regarded as a representative New Forest mire because the *Sphagnum* Bog complex, an important component of the whole system, is quite unlike any other site in the Forest. This site was chosen for investigation because it offers a marked contrast in peat stratigraphy to the other sites investigated. Furthermore, the possible dominant influence of direct precipitation in the water budget offers considerable research potential, unlike most other New Forest mires where climatic control of mire development is more indirect and may be confounded by other catchment variables. The core chosen for study (CMI) had previously been analysed for pollen and other microfossils (see Barber and Clarke, 1987), and this work will be referred to here. Five radiocarbon samples have been dated (see Appendix 2).

The results of macrofossil analysis from CMI are shown in Figure 5.9 and additional results of microfossil analysis for diatoms and fungal hyphae (Barber, in prep.) are shown in Figure 5.10.

The core was divided into seven macrofossil zones:

1 : 500 - 484cm : The sub-peat sediment
2 : 484 - 456cm : The "Nivea" layer

3 : 456 - 406cm : *Sphagnum* phase
4 : 406 - 340cm : *Molinia* phase
5 : 340 - 116cm : Pool sequence
6 : 116 - 15cm : *Molinia - Sphagnum - Erica tetralix* phase
7 : 15 - 0cm : Recent peat accumulation

It is difficult to over-emphasise the contrast between the macrofossil assemblages of *Sphagnum* Bog and other mires in the Forest. On the one hand, the samples from CMI show generally excellent preservation with a large proportion of each sample being identifiable. But on the other hand, the assemblages are noticeably species-poor compared to other sites, particularly with respect to seeds and fruits. This may reflect a generally low abundance of vascular plants relative to *Sphagnum*, but the low productivity of this site may also be significant. On the whole, much smaller standard errors were obtained for sample estimates in CMI compared to other cores. Although better preservation may be one reason for this, the lower within-sample variance is due mainly to the smaller and more uniform size of the individual macrofossil elements (i.e. mainly *Sphagnum* leaves in CMI vs roots, stems, *Sphagnum* leaves, bark etc. in other cores). A smaller number of sample estimates than the 15 used here may have been equally acceptable - results indicate that between 5 and 10 sub-samples would have been more than adequate for most purposes - and this may be preferable more generally for such (ombrotrophic-type) deposits.

5.3.2. Macrofossil zone 1 : The sub-peat sediment: 500 - 484cm

These deposits consisted of gleyed loamy fine sand with only a small proportion of organic matter. There were frequent rounded sand grains present and equally abundant particles of muscovite mica of a similar size. Despite their mainly inorganic composition, these sediments contained a relatively wide range of macrofossils. Cream-coloured, apparently mineralised, remains of *Calluna vulgaris* were found in the 485 - 487cm sample including leaves, branches, flowers and seeds. Ericaceous roots of normal-colour and texture were also present and these <u>may</u> represent penetration from a higher level, following mineralisation, although this is not clear, as will be discussed later. A needle of *Juniperus communis* was also recorded from this sample. The

Sphagnum assemblage was dominated by *S.subnitens* with section *Cuspidata* and *S.papillosum*, and tentative *S.* cf *compactum*. The vegetative remains were accompanied by a marked influx of *Juncus acutiflorus*-type seeds and a single seed of *Typha*.

The pollen assemblage in this zone is characteristic of the earliest Flandrian, preceding the rise of *Pinus* and *Betula* in the Boreal, and is suggestive of a date around the Late Devensian - Flandrian transition. Unfortunately, the lowest radiocarbon sample (435 - 445cm) yielded an aberrant date so that a direct estimate of age is not possible. However, both *Sphagnum* Bog and Flush Bog, some 250m apart, exhibit a very similar sequence of vegetation change in the earliest Flandrian (Barber and Clarke, 1987), the main features of which are:

> (i) Peak in Gramineae; (ii) Peak in Ericales; (iii) Peak in *Betula* followed by sustained lower levels, (iv) A secondary Ericales peak coupled with peaks of *Rumex*, *Plantago;* and *Artemisia;* (v) A secondary Gramineae peak, start of *Pinus* expansion; (vi) *Pinus* expansion/peak.

At Flush Bog events (iii) and (v) have been dated to 10070 $\pm$ 60 (Appendix 2), the rapid accumulation rate at this site during the Boreal being particularly noteworthy. The first *Betula* peak (event (iii)) at *Sphagnum* Bog occurs at 484cm, and thus the start of organic matter preservation is around 10100 BP, the closing phases of the Loch Lomond Stadial. The secondary Gramineae peak and the beginning of the *Pinus* rise occurs at 468cm.

Several features suggest marked, but decreasing, instability of the 'soil' surface within this zone, and it maybe that the levels of erosion and deposition prior to this time were too great to permit the accumulation of Late-Devensian peat at *Sphagnum* Bog. The high relief and steep slopes of Burley Beacon to the east may be important in this respect. This zone represents the accumulation of 16cm of sand and above-ground plant material, and this must be net deposition rather than simple re-working of sediments *in situ* since Flush Bog and *Sphagnum* Bog show the same pattern of vegetation change during this period. The high influx of *Juncus* seeds associated with this zone reflects the amount of bare ground that would have been available.

Macroscopic charcoal was absent from these sediments and charcoal was also notably scarce in the pollen samples from both *Sphagnum* Bog and Flush Bog. This contrasts with the Loch Lomond Stadial sediments of Church Moor, which are mainly older than the estimated age for this zone at Cranes Moor. The local vegetation at Cranes Moor during this time may be described as wet heath/*Calluna* bog, and it is evident from both pollen cores at Cranes Moor that the Ericaceae were prominent in the surrounding catchment, including *Empetrum*. The early peak in *Betula* pollen in both cores probably marks the rapid climatic amelioration at the end of the Loch Lomond Stadial.

5.3.3 Macrofossil zone 2 : The "Nivea" layer : 484 - 456cm

Following Seagrief's (1960) description of white basal muds resembling face-cream, this deposit has become known as the "Nivea layer" and this is, indeed, an appropriate term. The gel-like matrix of the sediment is an alumino-silicate called proto-imoglite allophane (I am grateful to Dr.J.Catt for this analysis) which has been suggested to have an important role in podzolisation as was discussed briefly in Chapter 3. The organic content in this layer increased upwards grading into pure *Sphagnum* peat above, and, like zone 1, the macrofossils appear to have been partially mineralised.

The *Calluna* in zone 1 continued into this zone as an important component of the vegetation in association with a diverse *Sphagnum* flora, in which there is no clear dominant. Together *S.compactum*, *S.subnitens* and section *Acutifolia* formed the bulk of the assemblage with *S.papillosum* and section *Subsecunda* in smaller frequencies. The presence of *S.compactum* was also noted by Seagrief (1955), and this is a particularly noteworthy record since Cranes Moor is the only site from which this species has been found as a macrofossil (Dickson, 1973). *Sphagnum* becomes progressively more abundant during this zone, and in the sample from 457 to 459cm the assemblage is almost entirely composed of well preserved yet partially-mineralised remains of *S.subnitens*. This species was also recorded by Seagrief (as *S.plumulosum*) between 370 and 285cm in his core from *Sphagnum* Bog and, as will be seen, it continued to be the major dominant of this part of Cranes Moor for approximately 4000 years.

Zone 2 essentially represents a transition between the *Calluna*-dominated community of zone 1 and the subsequent *Sphagnum*-dominated mire; the precise boundaries of this zone are mainly defined by inorganic features of the stratigraphy.

The formation of the Nivea layer is poorly understood and it would be unwise to speculate in the absence of a more thorough investigation of the soil chemistry. It is possible, however, to assemble several lines of evidence which may help to shed light on the processes involved. Firstly, the Nivea layer occurs between pollen peaks of *Betula* followed by *Pinus*, with high frequencies of grasses and herbs. This can be correlated with the Flush Bog data and suggests a date of approximately 9600 BP for the lower part of this zone (see above). More importantly, it demonstrates that the Nivea layer is diachronous across Cranes Moor, since the sediment described by Seagrief was after the expansion of *Pinus* with rising levels of *Corylus*, between 350 and 370cm. The same event in the pollen assemblage of CMI has been dated to 8590 $\pm$ 90, at a depth of 362 - 372cm. Farmer *et al* (1985) suggest that allophane may play a direct role in the podzolisation process, with it being deposited from solution as a gel in illuvial horizons, rather than from *in situ* formation. The origin of allophane is attributed to intense acidic weathering of micaceous minerals by Farmer *et al*, (1985). The presence of this deposit may be of significance to the current debate on podzol formation (Buurman and van Reeuwijk, 1984; Farmer, 1984 and references therein). The Nivea layer tends to support the hypothesis of translocation. Perhaps what is more remarkable, is the parallel observation by Farmer *et al*, (1985) that allophane can impregnate cell walls of decomposing roots to form a pseudomorph of the original cell structure. The diachronous pollen assemblages within the Nivea layer demonstrate that its formation took place after deposition of the peat. The mineralisation process affected the organic remains in the sub-peat deposits and the *Sphagnum* in the lower part of zone 3 also appears to have been partially affected. A further point is that the Nivea layer occurs at the base of the peat column in both this and Seagrief's cores.

In all, these observations might suggest a process involving the movement

of groundwater containing allophane along the basal peat-sand interface some time after peat formation (and podzolisation,) had begun. However, the problem with this hypothesis is the presence of both unmineralised ericaceous roots and apparently mineralised *Calluna* leaves, flowers etc. in the 485 - 487cm sample from the sub-peat sediment (zone 1). If this is explained by the penetration of roots from plants growing in zone 3 after mineralisation took place, then it would require a depth of penetration in excess of 30cm by *Calluna* which is normally shallowly rooting. Also, this hypothesis does not explain the absence of unmineralised roots in zone 2 in between the other two zones. One can be more definite in concluding that the process of mineralisation was of little ecological significance. First, the event was diachronous and, secondly, there is little response in the macrofossil composition to the marked stratigraphic changes in this core, with only very gradual change in the mire communities over the first 1000 years of mire development.

5.3.4 Macrofossil zone 3 : *Sphagnum* phase : 456 - 406cm

This zone spans the first half of the *Pinus*-dominated period in the Boreal, starting from 9500 - 9000 BP, and is initially composed of almost pure *Sphagnum subnitens* peat with a little *Juncus* epidemis present. The peat was very pale in colour with slight humification and well-preserved *Sphagnum*. The lowest sample graded into the Nivea layer and the *Sphagnum* also appear partially mineralised and granular in texture similar to the peat described by Seagrief (1955) immediately above the Nivea layer in his core (325 - 350cm). This is followed at 422cm in CMI by darker, more degraded peat reflecting a transition to drier conditions on the mire surface at this point. *Calluna* remains returned to the macrofossil assemblage and there is an increase in monocot material. The latter is initially present in low quantities, with Cyperaceae stem material recorded in the 424 - 426cm sample, but becomes the main peat component toward the top of the zone. However, the majority of these remains are due to rootlet penetration from *Molinia caerulea* in the next zone. *Sphagnum subnitens* remains the dominant moss species but *S.tenellum* and *Polytrichum* are also represented at 408 - 410cm. Both *S.subnitens* and *S.tenellum* were recorded by

Seagrief (1955) in his core during the early Boreal (zone v) between 370 and 285cm (see Table 5.3).

5.3.5 Macrofossil zone 4 : *Molinia* phase 406 - 340cm

The opening of this zone is marked by the invasion of *Molinia* and *S. tenellum*. Although *Molinia* is not abundant in absolute terms, the amount of above-ground remains in the macrofossil assemblage is relatively high, including frequent stem bases, and this suggests that this species was an important component of the community. *Calluna* stems and leaves persist in the first part of this zone but subsequently disappear, possibly reflecting increased wetness. Overall, *S. tenellum* is the commonest species but *S. subnitens* is present throughout almost the zone and attains dominance in the sample from 361 - 363cm. Degraded material is virtually absent but increases markedly in the uppermost sample, while the humification of remains increases towards the top of the zone. These changes in preservation are not reflected so clearly by the colour of the peat, which remains a more uniform dark brown across the whole zone. The best interpretation of this evidence is for a fluctuating water regime which would favour both *Molinia* and *S. tenellum*. Unusually, above-ground *Molinia* remains occur throughout the zone while its rootlets are concentrated around 408 - 410cm, showing that *Molinia* became more deeply-rooting as this zone progressed. A sample from a depth of 362 to 372 depth was dated to 8590 $\pm$ 90 BP, and this zone spans an estimated period from 9000 to 8250 BP

5.3.6 Macrofossil zone 5 : the 'pool' sequence : 340 - 116cm

This zone comprises a series of sediments, dominated by *Sphagnum*, which were formed under wet conditions, reflecting what must have been wet lawn or bog pool environments. Despite several distinct phases, there is little justification in further division of this zone, without arbitrary splitting. An unusual feature of the zone is the dark coloration of the peat and, in places, poor preservation while all the available fossil evidence indicates locally wet conditions on the mire.

Between 340 and 320cm the peat becomes darker than the previous zone

but this is coupled with a marked increase in the abundance of diatoms and the appearance of frequent Cladocera remains and *Sphagnum* section *Cuspidata*. From 320 to 256cm, the peat becomes paler with increasing amounts of algal mud which form a somewhat laminated sediment between 280 and 260cm. This phase corresponds to the maximum abundance of diatoms, with a peak centred around 300cm. The diatom assemblage was dominated almost completely by *Navicula serians* a bog pool species found in abundance in the present pool system of Cranes Moor. The macrofossil assemblage is composed of a diverse *Sphagnum* community comprising mainly *S.papillosum* (the only occurrence other than in the basal deposits of the core), *S.subnitens*, section *Subsecunda* and *S.tenellum*, with minor amounts of *S.cuspidatum* section *Cuspidata* undet. and *S.palustre*. Leaves of *Calluna* were recorded from the lowest sample at 311 - 313cm but otherwise this species was absent except for some probable rootlet penetration in the 262 - 264cm sample which is mainly composed of stratified algal muds. Only small amounts of monocot material occur, some of which may be attributable to *Rhynchospora* which was recorded at 295 - 297cm, while *Molinia* was tentatively identified in the sample from 311 - 313cm. The latter sample also contained a branch of *S.palustre* with squarrose leaves, a growth-form which is often encountered with depauperate specimens of *S.palustre* growing on the side of *Molinia* tussocks today.

The pool phase is interrupted by a darker and more humified layer between 256 and 240cm, containing frequent *Calluna* rootlets and dominated by *S.subnitens*, which may be dated to 7000 $\pm$ 80 between 238 and 248cm. However, this is a short-lived phenomenon and pool sediments return at 240 to 200cm. Again, there is major increase in diatoms, more frequent Cladocera and a diversification of *Sphagna*. The second pool phase appears less well-developed than the first and *Calluna* persists in the macrofossil assemblage throughout, while monocot remains are totally absent. The initially diverse *Sphagnum* community becomes dominated by *S.subnitens* in the latter part of this phase and this species remains dominant in the subsequent darker and more humified peat layer between 200 and 180cm, which exhibited a 'felted' texture.

The final phase in this zone contain an assemblage which indicates the

return of wetter conditions again, probably in the form of a wet lawn environment in which the degree of preservation is better than in the pool sediments below. The most significant feature is the appearance of *Erica tetralix* for the first time in the core at 166 - 168cm, which may be estimated to be about 6000 BP. This phase is initially dominated by *S. subnitens* but by 152cm has become completely out-competed by section *Subsecunda*. This sample contained specimens with broad, flaccid branch leaves which closely resembled submerged leaves of *S. auriculatum* var *auriculatum*. A peak in diatoms also occurred at this depth, in both macro- and microfossil samples. Tentative *Rhynchospora* remains were identified in the monocot material and it is probable that *Molinia* rootlets were also present. The appearance of fungal hyphae (Fig. 5.10) may be associated with presence of the monocot remains. The wet phase is datable to 5750 ± 60 on radiocarbon analysis, and probably spanned a period from about 6100 to 5300 BP.

5.3.7 Macrofossil zone 6 : *Molinia* - *Sphagnum* - *Erica tetralix* phase : 116 - 15cm

The wet lawn period is terminated by the accumulation of more decomposed peat with much more abundant monocot remains and sustained high levels of fungal hyphae (Fig. 5.10). The macrofossil assemblage in this zone suggests a community dominated by *Molinia*, *Sphagnum* and *Erica tetralix*. The *Sphagna* show some variation in dominance between section *Subsecunda*, *S. submitens*, *S. tenellum* and section *Cuspidata* and this may reflect slight changes in wetness. The reduction in fungal hyphae may also reflect a higher water table (Middeldorp, 1984) in the middle of this zone. Contemporary pink *Eriophorum* rootlets were found in several samples from 55cm upwards. In the sample from 69 - 71cm, small amounts of sub-angular sand were found and this corresponds to *Ulmus* decline and increase in herbs and grasses which occurs at the same level and is dated to 4550 ± 60 BP. The end of this zone, at approximately 4000 BP, is marked by a hiatus due to peat cutting and the mire community at this time appears to have been dominated by *Molinia*, with some section *Subsecunda* and *Cuspidata*, and with a relatively poor degree of preservation compared to the rest of the deposits at Cranes Moor.

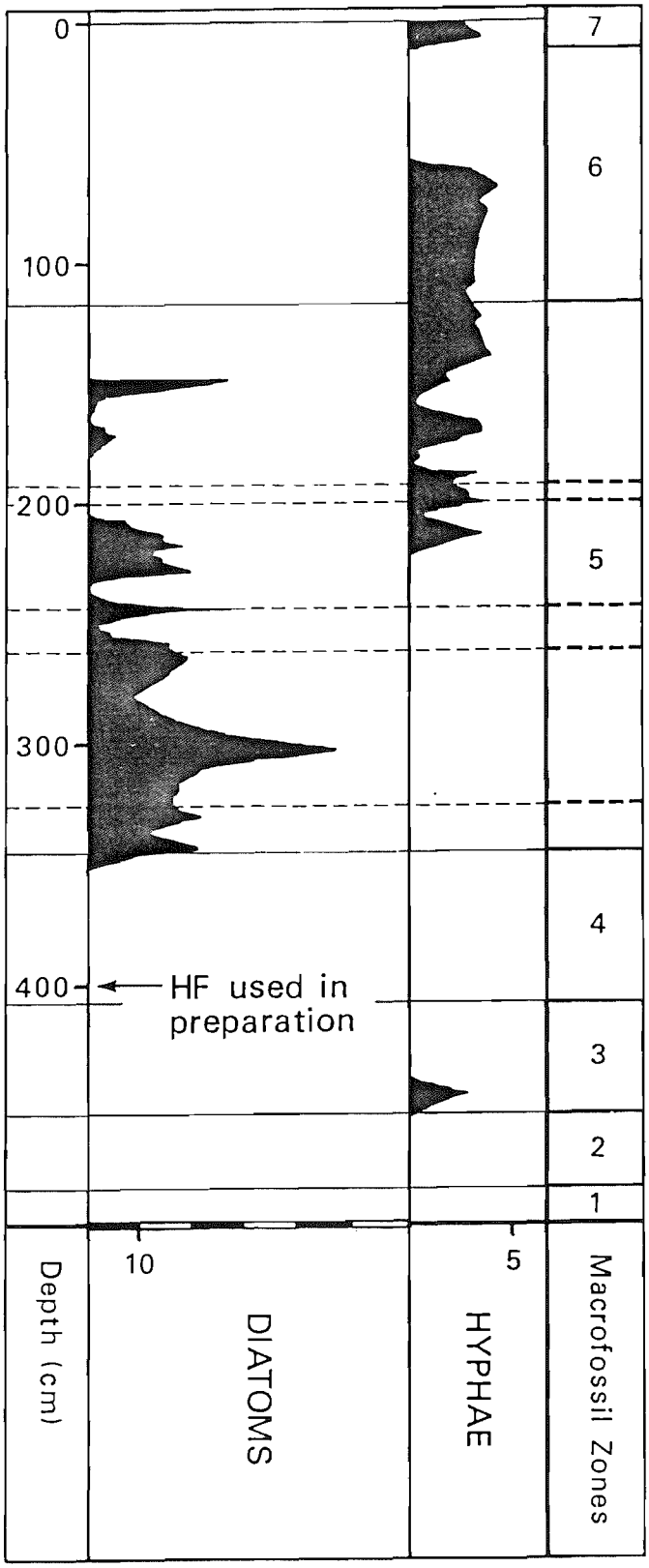


FIGURE 5.10 : Fungal hyphae and diatom microfossils from CMI (analysis by A R Tilley).

5.3.8 Macrofossil zone 7 : recent peat accumulation : 15 - 0cm

From the *Pinus* marker horizon (evident in recent peat accumulations - see Barber and Clarke, 1987; Clarke and Barber, 1987), it is possible to establish that at least 12cm of peat has developed since the re-expansion of *Pinus* after it was re-introduced in 1775. The recent peat is composed mainly of *Molinia* rootlets, with small amounts of *Sphagnum tenellum* and remains of *Erica tetralix* including branches and leaves. The contact between the recent peat and the cut surface of the mire is not sharp, but palaeoecological analyses of CMI show that the hiatus occurs between 10 and 16cm, and is probably nearer 15cm. This compares with a hiatus in Seagrief's (1955) pollen diagram between 10 and 20cm, and changes in the water content and density at 20cm and 10 - 15cm, respectively, in Giles' (1977) analysis of the upper peat deposits, both authors having sampled the central area of *Sphagnum* Bog not far from CMI.

5.3.9 Discussion

Comparison of CMI with the core described by Seagrief (1955) shows that both sequences correlate remarkably closely until the beginning of the series of pools and wet lawn in CMI (Figure 5.11, although the changes in stratigraphy become increasingly diachronous towards the base. The subsequent pool phase (mz 5) is absent from Seagrief's core and, instead, a *Sphagnum* peat comprised of *S.papillosum*, *S.palustre* and *S.recurvum* was found (see Table 5.3). Interestingly the point of divergence between the cores is marked by the transitory appearance of *S.papillosum* and the only occurrence of *S.palustre* in CMI. This may reflect increasing differention of the surface into hummocks and hollows - coupled with greater diversification of the *Sphagnum* assemblage - at 8250 BP or thereabouts. The rate of accumulation in this *Sphagnum* zone of Seagrief's core is initially greater than the pool sequence but becomes much lower during the final wet lawn phase with these lower rates continuing into mz 6 of CMI (Table 5.4). Several other palaeo-ecological studies (such as Aaby and Tauber, 1975; Middeldorp, 1986) have reported high accumulation rates in hummock peats compared to pool sediments, despite the greater decomposition of material beneath hummocks

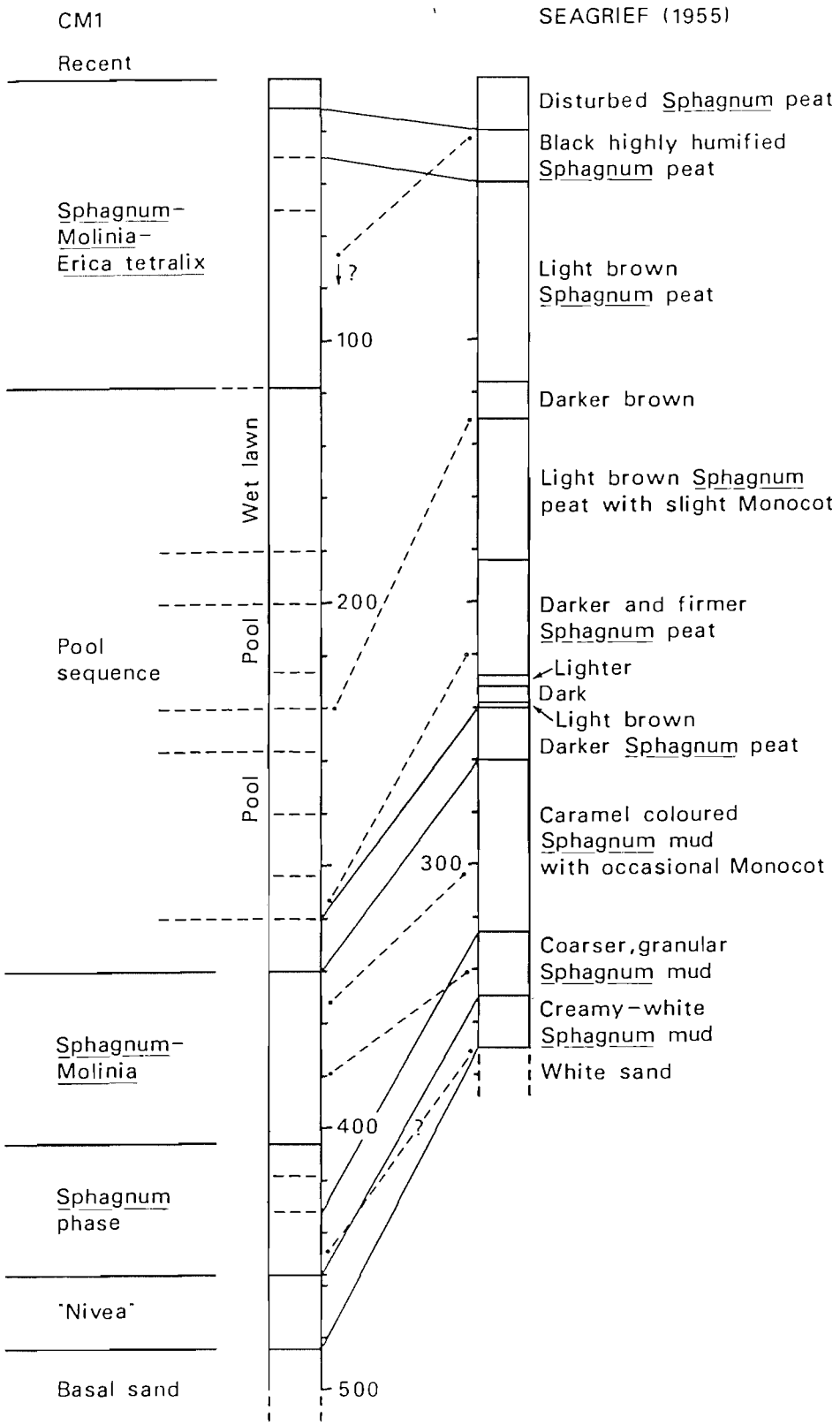


FIGURE 5.11 : Correlation of peat stratigraphy (solid lines) and pollen assemblages (pecked lines) between CMI and Seagrief's (1955) core from *Sphagnum* Bog.

TABLE 5.3 Summary of macrofossils from lower depths of *Sphagnum* Bog, Cranes Moor recorded by Seagrief (1955)

	Pollen Zones and Depth		
	V 370 - 285	VIa 285 - 220	VIb 220 - 140
Betula pubescens	+	+	
Carex sp.	+		
Cladium mariscus	+	+	+
Erica tetralix	+	+	
Pinus sylvestris	+		
Sphagnum compactum	+		
S.palustre	+	+	+
S.papillosum	+	+	+
S.recurvum (as *S.pulchrum*)[1]		+	+
S.subnitens (as *S.plumulosum*)	+		
S.tenellum	+		

[1]This now thought to be *S.recurvum*, rather than *S.pulchrum*, with the more recent progress on the taxonomy of the complex '*S.recurvum* group' (*sensu lato*). No other past or present records for *S.pulchrum* exist for the New Forest.

TABLE 5.4 **Comparison between the rates of accumulation in** CMI and Seagrief's (1955) core

Depths (cm) in CMI	Relative accumulation rate in Seagrief's (1955) core
240 - 70	50%
315 - 240	168%
350 - 315	23%
380 - 350	133%
450 - 380	40%

before its inclusion in the catotelm (q.v. Clymo, 1984). Barber (1981b) found that the higher accumulation rates of hummocks often occurred in rapid spurts of growth, indicating that more complex longer-term mechanisms are involved than the results of contemporary studies (e.g. Clymo, 1970; Boatman, 1977) might suggest.

Subsequent to the divergence in the cores, no correlation in terms of peat stratigraphy was found, although a highly humified zone occurs in both cores immediately below the recent peat accumulation. However, in contrast to CMI, the hiatus due to peat cutting in Seagrief's core is located before the elm decline. Thus, this highly humified band of peat is most likely a secondary phenomenon due to further decomposition following re-exposure of the cut mire surface.

The question whether *Sphagnum* Bog was, or is, a raised mire dependent on rain water has been considered by most workers who have carried out research on this site. However, the full impact of peat cutting has been overlooked until comparatively recently even though Seagrief (1955) was aware of evidence for the disturbance and truncation of his pollen diagram.

The main difficulty in determining the hydrological status of *Sphagnum* Bog is in the determination of the relative contributions to the mire water budget of direct atmospheric precipitation (meteoric input) and indirect groundwater flow (telluric input). The absence of techniques for the direct measurement or estimation of telluric inputs is responsible for a major gap in mire hydrology (Ingram, 1983). Indirect estimation is based on measuring all other components in the water budget but this method is susceptible to the errors associated with estimating these variables, such as obtaining a global evapotranspiration estimate from lysimeter measurements (Ingram, 1983). Other approaches to the problem may be considered but these, too, are not without difficulties. In particular, it is hard to differentiate between meteoric water and telluric water derived from areas of base-poor lithology, such as the immediate Barton Sand catchment of the shielded area. Newbould (1960) observed that, in such cases, floristics were a poor discriminant of the "mineral soil-water" limit, and Rose (1953) has commented on the similarities

between ombrotrophic mire vegetation and the vegetation in the marginal zones of valley mires deriving water from the surrounding leached soils of a heathland catchment. The chemical environment of heathland top-soils, being highly acidic and infertile, is similar to that of ombro-trophic peat with a pH often less than 4.5 and a relatively high Ca^{2+}/Mn^{2+} ratio. There are thus difficulties in using chemical criteria (Gorham, 1956; Bellamy, 1959) to separate heathland runoff and direct precipitation. Hence, although all the evidence from the present vegetation (floristics, water chemistry, production studies) demonstrates the shielded area to be markedly oligotrophic, it cannot be used to prove that vegetation is ombrogenous in origin. In addition, the disturbed and cut nature of the mire surface has created a situation which is difficult to interpret, and the pool system in particular appears to be almost entirely man-made. This is a good illustration of the dangers involved in interpreting process from morphology alone. Moreover, it may be argued that the present partially-domed surface of the mire is an artifact of peat cutting, especially since the boundary between the cut surface and recent peat is diachronous.

However, despite these reservations and the caution that is required the present situation strongly suggests that direct precipitation is the major water source for *Sphagnum* Bog in contrast to other New Forest mires and other parts of the Cranes Moor system. Topographic surveys of the site by both Newbould (1954) and Giles (1977) have shown that the centre of the *Sphagnum* Bog area is raised on three sides, being some 40+cm higher than the mire margin to the south and 80 - 100cm higher than to the west and north. Only to the east (the possible source of groundwater), does the mire surface rise towards the margin, which is some 100 - 140cm higher than the centre. The mire is thus not domed, but forms a gently-sloping ridge, along which the gradient is approximately 1 in 150 (0.4^{o}) - a value in the same order as profiles of other valley mires in which lateral groundwater flow is clearly dominant and similar to the overall gradient (0.5^{o}) of the mire (Newbould, 1960).

However, two factors may be responsible for reducing the role played by lateral seepage in the shielded area. Firstly, as its name implies, it is protected from groundwater influence to an extent by topography. This

was recognised by Seagrief and Newbould who were working on Cranes Moor during the same period. Seagrief (1960) pointed out that the *Sphagnum* Bog was flanked by a low ridge to the east which protected it from the waters draining from Burley Ridge above. Most of this drainage, Seagrief suggested, was received by Flush Bog and to a lesser extent by the *Schoenetum* running around the northern margin of *Sphagnum* Bog, so that *Sphagnum* Bog itself receives a restricted groundwater supply. Newbould's (1960) observations on water flow and water chemistry, and latterly those of Giles (1977), confirmed this hypothesis. The low productivity of this area recorded by both these workers also suggests relatively small groundwater influence, as does the presence of only the non-tussock growth form of *Molinia*.

The second factor which may restrict lateral seepage is the presence of humified *Sphagnum* peat and pool deposits, the hydraulic conductivity of which is considerably less than typical valley mire or fen peats of similar humification (Ivanov, 1981; Ingram, 1983). Not only will this impede water flowing laterally from the ridge, but it will also favour the generation of the groundwater mound necessary for ombrotrophic mire development by its failure to rapidly transmit water received from precipitation. Newbould (1960) doubted that the climate of the New Forest would permit the development of ombrotrophic peat because of the soil moisture deficit which accumulates during the summer months in southern England. However, raised bogs have developed in southern England, notably the Somerset Levels (Clapham and Godwin, 1948). In Yorkshire, raised mire development took place at Thorne Waste, where the mean annual precipitation is 568mm (Smart *et al*, 1986). In continental Europe, raised mires have developed in East Poland, where the average is 650mm/yr (Kulczynski, 1949) and in Estonia with a regional mean of 610mm/yr. (Karing, 1984). This compares with a mean of 800mm/yr. at Burley, according to Newbould (1960) Evapotranspiration rates are not available for Burley, but the Soil Survey have recently analysed meteorological data from 954 sites in England and Wales which show that potential evapotranspiration varies little on a regional basis relative to precipitation, with a maximum of 575mm/yr. and a minimum of 500mm/yr. recorded across the whole of south-east England (Jarvis *et al*, 1984).

While, in comparison, figures from the well-known Lake Agassiz peatlands in N.America (Siegel, 1983) are 530 - 600mm/yr. for precipation and 430 - 480mm/yr. for evapotranspiration. Although continental sites will generally have lower temperatures in winter compared to the New Forest, the summer soil moisture deficit is probably a more important control on ombrotrophic peat development. A geophysical model of groundwater mound formation has been tested by Ingram (1982), who found that it enabled close prediction of the observed height and shape of Dun Moss, a raised mire in Perthshire. The model requires that the flow of water through peat behaves according to Darcy's law; despite earlier doubts (Rycroft *et al*, 1975) this assumption is currently accepted by peatland scientists but for differing reasons (cf Ingram, 1983, and Hemond and Goldman, 1985). Its usefulness is due to the fact that it relates the dimensions of a raised mire to its water budget and other hydrological variables, such that it has considerable predictive value (see also Ivanov, 1981, Chapter 1). By estimating the values of the model's parameters, it is possible to examine whether it is possible, on hydrological grounds, for an ombrotrophic mire to develop at Cranes Moor under present conditions. With only a little simplification, *Sphagnum* Bog may be regarded as a roughly circular mire confined in a more or less parallel-sided valley, bounded by the Bracken Ridge and Pine Ridge of Newbould. In this case, the dimensions of a groundwater mound are related to the hydraulic conductivity, K, of the peat and to a component of the water budget, U, by the expression (from Ingram, 1982).

$$\frac{U}{K} = \frac{H^2}{L^2} \qquad 5.1$$

where H is the maximum depth of the groundwater mound (i.e. the raised water table), L is the radius of the mire and U is net recharge which may be calculated from the mire water budget. This is defined as

$$P - E - U - G - \Delta W = 0$$

where P = precipitation, E = evapotranspiration, G = leakage, and W = the change in storage. For convenience, $\Delta W = 0$ if these variables are measured over a whole year. It is a necessary assumption that $G \ll U$, i.e. there is negligible leakage of water through the base of the peat into the bedrock. This is reasonable in the case of Cranes Moor since the bedrock will be saturated by the regional groundwater table. Although values

TABLE 5.5 Values of hydraulic conductivity K (the co-efficient of seepage) for different peat types

Type	Humification	Average (cms^{-1})	Range (cms^{-1}) Max.	Min.	Source
Dun Moss	von Post H = 4	5×10^{-4}	2.1×10^{-4}	7.9×10^{-4}	Ingram, 1982
Blanket peat	-	-	1×10^{-4}	1×10^{-7}	Stewart and Lance, 1983
Lowland raised bog (Germany)	-	1.7×10^{-3}	-	-	
Bog peat (Sphagnum)	very slight	1.5×10^{-2}	1×10^{-2}	2.5×10^{-2}	Ivanov, 1981
	slight	4×10^{-3}	2×10^{-3}	7×10^{-3}	
	moderate	5×10^{-4}	1×10^{-3}	2.5×10^{-4}	
	high	5×10^{-5}	8×10^{-5}	2×10^{-6}	
Fen peat	slight	5×10^{-3}	1×10^{-2}	2×10^{-3}	
(monocot-moss)	moderate	8×10^{-4}	2×10^{-3}	2×10^{-4}	

are not available for all these variables at *Sphagnum* Bog, it is possible to set upper and lower limits from which the range of conditions may be defined in which a raised mire could be sustained. Using the precipitation measurements from Burley, an upper and lower limit for U may be determined, by elimination, from the minimum and maximum values for potential evapotranspiration in southeastern England. Since the ratio of evapotranspiration to potential evapotranspiration lies between 1.0 - 1.1 for moss-dominated bogs (Ingram, 1983) these values should provide reasonable bounds to the actual rate of evapotranspiration. The hydraulic conductivity, K, of the peats at *Sphagnum* Bog is unknown but it is possible to select a range of appropriate values from studies elsewhere (Table 5.5). The field determination of peat hydraulic conductivity is notoriously difficult and, in any case, a single figure is unlikely to be very representative of the peat mass as a whole which will contain a variety of deposits of differing humification, etc. A range of values is therefore not an unreasonable starting point for this approach to the problem. Table 5.6 shows the expected maximum height of the groundwater mound (and therefore the mire) at *Sphagnum* Bog for two values of K.

TABLE 5.6 Predicted values for the maximum height of a groundwater mound at *Sphagnum* Bog, within model parameter limits. Y = net recharge, K = the co-efficient of seepage.

	K (cms^{-1})	
	8×10^{-4}	8×10^{-5}
U min.	2.4m	7.5m
U max.	2.6m	8.7m

The first is based on the measurements of hydraulic conductivity reported by Ingram (1982) and is the lowest value recorded (approximately 8×10^{-4} cms^{-1}), since the description of the peats from Dun Moss suggests that they are generally slightly less humified than *Sphagnum* Bog. On this basis a peat depth of about two and a half metres could be expected. The second value of K assumes that the peats are an order of magnitude less permeable (see Table 5.5), and yields depths of about 8m. All these

estimates are based on the E - W width of *Sphagnum* Bog (radius = 80m), if the slightly larger N - S length of the mire (radius = 100m) is used the expected depths are a little greater - for example, the smallest predicted value, 2.4m, becomes 3.0m.

Although these calculations are necessarily approximate, two very important conclusions may be drawn. First, it is perfectly possible for an ombrotrophic mire to develop in the *Sphagnum* Bog basin under the conditions likely to be prevalent at Cranes Moor. Second, the most important factor determining the formation of a groundwater mound (i.e. the development of a raised mire) in the New Forest is not the climate but the hydraulic conductivity of the peat.

It is worth examining, with reference to these two points, the sensitivity of the model to variations in the value of the variables involved. Of all the variables, it is the hydraulic conductivity K which tends to have the largest effect on the model and this is simply because the hydraulic conductivity of peats is known to vary so widely - for example, the values in Table 5.5 range across five orders of magnitude. This problem and the difficulty of measuring field permeability are well known to engineers (Bolton, 1979). By contrast, the differences in the size of mires, or units within mire complexes, are in general unlikely to be more than an order of magnitude between sites (NB. the dimension L^2 is actually used). Likewise, U, the net recharge of water into the system, does not vary that greatly; for it can be seen from the data described above that the difference in U between the climatic extremes of continental USA and southern England is a factor of only 2.5 to 6 times that of southern England. This is of some interest, since it suggests that post-glacial changes in the precipitation: evaporation ratio are unlikely to have significantly affected the overall potential for raised bog development, although remaining an important determinant of mire geometry and growth. Table 5.6 shows that the differences in the predicted height of *Sphagnum* Bog due to the upper and lower limits of recharge U were only 8 - 16%, but alteration of the hydraulic conductivity resulted in a variation in depth of 213 - 235%.

The values of K used in these calculations are slightly on the low side

of the range in Table 5.6, i.e. it assumed that the peats at *Sphagnum* Bog are of relatively low permeability. This assumption may be valid on two counts. First, none of the published figures for hydraulic conductivity distinguish between hummock and hollow deposits, yet these clearly have different characteristics, and in the case of pool deposits composed of *Sphagnum* and algal mud the effective pore size will be very small indeed. Moreover, field estimates of K are not practicable below c1.5m, so that compacted and more decomposed peats at depth are not sampled. Second, it is possible to calculate the overall value of K for *Sphagnum* Bog based on its present dimensions (i.e. depth = 5m). This yields a figure of 1.8 - 3.8 x 10^{-4} cms^{-1} which is an overestimate since some peat has been removed. The sensitivity of this model to variation in K means that predictions based on single 'point' estimates of hydraulic conductivity must be treated with some caution. A range of values may be more appropriate when considering the possibility of raised mire development. Although Ingram (1982) reported close agreement between this model and the shape of Dun Moss, substitution of the maximum and minimum hydraulic conductivity measurements obtained from Dun Moss yields a range of predicted depths from 7.1 to 13.8m, compared to the 8.2m observed!

Finally, the peat deposits themselves provide some of the strongest evidence for the development of predominantly ombrotrophic conditions in *Sphagnum* Bog. The peat is exceptional in the New Forest - and indeed in southern England - in terms of its depth and composition. The almost pure *Sphagnum* peat and bog pool deposits closely resemble those of ombrotrophic mires in north and west Britain. There is thus the potential for raised mire development at Cranes Moor under present conditions, and the evidence to support a predominantly ombrotrophic status for the mire in the past.

The accumulation rate of CMI is shown in Figure 5.12, based on the four upper radiocarbon dates. Two additional age estimates are also shown based on the pollen correlations with Flush Bog discussed in zone 1. The accumulation rate based on radiocarbon dates suggest a remarkably constant rate of growth. Clymo (1983, 1984) has argued that the age-depth profile of a peat bog should be concave. His argument is based on the dynamics of

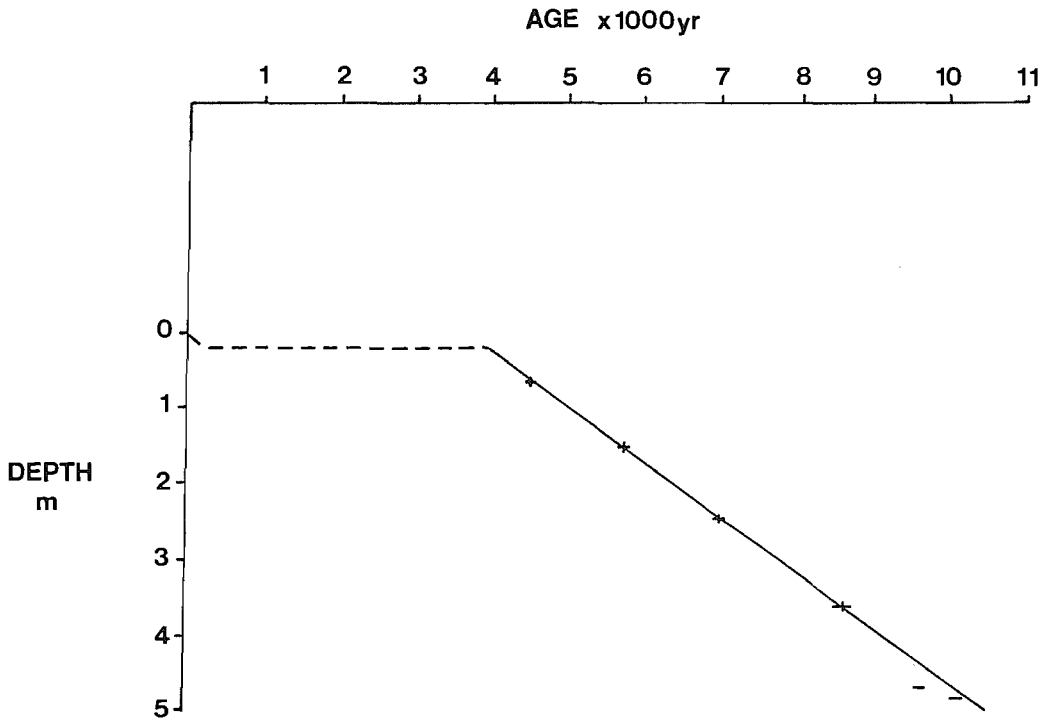


FIGURE 5.12 : Age-depth relationship for CMI.

production and decomposition of the peat mass as a whole, and requires a small (c 0.01% per year) but nonetheless significant rate of decay within the catotelm. This imposes a geometric constraint to the ultimate depth of a mire since the net accumulation of the peat mass over time is a function of volume but input to the system is only a function of area (surface production). If this assertion is true, and the available evidence is in agreement with this (Clymo, 1984), then the maximum height of a mire may be limited by ecological factors (viz. the ratio of input and decay within the catotelm) rather than the hydrological variables discussed above. In fact, these two differing theoretical constraints on bog growth are not as unrelated as they might seem, since hydraulic conductivity is dependent on decomposition, and production/ decomposition processes are heavily influenced by climate. A climatic approach may provide a more unified framework for the theory of peat bog growth. Clymo's model considers accumulation in terms of mass and unfortunately the bulk density of the peat in CMI was not measured. This means that the apparently non-concave profile of CMI cannot be taken as firm evidence with which to falsify the predictions of Clymo's model - although Clymo (1984) assumes a constant bulk density, in the absence of actual measurements, for the profile from Draved Mosse (Aaby and Tauber, 1975) which supports his hypothesis. A further difficulty with the CMI profile is that the last 4000 years peat accumulation is missing, so that any trend towards concavity will be under-emphasised in the remaining depth profile. However, Figure 5.12 does show that peat accumulation did not slow down in the Atlantic period, contrary to the conclusions of both Seagrief (1960) and Newbould (1960) despite their suspicion of human disturbance (see also Taylor, 1983).

A straight line drawn through the depths of the radiocarbon dates in Figure 5.12 produces a mean "accumulation" rate of 75cm per 1000 yr (14 yr cm^{-1}), a figure not dissimilar to many raised mire sites (see Barber, 1982, for a comparative review of data). The depth of recent peat on *Sphagnum* Bog suggests that modern peat has been accumulating at a very similar rate in *Sphagnum* Bog. The modern rate of accumulation lies between 50 - 80cm per 1000 yr. (20 - 12.5yr cm^{-1}), although this may be an overestimate since much of this material is still within the acrotelm. Extrapolation of the age-depth profile to the present, therefore, may not be that unrealistic as an estimate of the peat removed

from Cranes Moor. This would imply that 2.8m of peat has been removed.

In the absence of exposed sections on Cranes Moor, it is unwise to interpret too closely the stratigraphic changes in CMI in terms of climate (Aaby, 1976; Barber, 1981b), although Barber (1981b) has shown that even micro-scale changes in the mire surface may be related to climatic factors. Nonetheless, data from CMI and Seagrief (see Table 5.4 and Figure 5.10) suggest that significant changes in the mire surface, reflecting a shift towards a wetter climate, may have occurred across the whole of *Sphagnum* Bog around 8250 BP. In CMI this was marked by the development of a bog pool which replaced a drier community principally composed of *Sphagnum tenellum*, *Molinia* and *Calluna* (cf the early Flandrian in Church Moor, m.z.5, when drier conditions are also indicated). This indicates the onset of wetter conditions in the mid-Boreal which then continued into the Atlantic. The subsequent macrofossil assemblages in zone 6 suggest a locally drier mire surface, but this shift to drier conditions may be due to autogenic factors rather than climate (Aaby, 1976; Barber, 1981b). Scaife (1980) found stratigraphic evidence for a pronounced shift towards drier conditions on the Isle of Wight in the early Boreal (c9900 BP). Lake silts were replaced by humified peat, with nodular clay at the junction, possibly indicating dessication cracks. However, the drier period in the early Boreal appears to have been a short-lived phenomenon and there is little climatic distinction between the latter part of the Boreal and the Atlantic period. (Scaife, 1980).

5.3.10 Summary

1. Organic preservation began around the Late Devensian/Flandrian transition at about 10100 BP. Considerable, but declining, surface instability is evidenced by the accumulation of 16cm of inorganic sediments containing a varied macrofossil flora indicative of mire-wet heath conditions.
2. Development after this phase is made complex by the secondary formation of the so-called 'Nivea layer', containing large amounts of proto-imoglite allophane and apparently mineralised organic remains. This may be related to important but as yet poorly-understood

pedogenic processes connected with podzolisation.

3. Early development of the mire started with a *Calluna-Sphagnum subnitens* community which was replaced by *S.tenellum* and *Molinia* as dominants.
4. Subsequent development involved the accumulation of a pool and wet lawn sequence over some 220cm of peat. This may be correlated with changes elsewhere on the mire and indicates a greater differentiation into hummock-hollow communities due to increased wetness following c8250 BP, the mid-Boreal, and continuing into the Atlantic period. A similar history of climatic change has been detected on the Isle of Wight.
5. The peat column is truncated by peat cutting at c4000 BP when the mire was dominated by a *Sphagnum - Molinia - Erica tetralix* assemblage. A diachronous secondarily-humified peat layer is present across the mire beneath the junction with recent peat.
6. Recent peat accumulation rates (50 - 80cm per 1000yr.) are similar to rates on the mire (mean = 75cm per 1000yr.). There is no available evidence for a concave age-depth profile.
7. The question of raised bog development is partially confounded by extensive peat cutting and by the fact that floristics are a poor discriminant of meteoric and telluric water supply in an area of base-poor lithology. Also, measurement of the groundwater flow presents technical difficulties to the determination of the present hydrological status of the mire. However, it can be shown that it is possible for a groundwater mound to be sustained by the hydrological conditions thought to be present at *Sphagnum* Bog. Both the gross peat stratigraphy and the detailed macrofossil composition are consistent with ombrotrophic mire development at *Sphagnum* Bog.

5.4 STEPHILL BOTTOM (SHATTERFORD BOTTOM - DENNY BOG)

5.4.1 Introduction

Stephill Bottom is part of the Shatterford Bottom - Denny Bog system which is one of the largest mire complexes in the Forest. The place-name refers to a general area south of Beaulieu Road Station where there is a sharp bend in the valley. This is an area of low relief which has been largely

denuded of the Plateau Gravel drift which, in the vicinity of Stephill Bottom, survives as small remnants overlying the fine sand of the Barton Sand (see Figure 2.10). The lithology of this area is discussed further in Section 1. The mire lies within an extensive tract of heathland comprising dry and humid heath communities on the interfluves. The mire at Stephill Bottom is well-defined in relatively steep but small valley-sides which concentrate the axial drainage of the valley into a water track (*sensu* Ingram, 1967) occupying most of the width of the valley mire. Hydraulically, then, this site may be regarded as a fen which sustains a relatively thick acrotelm (Ingram, 1983). The area is subject to relatively high intensities of grazing from commoners' ponies but the wet conditions at Stephill Bottom mean that only the mire margins are heavily grazed. In dry summers, however, ponies are able to penetrate to the centre of the mire. The vegetation is dominated by vigorous *Molinia caerulea* tussocks, probably related to the aerated water flow (Rutter, 1955), with often abundant *Carex echinata*. Between the tussocks *Sphagnum auriculatum* and *S.papillosum* occur in low cushions with *S.cuspidatum*, *Drosera rotundifolia*, *Potamogeton polygonifolius* and *Hypericum elodes* in runnels. *Juncus articulatus* and *Eriophorum augustifolium* also occur in the centre but are more frequent toward the edges of the mire, as is *Myrica gale*. The more-heavily grazed mire margins also support frequent *J.bulbosus* and *Eleocharis multicaulis* with *Drosera intermedia* and locally *Ranunculus flammula*. In addition to grazing, the mire system has also been affected by past peat cutting (see Figure 5.13), although it might be noted that there is air photo evidence for even more extensive removal of turves from the wet heath around the edge of the mire. Part of the mire system, mainly Denny Bog, is enclosed within an earth bank and ditch Bishop's Dyke, possibly of medieval origin, which crosses the northern limb of the mire some 200m downstream of Stephill Bottom. As will be shown, the sample site has escaped peat cutting and the hydrology of the site has been largely unaffected by the construction of the Bishop's Dyke.

This site has been the subject of little detailed study of either its past or present ecology, although the significance of this mire system is recognised in most of the major reviews of valley mires in the New Forest and southern England generally (Rose, 1953; Tubbs, 1968;

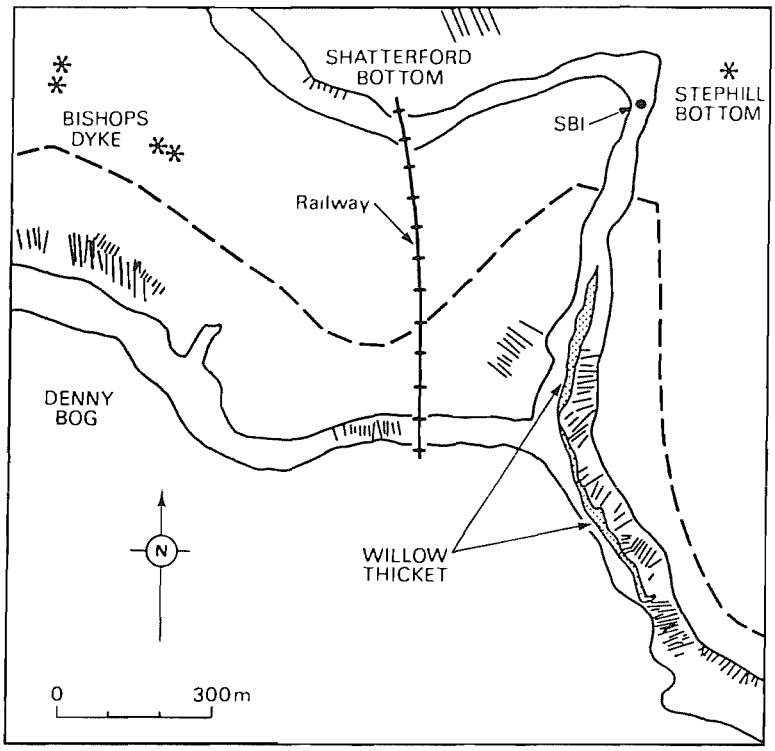


FIGURE 5.13 : Map showing location of SBI. Air photo evidence for peat and turf cutting (vegetation stripes) is also shown. Asterisks denote tumuli.

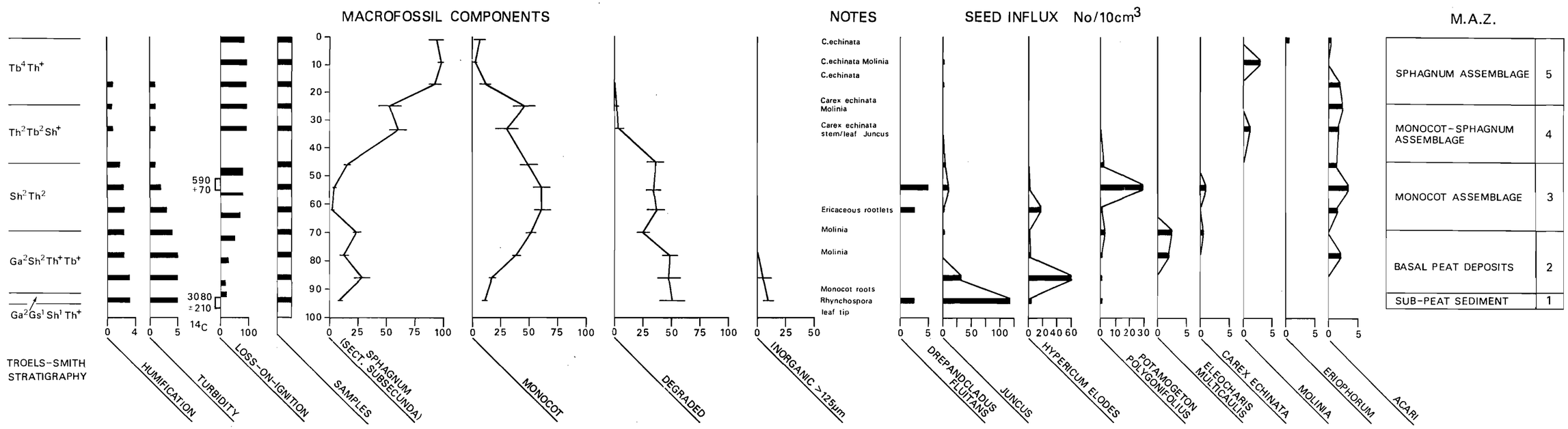


Fig 5.14 Macrofossil Diagram from Stephill Bottom (SBI)

Ratcliffe, 1977a). Stephill Bottom was chosen for study because it is representative of a large number of valley mires occurring in the New Forest, especially in the southern half. It is typical of the majority of New Forest mires which are generally less suitable for palaeoecological study-especially pollen analysis - due to difficulties in sampling and shallow peat depths. The sample site is shown in Figure 5.13. The core (SBI) was located in a small low cushion of *Sphagnum auriculatum* var *auriculatum* due to ease of sampling, a bias which is readily apparent in the macrofossil diagram (Figure 5.14), as will be discussed later. A $1m^2$ quadrat centred on the core was composed of *Sphagnum auriculatum* 65%, *Molinia caerulea* 35%, *Juncus bulbosus* 30%, *Eriophorum augustifolium* 10% and *Potamogeton polygonifolius* 5% (absolute cover). The surrounding vegetation was dominated by *Molinia* and *Carex echinata*. Two sampling techniques were used; for the lower, more consolidated peat and sediments (95 - 45cm) a Russian borer was used. While for the upper, fluid peat a surface core was cut using a large serrated knife (45cm - 0cm). The lower part of the latter core (45 - 34cm) was found to be unsuitable for laboratory sampling due to the poor integrity of the peat. Two radiocarbon samples were dated (Appendix 2). After macrofossil analysis, the core was used for palynological study by Dodd (1985) for an undergraduate research project.

The core was divided into five macrofossil zones:

1 : 95 - 91cm : the sub-peat sediment
2 : 91 - 69cm : basal peat deposits
3 : 69 - 45cm : monocot phase
4 : 45 - 24cm : monocot - *Sphagnum* phase
5 : 24 - 0cm : *Sphagnum* phase

The main significance of this site lies in the relatively small amount of vegetation and hydrological change indicated by the macrofossil assemblages during peat development, coupled with the widespread occurrence of this mire type in the New Forest.

5.4.2 Macrofossil zone 1 : The sub-peat sediment : 95 - 91cm

This zone is distinguished from the next also relatively inorganic zone by the comparatively high proportion of humified organic matter present. A second stratigraphic feature is the presence of fine-medium gravel which

is absent from the upper inorganic horizons. The low organic content of this zone amounted to only 21% organic matter (dry weight) in a sample from 91.5 - 93cm. It is possible that some of this material may be due to post-depositional rootlet penetration, while the humified matter may be derived from the soils of the sediment source areas. Nevertheless, this zone contains a rich contemporary macrofossil assemblage, including much above-ground remains and there is no substantive reason to suppose that significant rootlet penetration from above has occurred. The valley-bottom plant community during this period included *Rhynchospora* (cf *alba*), *Juncus acutiflorus*-type, *Hypericum elodes* and *Potamogeton polygonifolius* with *Drepanocladus fluitans* and several species of *Sphagna*. The *Sphagnum* flora is more diverse at this stage than any time subsequent in the core, although even in this zone section *Subsecunda* (cf *auriculatum*) is dominant, with section *Cuspidata* (undet) accounting for less than 10% of the assemblage and *S.papillosum* occurring only as a trace record. A peak in *J.acutiflorus*-type seeds occurs in the basal samples and this pattern is repeated in Cranes Moor and both cores from Hive Garn Bottom. The presence of charcoal - only found in this zone - is also of note in relation to sediment deposition and soil erosion (see section 1). Radiocarbon dating places the bottom of this zone at 3080 $\pm$ 210 BP, equivalent to the middle Bronze Age although there is a large standard deviation due to the low carbon content of the sample. The pollen assemblage in this zone (Dodd, 1985) is little different to that of macrofossil zone 2 discussed below.

5.4.3 Macrofossil zone 2 : Basal peat deposits : 91 - 69cm

Macrofossil zone 2 is marked by an environment of declining sediment deposition with increasing organic content in addition to the absence of coarser sediments found in zone 1. The pollen assemblage (Dodd, 1985) associated with mz.1 and 2 shows that open conditions were prevalent in the surrounding area. High levels of Ericaceae pollen occur from the beginning of the core (10 - 20% total pollen) and are comparable to the present day. The low relative representation of Ericaceae pollen, and the absence of this taxon from the macrofossil assemblage both support the conclusion that heathland was well developed in the catchment before

peat accumulation began in earnest during the latter part of macrofossil zone 2. Indeed, Ericaceae pollen declines in m.z.2 from a peak in m.z.1 - although this is most likely an artefact of increasing Gramineae pollen influx from the local vegetation due to relative effects in the pollen sum. Dodd (1985) also reports high frequencies of herbs traditionally associated with arable and pastoral agriculture. Some of these taxa are well represented in the pollen assemblage throughout the core and may not be directly associated with human activity, for example the Ranunculaceae may be derived from *Ranunculus flammula* which is locally common around the mire margins today. However, several herb taxa are restricted to the lower deposits, notably Cruciferae, Umbelliferae and *Rumex*, and indicate agricultural activity associated with sedimentary inputs to the valley bottom during the early phases of mire development.

The reproductive macrofossil assemblage remains relatively diverse during this zone with *Carex echinata*, *Juncus acutiflorus*-type, *Eleocharis multicaulis*, *Hypericum elodes* and *Potamogeton polygonifolius* indicating wet and slightly flushed conditions in the mire. There is a rising dominance of monocot remains with rootlets forming the bulk of the peat, including *Molinia caerulea*, and this suggests a graminoid-dominated mire surface with *H.elodes* and *P.polygonifolius* occupying wet runnels, although some rootlet penetration from above may have occurred. *Sphagnum* section *Subsecunda* (cf *auriculatum*) is also well represented in this zone, possibly reflecting preferential preservation of *Sphagnum* leaves relative to other components of the above-ground biomass (see Clymo, 1983).

5.4.4 Macrofossil zone 3 : monocot phase : 61 - 45cm

Monocot rootlets, lacking any diagnostic features dominate this zone. Although the identity of this material is unknown, it is probably closely related to the remains of *Molinia* and *Carex echinata* which are important components of the peat above and below this zone. The *Sphagnum* remains continue to be composed entirely of section *Subsecunda*, and the preservation of material including stem leaves allowed identification to be made of *S.auriculatum* var *auriculatum*. This core, therefore, shows the persistence of this species as complete dominant of the *Sphagnum* assemblage

throughout the 3000 years of its development. In zone 3 large (5.0 x 2.7mm) and 'flaccid' branch leaves were found, closely resembling the submerged growth-form of this species, and indicating the continuation of wet conditions. The frequent remains of *Drepanocladus fluitans*, *Potamogeton polygonifolius* and *Hypericum elodes* also support this conclusion.

The upper boundary of zone 3 is effectively defined by the upper limit to sampling using a Russian borer, corresponding to the boundary between the catotelm and acrotelm. The radiocarbon date from 51 - 55cm of 590 $\pm$ 70 BP appears relatively young for its depth but this, too, is probably related to the functional morphology of the mire rather than to contamination.

5.4.5 Macrofossil zone 4 : Monocot - *Sphagnum* phase : 45 - 24cm

Contemporary rootlets occur with increasing frequency from the bottom of this zone towards the surface. However, stem and leaf remains are frequent with *Carex echinata* and *Molinia caerulea* comprising the main components of the monocot material. *Sphagnum* section *Subsecunda* (cf *auriculatum*) shows an increased abundance over m.z.3 and the reduced seed influx may reflect the development of a low hummock above the water level. The beginning of this zone is marked by the appearance of *Pinus* in the pollen assemblage, followed by a dramatic expansion of this species in the pollen diagram (Dodd, 1985), thus dating the beginning of this phase to approximately 1800 AD. This will be considered in more detail below.

5.4.6 Macrofossil zone 5 : *Sphagnum* phase : 24 - 0cm

The assemblage in the final phase of the core is dominated by the *S.auriculatum* var *auriculatum* present at the core site today. Although monocot remains are less abundant, both *Carex echinate* and *Molinia* remain important structural elements in the local mire community. The presence of *Molinia* seeds is unusual since this species has a very low representation in the seed assemblages of New Forest mires despite its abundance as a vegetative macrofossil.

5.4.7 Discussion

It is important, firstly, to address the problem of possible peat cutting at this site since much of the following discussion depends on the outcome of this issue. There are signs on the ground and more extensive indications on air photographs for considerable past peat cutting activity in the Denny-Shatterford mire system (Fig. 5.13), although these are not evident in Stephill Bottom around the area of the core, SBI. There is further need for caution since the major stratigraphic change at 45cm, between the lower humified and more consolidated peat (zones 1 - 3) and the upper less humified, "liquid" peat (zones 4 and 5), coincides with the appearance of recent pollen assemblages characterised by *Pinus* and with changes in the macrofossil assemblage. However, the possibility of peat cutting in this core can be dismissed by several lines of independent evidence. Firstly, the rise in *Pinus* is gradual, increasing from 4% to 38% over 45 - 25cm (Dodd, 1985) and despite the marked influence of this species on the relative abundance of other taxa, there is no hiatus in her pollen diagram as would be expected from other sites affected by peat cutting in the New Forest. Similarly, the macrofossil changes are best explained by other factors, particularly increasingly incomplete decomposition towards the surface. Secondly, if the peat column has been truncated by cutting at 45cm then the peat removed must post-date the upper radiocarbon date of 590 $\pm$ 70 BP and predate c1800 AD (the *Pinus*-marker horizon). Thus, only 500yr of peat accumulation could have been removed, which is equivalent to only 8cm growth if the mean "accumulation" rate from 3080 - 590 BP is extrapolated upwards. Thirdly, the stratigraphic break corresponds to the functional division of the mire into two layers, the catotelm and acrotelm. Nor is the boundary sharp. In other words, this is a natural phenomenon reflecting a relatively thick (c45cm) acrotelm - as would be expected from a water track sustaining flushed and relatively well-oxygenated conditions (Ingram, 1978; 1984). Fourthly, comparison of past macrofossil assemblages and the present plant community suggests a marked continuity of wet and slightly flushed conditions from the beginning of peat inception. These conditions would have been unsuitable for peat exploitation.

The relationship between the acrotelm-catotelm division on the one hand, and the past macrofossil assemblages and the present vegetation on the other, is critical to the understanding of mire development at this site. One of the main reasons for this is because the acrotelm occupies 40 - 50% of the total mire thickness. This relationship hinges on the interdependence of mire hydrology and vegetation. The flow rates within the water track maintain a nutrient-flushing effect and aerated conditions, which sustain tussock-forming graminoids (in this case *Molinia* and also *Carex echinata*). In turn, the remains of these species lend structural support to the peat, creating relatively large pore spaces and hence high hydraulic conductivity compared to *Sphagnum*-dominated peats (see Ingram, 1984 for further discussion). Consider the peat accumulation rates at this site; three age-depth ratios can be determined using the radiocarbon dates and the *Pinus* horizon:

(i) 3080 BP (93-97cm - 590 BP (51-55cm) = 17cm per 1000yr (59yr cm^{-1}),
(ii) 590 BP (51-55cm) - 150 BP (45cm) = 18cm per 1000yr (55yr cm^{-1}),
(iii) 150 BP (45cm) - +30 (present; 0cm) = 250cm per 1000yr (4yr cm^{-1}).

The two estimates obtained for peat within the catotelm are remarkably similar. The anomalous high accumulation rate of recent peat is simply due to the fact that this material is still within the acrotelm and has not fully undergone decomposition. Comparison of the age-depth ratios within the catotelm and acrotelm suggests that only 7% of the organic matter entering the acrotelm from the mire surface actually reaches the catotelm in Stephill Bottom. This figure is only two-thirds that estimated for the proportion entering the catotelm of raised bogs (Clymo, 1984), but a low figure is to be expected for the relatively thick acrotelm of a water track. The dynamics of peat accumulation at Stephill Bottom contrast with Cranes Moor. The mean accumulation rate for *Sphagnum* Bog (CMI) is approximately four times greater than the figure for Stephill Bottom, yet is sustained by a mire surface productivity which is only a half to a quarter that found at Stephill Bottom (compare the measurements in Newbould, 1960 and Giles, 1977 with those given by Putman *et al*, 1982 for Stephill Bottom). This illustrates the importance to the rate of peat accumulation in the catotelm of the production-decomposition ratio within the acrotelm (Clymo, 1984). The fact that zones 4 and 5 are located within the present acrotelm of the mire also

explains the decline in degraded material during these two zones.

The thick acrotelm has other implications for the interpretation of mire development at Stephill Bottom. At any depth, the macrofossil assemblage reflects the plant material which survived into the catotelm, having undergone decomposition during its passage through the acrotelm - but the true surface of the mire would have been defined by the thickness of the acrotelm at that time. Since the macrofossils in SBI indicate similar hydrologic conditions throughout its development, it is not unreasonable to assume that the acrotelm thickness (c45cm) has also remained relatively constant (see Clymo, 1984). Thus, for a given sample depth - say 55cm - the actual height of the mire surface at that time (c600 BP) would have been, in this case, only 10cm or thereabouts below the surface of the mire today.

The representation of vegetation remains in the macrofossil assemblage is also affected by the morphology of the water track. Firstly, the tussocky structure of the vegetation creates a coarse-scale mosaic in the local mire vegetation sampled by the core. This contrasts with more homogeneous community in a *Sphagnum* lawn, say. Consequently, the macrofossil assemblage is strongly influenced by this spatial heterogeneity and by the location of the core. This can be seen in the upper zones of SBI, whose composition is heavily biased by the sample location within a low *Sphagnum* hummock. This effect is most pronounced in the acrotelm since it lacks the spatial and temporal smoothing found within the catotelm. Secondly, the thick oxygenated acrotelm heavily favours the preservation of below-ground material - this also accounts for the high proportion of *Sphagnum* in the above-ground remains that have survived to become preserved in the catotelm (Clymo, 1965).

The main conclusions concerning mire development at Stephill Bottom may be summarised as follows, based on the core SBI and the stratigraphy and macrofossil content of the sediments below the peat. A significant general point to come from these results is that it is important to differentiate between mire development as a plant community responding to certain soil conditions, and mire development as a peat-accumulating

system governed by production and decomposition processes. The macrofossils within the sediment unit beneath the peat, between 220 and 240cm, show that mire communities (and heathland) had developed some time before 3100 BP. Although colluvial inputs were important, the sedimentary environment of this unit is not entirely clear and alluvial accretion may also have been significant. This may explain the range of macrofossils present in the unit since they appear to be derived from three vegetation types: (i) *Alnus* carr/riverine woodland growing in the valley-bottom at Stephill Bottom; (ii) *Carex echinata, Potamogeton polygonifolius* and, perhaps, *Erica tetralix* from unshaded mire communities; (iii) *Calluna* and *Erica tetralix* from heathland communities. The age of this unit is unknown but with more than a metre of overlying sediments before the radiocarbon sample at 93 - 97cm, a date nearer 4000 BP than 3000 BP is more likely as a minimum estimate, even allowing for high sediment deposition rates. A maximum age for these deposits can be inferred from the expansion of *Alnus* in the New Forest which, although diachronous, dates from about 7000 to 5000 BP (see section 5.2). The macrofossils in this sedimentary unit are evidence for the presence of waterlogged conditions in the valley-bottom before the disappearance of *Alnus*, which is counter to the hypothesis of mire development following forest clearance as was discussed earlier. The disappearance of *Alnus* is problematic: it is tempting to conclude that this is attributable to clearance by man, given the activity in this area during the Bronze Age. However, it may also be significant that there are no signs of subsequent re-colonisation throughout the peat column, nor is there today. Possibly conditions are unfavourable for the establishment of *Alnus* since the decline in mineral deposition and the development of the water track.

After these deposits, the next available macrofossils, in zone 1, also indicate flushed and wet conditions to be prevalent in the valley - even before peat accumulation proper began. The subsequent macrofossil assemblages reflect changes in microhabitat but also reflect the overall vegetation type present in this part of the mire. The species composition of these assemblages comprises a large proportion of those species in the present-day vegetation and the peat is largely composed of the contemporary dominants, *Molinia, Carex echinata* and *Sphagnum auriculatum*. Other

species frequent in both the peat column and the present vegetation are *Hypericum elodes*, *Potamogeton polygonifolius* and *Juncus acutiflorus*-type.

Two important conclusions can be drawn from these results. First, the macrofossils indicate that conditions (i.e. the soil and hydrological environment) have remained very similar for much of the latter part of the Flandrian, possibly pre-dating peat inception by some time. Second, the present vegetation at the site has persisted in a similar form for the last 3000 years. This site emphasises the significance of the functional division of mires into the acrotelm and catotelm, and the importance of distinguishing between mires as plant communities and as peat-accumulating systems. In sum, Stephill Bottom provides evidence for very little change over the last 3000 years.

5.4.8 Summary

1. Macrofossils incorporated with inorganic sediments show that mire communities, and possibly heathland, had developed before the beginning of peat inception at 3100 BP.
2. Early phases of peat inception are associated with declining inorganic inputs. At the same time, there is evidence of agricultural activity in the catchment and charcoal was found in the lowest organic deposits.
3. Macrofossils indicate wet and slightly flushed conditions from the very beginning of peat formation, when a thick (c50cm) acrotelm may have already been present. Peat accumulation rates are very low.
4. The macrofossil assemblages are heavily influenced by spatial heterogeneity of the vegetation and differential preservation, which are both related to the thick acrotelm of the water track.
5. Similar vegetation and hydrologic conditions appear to have persisted at this site for at least 3000 years.

5.5 HIVE GARN BOTTOM MIRE COMPLEX

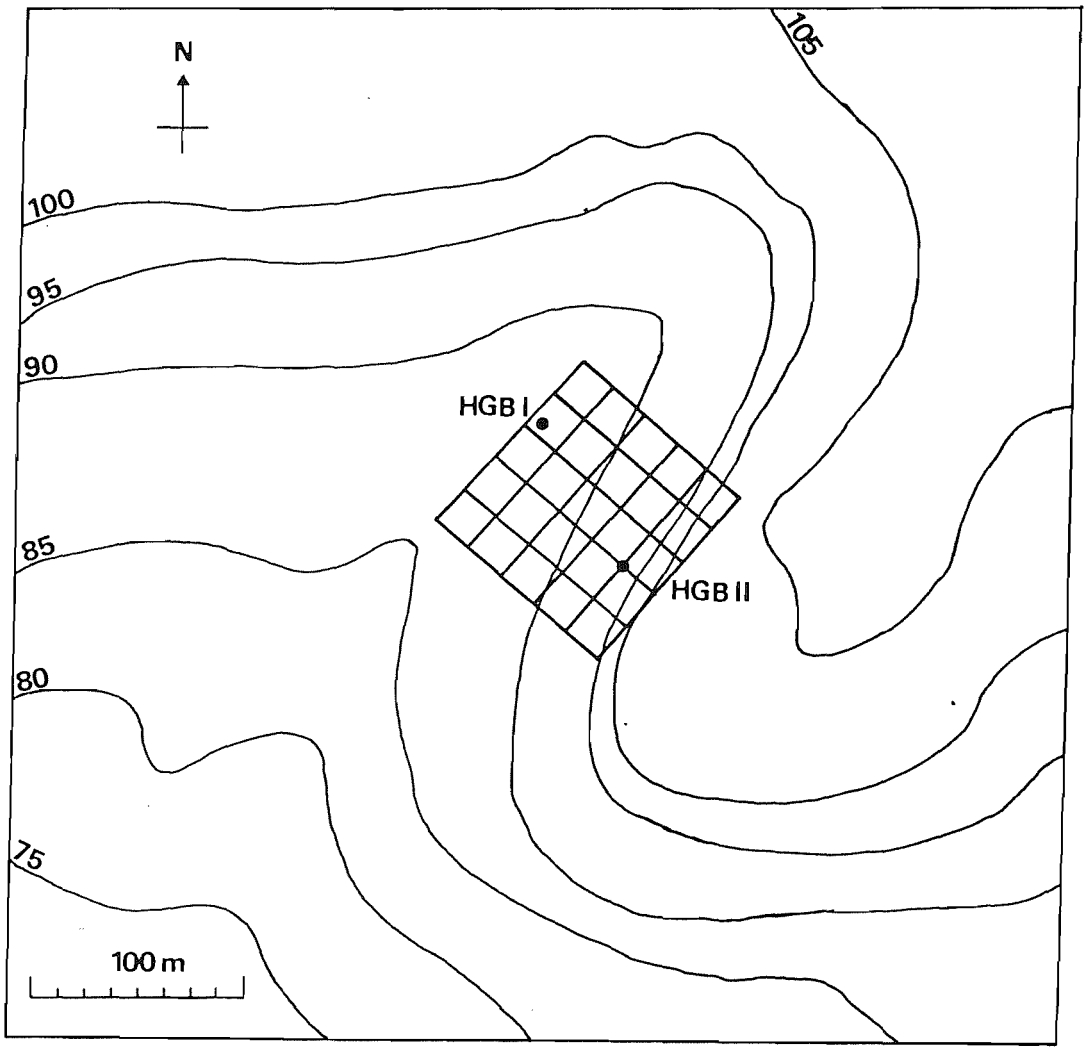
5.5.1 Introduction

The small valley-bottom and seepage step mire complex of Hive Garn Bottom occurs within a steep-sided valley cut into the 105m OD high-level terrace in the north-west of the Forest. Aspects of soil development and vegetation are discussed elsewhere (see section 1) and the relationships between soils and vegetation have been described by Clarke and Allen (1986). The lithology of this site is complex and there are extensive drift deposits of variable thickness. A flushed zone of seepage occurs between slowly permeable clay strata of the Bracklesham Beds and upper, sandy facies of the Bracklesham Beds overlain by variable Plateau Gravels (see Figure 3.4). This has resulted in a zone of wet heath and mire vegetation on the valley-side fringing the edge of the plateau. In the bottom of the valley, where water collects, mire development has also occurred and the two systems coalesce at the head of the valley.

The vegetation of both mires is dominated by *Molinia*, *Narthecium*, *Erica tetralix*, *Eriophorum angustifolium* and *Sphagna*, with frequent *Juncus bulbosus*, *Rhynchospora alba*, *Drosera rotundifolia*, *Carex echinata* and liverworts, especially *Odontoschisma sphagni* and *Lepiodozia setacea*. In the valley bottom *Sphagnum papillosum*, *S.auriculatum* and *Juncus acutiflorus* are more common, while *Trichophorum cespitosum* is virtually restricted to the seepage step (and wet heath) with more abundant *S.tenellum* and *Calluna*. Much of the surrounding area is dominated by mainly humid heath, on the plateau and valley-sides, with smaller areas of *Pteridium* and acid grassland with some *Ulex europaeus*. In the lower part of Hive Garn Bottom there is an area of unenclosed woodland, comprising mainly *Quercus*, *Fagus* and *Ilex* with some self-sown *Pinus*.

The area is grazed by ponies and deer and a number of pony paths cross Hive Garn Bottom, following the valley, for access onto the plateau top. Past human activity includes a Roman pottery industry with kilns discovered at Ashley Rails on the edge of Pitts Wood Inclusure, some 120m to the south of Hive Garn Bottom (Sumner, 1927; Mulford, 1975).

Hive Garn Bottom Study Plot



Contours in m OD

FIGURE 5.15 : Map showing location of HGBI and II.

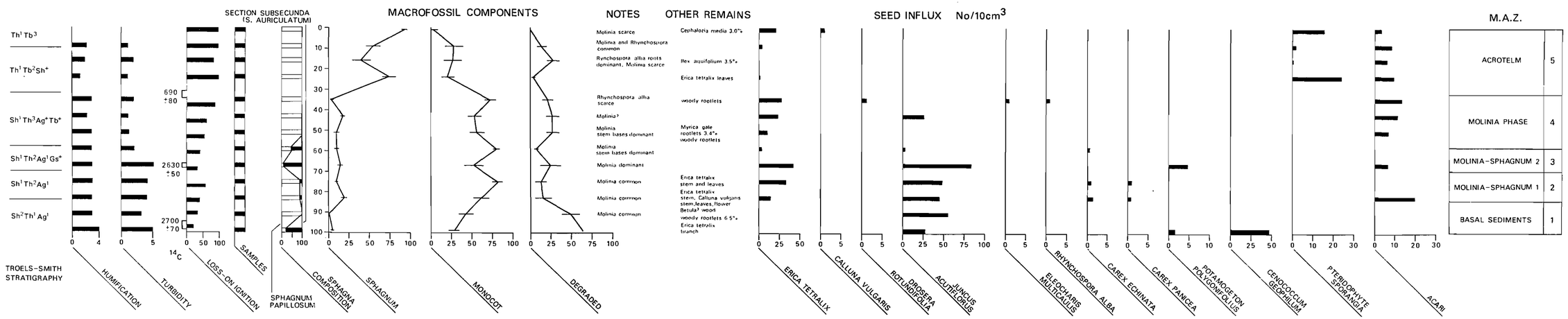


Fig 5.16 Macrofossil Diagram from Hive Garn Bottom (HGBI)

The ecology of this area has been studied less intensively than some other parts of the Forest and until this project little palaeoecological information was available. During 1984-85, the peat cores from Hive Garn Bottom were also used for pollen analysis by K.Willis (1985) in addition to her brief study of modern pollen deposition in the valley.

5.5.2 Valley Bottom Core (HGBI)

5.5.2.1 Sampling

The core was located in the deepest part of the mire (Figure 5.15) and the lower section (100 - 34cm) was obtained using a Russian borer. The upper peat in the acrotelm was poorly consolidated and a surface sample (25 - 0cm) was taken using the same method as in SBI. The stony sediment below the peat prevented coring to a greater depth, but it was subsequently possible to sample from approximately 118cm for analysis by K.Willis. The surface vegetation, in a $1m^2$ quadrat centred on the core, comprised *Molinia* 40%, *Narthecium* 30%, *Rhynchospora alba* 20%, *Erica tetralix* 10%, *Drosera rotundifolia* 5%, *Sphagnum papillosum* 45%. Again, for ease of sampling the core was located in a *Sphagnum* hummock. Three radiocarbon samples were dated (Appendix 2).

The following macrofossil zones were identified (Figure 5.16):

Macrofossil zone 1 : Basal sediments : 100 - 84cm
Macrofossil zone 2 : *Molinia* - *Sphagnum* phase 1 : 84 - 70cm
Macrofossil zone 3 : *Molinia* - *Sphagnum* phase 2 : 70 - 58cm
Macrofossil zone 4 : *Molinia* phase : 58 - 32cm
Macrofossil zone 5 : Acrotelm : 32 - 0cm

The differences between these zones are, however, relatively slight and all the assemblages indicate a community similar to that present today. This core shows that this mire community has persisted from the earliest preserved remains with only relatively minor changes in composition.

5.5.2.2 Macrofossil zone 1 : Basal sediments : 100 - 84cm

The basal sediments were mainly inorganic and contained macrofossils in a poor state of preservation. Nevertheless, the assemblage show that mire

vegetation was already established at the site, with *Sphagnum* section *Subsecunda*, *S.papillosum*, *Potamogeton polygonifolius* and *Juncus acutiflorus*-type. A branch of *Erica tetralix* was also found at 98 - 100cm. Most of the recognisable remains were monocot rootlets, including *Molinia* which was identified at 92 - 94cm. Fruiting bodies of *Cenococcum geophilum* were also encountered in the lowest sample (van Geel, 1978 also found this species in subsoil deposits as well as dry mire surfaces).

A radiocarbon date of 2700 ± 70 BP was obtained from this zone (95 - 98.5cm), and a date of 2630 ± 50 BP for a sample some 30cm higher in the core (66 - 68cm). These dates are surprisingly similar in view of their separation by depth, although they may differ by 300 years or so if an estimate based on two standard deviations is used. Two explanations are possible for the closeness of these dates (discounting a third possibility, that the age of the 66 - 68cm sample had been overestimated, which is least likely). Firstly, there may have been a high rate of sediment accumulation during this period due to the continuing inorganic deposition and possibly linked to the clearance activity indicated by the pollen data within the catchment (Willis, 1985). Secondly, the lower radiocarbon sample may have been contaminated by the penetration of younger rootlet material.

Certainly, the total sediment accumulation rate is relatively very high (30cm in less than 300yr), but the average organic content of this sediment unit is only about 35%. Thus, the organic accumulation rate is about 35cm/1000yr (28yr/cm), which although high is the same order of magnitude as the age-depth ratios of other sites investigated. However, the accumulation rate for the organic component in the rest of the catotelm in HGBI is low compared to other sites, at 9.8cm/1000yr (101yr/cm). This suggests that the lowest date is an underestimate, by as much as 1000yr. Rootlet contamination is more likely in HGBI than SBI, because of the less consolidated sediment matrix at Hive Garn Bottom compared to the compacted basal silts of the latter. Rootlet penetration in HGBI would have probably occurred from *Molinia* growing in zones 2 and 3, i.e. about 2600yr old, and perhaps also from ericaceous rootlets.

5.5.2.3 Macrofossil zone 2 : *Molinia* - *Sphagnum* phase 1 : 84 - 70cm

A slight stratigraphic change occurs at this zone with lower inorganic content and less degraded material. This is coupled with a more diverse macrofossil assemblage, which indicates the vegetation was dominated by *Molinia, Sphagnum papillosum, Erica tetralix* and *Calluna.* Zone 2 is also marked by the appearance of *Carex echinata* and *C.panicea,* both virtually restricted to this zone, and also mites which were not found in the less organic deposits.

5.5.2.4 Macrofossil zone 3 : *Molinia* - *Sphagnum* phase 2 : 70 - 58cm

The organic content of the peat drops markedly between 76 and 70cm and at the same time, the amount of degraded material increases. Although *Molinia* remains as the dominant, the macrofossil assemblage also changes. *Calluna, Erica tetralix* and *Carex panicea* all disappear, and the *Sphagnum* flora is once again dominated by section *Subsecunda.* Another similarity with zone 1 is the presence of *Potamogeton.* These changes were dated to around 2600 BP, but their cause is not apparent. There are no appreciable changes in the amount or type of tree pollen in Willis' pollen diagram but macrofossil zones 2 and 3 combined only include 3 samples in her diagram. Closer counting below 85cm revealed a very variable pollen assemblage over a short depth, with greatly fluctuating tree pollen, and this may have been missed further up the core due to coarser sampling. It is therefore not possible to reject the possibility of anthropogenic factors at play, nor is there any evidence for any other environmental change.

5.5.2.5 Macrofossil zone 4 : *Molinia* phase : 58 - 32cm

The upper part of the catotelm continues to be dominated by *Molinia* remains. Organic content rises from the low levels in zone 3 but the macrofossil assemblage is less diverse than zone 2, suggesting a more closed *Molinia* tussock canopy. The beginning of zone 4 coincides with total dominance of *Sphagnum papillosum* in the moss flora which continues to the surface. The top of this zone (32 - 34cm) has been dated to 690 $\pm$ 80 BP and from interpolation the beginning of zone 4 is about

2000 BP, so that this zone spans much of the period of peat formation at Hive Garn Bottom.

5.5.2.6 Macrofossil zone 5 : Acrotelm : 32 - 0cm

Like the core from Stephill Bottom, the uppermost peat layers in HGBI contain a macrofossil assemblage which is strongly biased by sample location. This is dominated by *Sphagnum papillosum* with identifiable monocot remains comprising both *Molinia* and *Rhynchospora alba* in approximately equal proportions. The remains of other species are, however, still very sparse. *Narthecium* was not identified but a significant proportion of the monocot rootlet material must be derived from this species in view of its abundance in the present vegetation on the site. The beginning of this zone dates from about 1300 AD and a sudden increase in *Pinus* pollen (1800 AD) occurs at 20cm (Willis, 1985). A gradual transition occurs between zones 4 and 5, so that the residence time of remains within the acrotelm at Hive Garn Bottom is some 600 - 700yr. It can be calculated from the age-depth ratio that some 90% of the peat mass is lost in the first 150yr.

A sudden appearance of Pteridophyte sporangia in this zone coincides with a peak of *Pteridium* spores in the pollen assemblage (Willis, 1985) and the spread of local vegetation is also shown by the *Ilex* leaf found at 15 - 17cm which can be correlated with the increase in *Ilex* pollen at 20cm. Today, both *Ilex* and *Pteridium* are found less than 10m from the site of the core.

5.5.3 Seepage step core (HGBII)

5.5.3.1 Sampling

This core was located at a point on the seepage step (Figure 5.15) where the maximum thickness of peat could be obtained for analysis, since the peats on the valley-side are thin and discontinuous. The sample was obtained using a Russian borer and it was possible to continue the core into the inorganic samples below to a depth of 63cm. The surface vegetation in a $1m^2$ quadrat centres on the core comprised *Molinia* 50%, *Eriophorum*

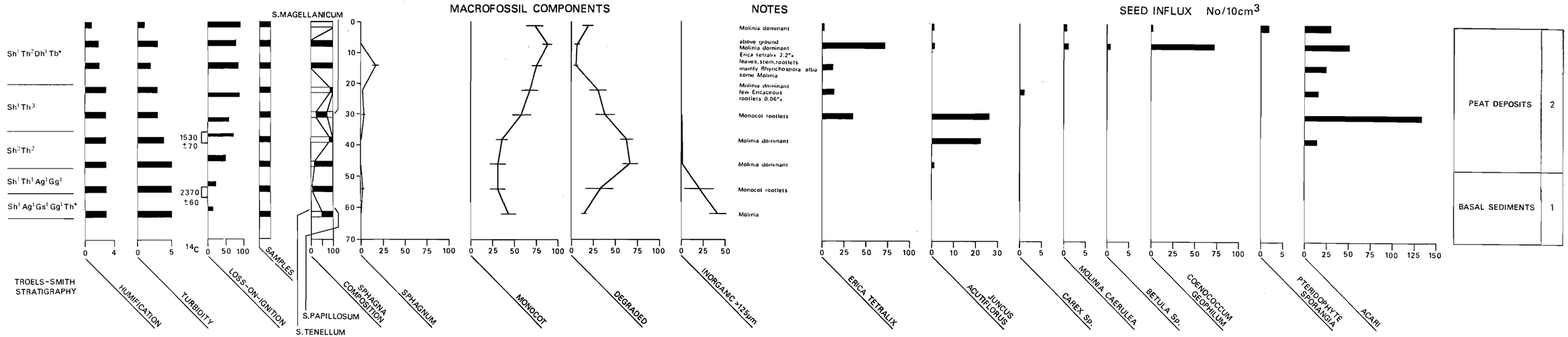


Fig 5.17 Macrofossil Diagram from Hive Garn Bottom (HGBII)

anustifolium 20%, *Narthecium ossifragum* 20%, *Erica tetralix* 5%, *Drosera rotundifolia* 5%, *Juncus acutiflorus* 5%, *Sphagnum cuspidatum* 10%, *S.papillosum* 5% and *Odontoshisma sphagni* 5%. Two radiocarbon samples were dated (Appendix 2).

Although the core encompasses some 2000 years of sediment accumulation, no significant changes in the macrofossil assemblage could be discerned on which to justify splitting the peat column into different zones (see Figure 5.17). The main change in the peat deposits is an increase in decomposition with depth - probably reflecting the impermanence of the water table in some summers. The two zones that have been identified correspond to division of the core into mainly inorganic and organic deposits, respectively. This core is of particular significance in that it is the first time that the development of a seepage step mire has been studied.

5.5.3.2 Macrofossil zone 1 : Basal sediments : 63 - 47cm

This zone was the least organic unit in all the cores examined in the study, with the bottom samples being about 90% inorganic sediment. Nevertheless, identifiable remains of *Molinia*, *Sphagnum papillosum* and *S.tenellum* were found at the very base of the core, showing that mire vegetation was established at the site during a period of much higher sedimentary erosion and deposition. Heathland also appears to have been well developed in the surrounding area with similar abundance levels of Ericaceae pollen (c20% non-arboreal pollen) to recent samples (Willis, 1985). A radiocarbon date of 2370 $\pm$ 60 BP was obtained for a sample from 53 - 56cm. If the age-depth ratio between this date and the one obtained from 36 - 39cm (20.2cm/1000yr, or 49.4yr/cm) is extrapolated to the base of the core, then an estimated age of 2740 BP is obtained for 63cm. This suggests a close correlation between HGBI and HGBII for this phase of sediment deposition and peat inception.

5.5.3.3 Macrofossil zone 2 : Peat deposits : 47 - 0cm

Sub-division of this zone would have been based on relatively minor features and it was also not possible to distinguish a catotelm-acrotelm structure

to the peat mass. Not unexpectedly, there is a gradual decrease towards the surface in the age-depth ratio and the amount of degraded material, both reflecting the cumulative effects of decomposition with depth. A sample from 36 - 39cm was dated to 1530 ± 70 and Willis (1985) found a sudden increase in *Pinus* pollen (1800 AD) between 24 and 20cm. The age-depth ratio between these two dated horizons is approximately 13cm/1000yr (79yr/cm), suggesting that the "accumulation" rate in the lower part of zone 2 has declined since zone 1. However, if both sections of the core are corrected for their organic content, then the net accumulation of organic material appears relatively constant, at 9.5-10cm/1000 yr. Interestingly, the decline in sediment deposition appears to have occurred in both cores around the same time, with loss-on-ignition rising above 50% in HGBI at about 1400 BP and HGBII 1700BP - a scarcely significant difference given the errors of estimation involved.

The assemblage continues to be dominated by *Molinia* with little *Sphagnum* except at 13 - 15cm. Generally the *Sphagnum* remains were poorly preserved with a preponderence of stem fragments over leaves. Thus, the composition of the *Sphagnum* assemblage may not be very meaningful in terms of the proportions of individual species. *Sphagnum tenellum* and *S.papillosum* are both frequent on the seepage step mire today and the record of *S.magellanicum* is notable as the only macrofossil record of this species encountered in the study. Mites and seeds of *Juncus acutiflorus*-type and *Erica tetralix* appear with better preservation, and vegetative remains of *Erica* occur from 23cm upwards. The increase in *Sphagnum papillosum* at 13-15cm coincides with abundant *Rhynchospora alba* remains, but this is the only indication of any major change in the *Molinia*-dominated community throughout peat development. This *Sphagnum-Rhynchospora* phase is short-lived, with abundant stem remains of *Molinia* at 8 - 10cm. Seeds of *Molinia* were found in the upper two samples. Preservation of *Molinia* reproductive remains appears to be poor and seeds were only found in sites where this species was very abundant (cf Stephill Bottom).

Like HGBI, the surface sample of this core contained small quantities of liverworts (5%), comprising *Odontoschisma sphagni*, *Cephalozia media* and *Lepidozia sedacea*. Traces of *Hypnum* (probably *jutlandicum*)were also found.

5.5.4 Discussion

There is evidence of mire communities at the limits of sampling in both cores, showing mire vegetation to have been present before the onset of peat formation within the catchment. Both cores also show a marked persistence, since at least 2600 BP, of vegetation types broadly similar to those present today with little significant change during the accumulation of the peat deposits. The small-scale changes in the composition of the macrofossil assemblage may be more apparent than real, due to the limitations inherent to the macrofossil technique.

There is evidence, too, of heathland communities in the earliest samples, as indicated by pollen and macrofossil remains. A significant feature of the pollen diagrams obtained by Willis (1985) is that the abundance of heather pollen in the basal samples (i.e. 2600 + BP) of both cores is similar to its frequency in the upper, more recent levels. This is particularly marked on the seepage step, where the lowest pollen assemblages suggest that the representation of heathland and woodland on the valley-side and plateau top was comparable to that today. A major decline in *Alnus glutinosa* pollen is noticeable in the cores from both mires (Willis, 1985), occurring between the radiocarbon dates of 1530 and 690 BP. *Alnus* is known to have a long history of exploitation in this part of the Forest, with charcoal recorded from the Roman pottery kilns at Ashley Rails (Sumner, 1927). However, there is no evidence for this species ever having been present on the mire (this species was not encountered in 41 other cores examined in the field), although it may have occurred downstream of the mire where peat gives way to a mineral soil. Alternatively, there could have been a change in management practice in nearby stands (such as coppicing) which altered pollen production. This is a possibility since the seepage step data suggest that the assemblages reflect more regional pollen rain, rather than that confined to the valley (Willis, 1985).

A decline in inorganic sedimentation occurs in both cores between about 2500 and 1500 BP, although inorganic sediments are present in lesser quantities in more recent horizons, especially in the valley bottom. Sedimentation is probably continuing in the present day but inorganics

are "diluted" in the largely undecayed plant remains of the acrotelm. Erosion of the seepage step occurred at the head of the valley in the wet winter of 1981/1982 but subsequently has been stabilised by *Pteridium*. Before 2500 BP, rates of inorganic deposition were much greater and the presence of pollen in the sediments at 118cm suggests that these higher rates of sedimentation continue back earlier into the Flandrian. Thus, seepage step erosion and valley deposition has probably been more active during the Flandrian than has previously been thought (Tuckfield, 1973).

5.6 Field stratigraphy from other sites investigated

5.6.1 Methods

A number of sites were examined in the field in conjunction with the NCC England Field Unit Survey of September 1981. The aims were to examine the relationships between the present vegetation and peat stratigraphy, and to obtain additional baseline data for sites not previously investigated by workers at the Palaeoecology Laboratory of the Geography Department, Southampton University. Moss polster samples were also taken for study of modern pollen representation. Unfortunately, it was not possible to take cores from all the England Field Unit quadrats in the time available. The following sites visited by the England Field Unit have been discussed earlier in this and preceding chapters: Stephill Bottom (part of the Denny/Shatterford system), Cranes Moor and Church Moor (see additional references therein for these sites), as well as Barrow Moor (see also Dawson, 1978; Arnold, 1980), Gritnam Bog (see also Puzey 1982), Hincheslea Bog, Matley Bog and Warwickslade Bog. Barber (1981a) discusses several of these sites and The Noads has been investigated by Dobson (1975) and Rakes Brakes Bottom by Marshall (1980). This section will deal mainly with the Longwater Lawn mire group and two sites from the Avon Water basin, and briefly with Cadnam Bog and Digden Bottom.

Field stratigraphy of valley mires is limited in two ways. First, it is not possible to excavate (or exploit) open sections for study. Second, most peat deposits are not formed primarily by *Sphagna* and other mosses so that many of the subtle and important changes in colour and texture related to environmental factors, are not available. The stratigraphy is made complex by the rooting patterns of the main peat-forming species.

This necessarily limits the interpretation of field stratigraphic data alone and highlights the need for laboratory studies to integrate macro-fossil remains over depth.

5.6.2 Results

The results for each core and site maps are shown in Appendix 6 for clarity. Stratigraphy is described using the Troels-Smith (1955) system for unconsolidated sediments (see Chapter 1) and is supplemented with brief notes. For ease of comparison, the stratigraphy and the EFU quadrat data is set out in tabular form for each core (vegetation abundance is given on the Domin scale).

(i) Longwater Lawn series: This is one of the most outstanding groups of mires in the New Forest, in terms of both structure and diversity, comprising Fort Bog, White Moor and Row Hill Bog. The centre of each long, thin mire system is dominated by "domed", axial carr woodland. In all cases the maximum peat depth is no more than a metre or so. The stratigraphy shows wood to be present throughout the peat column in the alder carrs. This is not solely due to a rooting effect since positively identified above-ground material was found half-way down at 35cm in Row Hill Bog. However, almost all cores contained *Phragmites* rhizomes although this species was not present in the surface vegetation. This cannot be explained by simple, sequential *Phragmites* - alder carr developmental phases. Firstly, in several cases *Phragmites* rhizomes occur close to the surface (to within 6cm in quadrat 140 at White Moor), indicating that this species has occurred relatively recently in the vegetation. Secondly, rhizomes were found in the middle of the peat column at Row Hill Bog (quadrat 127) with wood remains (including twigs) at the same depth, above and below. Thirdly, *Phragmites* was not always present in the alder carr peat. The evidence suggests that the carrs may have originated directly from the mineral sediments at the earliest stages of peat formation. This is not entirely unexpected since the alder carr at Matley Bog is growing on a mineral soil with little organic accumulation, and in nearby Stephill Bottom *Alnus* remains predate the peat deposits (before 3080 BP) and were growing *in situ* on inorganic sediments. The conclusion, therefore, is that the Longwater Lawn carr woodlands have been sufficiently open in the past (including perhaps the

recent past) to allow *Phragmites* growth. This may be related to more open canopies during early developmental phases, and also to coppicing and other forms of exploitation by man.

The sub-fossil assemblages at the carr margins and in open areas of the mires are very similar to the main peat contributors/dominants of the present vegetation. Overall, this suggests marked habitat and community stability.

(ii) Avon Water mires - Holmsley Bog: The carr at this site, now bisected by the railway embankment, exhibits a similar stratigraphy to those of group (i). Interestingly, *Phragmites* rhizomes were also restricted to a middle horizon (20 - 50cm) with wood throughout core 72. *Phragmites* was not recorded at the surface of the quadrat (no.72). The cores in the open mire along the main valley axis contained traces of wood (thought to be *Betula* and *Alnus*) in the lower peat horizons, indicating a more extensive distribution of scrub and scattered woodland in the past near the stream. Active willow thicket regeneration is currently taking place further upstream following clearance associated with past drainage activities.

- Wilverley Bog (including Avon Water East): Subfossil wood was found throughout both cores taken in the carr with *Phragmites* additionally present in the lower horizons (20 - 75cm) of one of them. Preservation of remains was poor in the cores taken east of Wooton Bridge, but otherwise the open mire peat assemblages showed little change to the surface vegetation.

(iii) Other sites - Cadnam Bog: This site was interesting in that the core within the carr showed about 1m of peat to be overlain by an inorganic layer with additional thin inorganic seams within the lower peat. The core was taken close to the confluence of two tributaries of the stream and this may account for these deposits. The remains indicate the probable persistence of a carr community throughout peat development. Little significant stratigraphic change was found in the core taken in the open mire.

- Digden Bottom/Linwood Bog: Only one shallow core was taken from this site and was dominated by fine monocot rootlets. Seagrief's (1955) core

in a deeper area of peat, to 145cm, also suggests no gross change in the mire vegetation, being dominated by rootlet peat with *Sphagnum* and some sparse wood remains. This pattern is repeated elsewhere in the mire (Davies, 1972). Seagrief placed the origin of this mire to the zone V1/V11 transition, based on the rise of *Alnus* pollen, which approximates to a period between about 5000 and 7500 BP (see earlier).

5.6.3 Discussion

Field stratigraphy has much less resolution than a laboratory-based analysis but is much quicker. Because of this only three vegetation types were recognised; carr woodland, communities growing adjacent to the carrs and open, unshaded areas of less tall vegetation. Figure 5.18 shows the percentage of cores in which the stratigraphy indicated changes in the vegetation during development, compared to the surface community. Similar proportions are obtained if the results from macrofossil analysis are also included. This graph suggests that the areas of carr woodland are the most likely to have undergone vegetation change and therefore could be regarded as the least stable vegetation type. However, the main reason for this is the presence of *Phragmites* in the peat but not the surface vegetation. As was discussed above, this may reflect a response to habitat disturbance rather than internally-driven vegetation change. There is no discernible trend in the vegetation changes occurring at the carr margins. Rather, the stratigraphy indicates apparently random fluctuations in the carr boundaries, in much the same way as the core from Church Moor. Little change was detectable in the cores from open mire communities using field stratigraphy alone - only two cores from Holmsley Bog (both containing wood) showed any major differences to the surface vegetation.

Conclusions drawn from these field-based cores must be qualified since interpretation is limited by methods of identification and abundance assessment. There is also a danger of over-emphasising identifiable remains (e.g. woody parts, *Phragmites* rhizomes), and these are best regarded as indicators of environment and vegetation type. Nevertheless, these results support a general conclusion from the macrofossil cores that there has been pronounced stability, or persistence, of mire vegetation types throughout their development during the Flandrian (see next section).

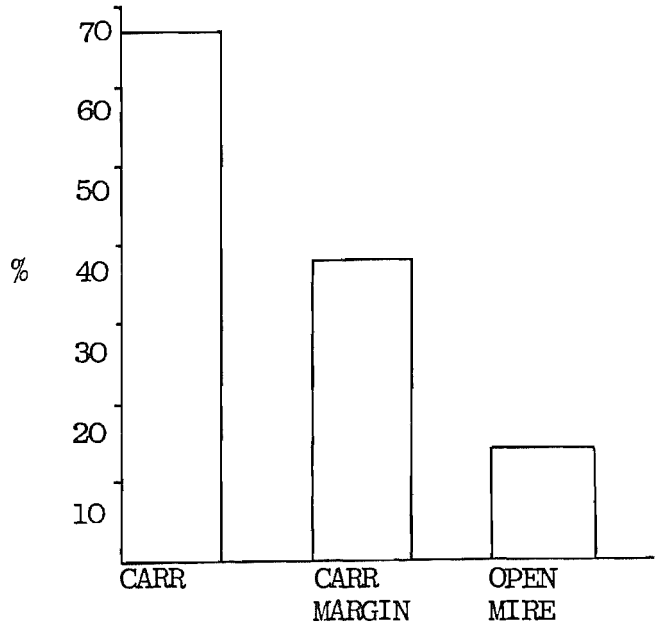


FIGURE 5.18 Proportion of cores showing vegetation change, as detected by field stratigraphy, during the development of three mire vegetation types

5.7 Discussion

Site-related details of mire development have been discussed under individual site headings. This section will deal briefly with the evidence for climatic change during the Lateglacial and early Flandrian, and will then consider the more general results of valley mire succession in the New Forest. Finally, the results from this study will be used to consider the methods used in palaeoecology and their application.

5.7.1 Climatic change in the Late Devensian Lateglacial and early Flandrian

The evidence for climatic change in the New Forest comes from Church Moor and Cranes Moor. The hydrology of valley mires makes it very difficult to interpret peat stratigraphy of most sites in climatic terms. This is mainly due to the complex of factors affecting recharge in the valley mire water budget (see Chapter 3). It is significant that the climatic changes detected at Church Moor (which has typical valley mire hydrology) reflect gross macro-climatic change, while conditions on Cranes Moor approach an ombrotrophic state in which recharge is related directly to precipitation. The following is a synthesis of the main events indicated by the peat assemblages of these two sites.

12440 ± 60 BP	Beginning of deterioration in climate becoming colder and markedly drier in the Loch Lomond Stadial. However, the environment does not appear comparable with the high arctic, possible due to a more fluctuating thermal regime. The apparent paradox of dry conditions but increased erosion may be explained by high peak discharges from spring snow-melt.
c10000 - 8260 BP	Decomposition processes are favoured at Church Moor, indicating continuing, possible seasonal, dry conditions. Relatively unhumified *Sphagnum subnitens* peat at Cranes Moor but sufficiently dry to allow growth of *Calluna*. Later a fluctuating water regime is indicated by *Sphagnum tenellum* and *Molinia* (c9000 BP). Scaife (1980) reports a relatively short-lived dry phase from the Isle of Wight during the first part of the Boreal chronozone.
8260 ± 50	The return of pollen preservation in Church Moor indicating wetter conditions. The "pool sequence" wet phase at Cranes Moor is independently estimated as beginning at c8250 BP.

5170 ± 50 BP	The macrofossil assemblage at Church Moor suggests increased wetness and acidification. This may be correlated with a wet phase shift at Cranes Moor between approximately 6100 and 5300 BP.

There is no further evidence from peat stratigraphy or species composition at Church Moor to indicate subsequent climatic change and, indeed, there has been a marked persistence in the vegetation; suggesting that valley mires are well buffered from the scale of climatic change that has occurred in the latter part of the Flandrian. At Cranes Moor conditions appear to become drier between c5300 BP and c4000 BP, when the peat column is truncated, but this transition cannot be interpreted climatically since it may be due to autogenic succession (Barber, 1981b). The difference in dates between the two sites for the last phase shown above may reflect the longer response time of a groundwater and catchment soil system at Church Moor compared to the *Sphagnum*-peat mire system at Cranes Moor.

5.7.2 Valley mire succession

Despite the comments of Watts (1978), there are still few links between ecological research of past and present communities, and this is seen no more clearly than in the study of succession. There is still no unified ecological theory of succession (McIntosh, 1981), which makes it particularly difficult to relate the findings of palaeoecology to the dynamics of contemporary succession. However, palaeoecology is particularly important to this field since it provides the only source of evidence for long-term ecological change and can be studied at a variety of spatial scales, as Watts (1973), Davis (1981) and others have pointed out.

In this respect, Walker's (1970) paper on the direction and rate in some British post-glacial hydroseres was a major advance. Not only does this remain some of the best evidence of succession over ecologically appropriate periods of time, against which theories can be tested, but it also anticipated recent numerical studies. However, most of these workers have neglected Walker's data as a test of their models (see Gittins, 1981, for an exception). Walker found that vegetation change in hydroseres could not be regarded as a deterministic process and variety was the keynote of succession, despite the importance of hydroseres in classical Climax Theory. Succession was neither orderly nor did it reflect the

vegetation zonation at any one time. Criticism of the holistic, classical view of succession during the 1970's largely ignored Walker's findings. Drury and Nisbet (1971, 1973), in particular, argued strongly for the individualistic approach to succession and pointed out the close relationship between Climax Theory and determinism in geomorphology. Their arguments were reinforced by the relevance of modern evolutionary thinking to succession (e.g. Pickett, 1976; van Hulst, 1978; Glenn-Lewin, 1980) which emphasised population processes. Nevertheless, the dichotomy continues with the holistic viewpoint exemplified by Odum (1975) and others who regard ecosystems as having emergent properties which are expressed in succession. One of the main reasons for this are differences in scale of investigation.

Walker analysed this data in the form of a transition matrix and concluded that only probablistic statements could be made concerning the direction of wetland succession. Although expressed differently, this closely paralleled the search for an individualistic or population-based model of succession. Attention has centred until recently on the development of Markov models to simulate vegetation change, using estimated probabilities of transition from one vegetation or species type to another (e.g. Horn, 1975; Waggoner and Stephens, 1970). Heathlands have been prominent in this approach (Gimingham *et al*, 1981; Usher, 1981; Lippe *et al*, 1985), perhaps because of their structural simplicity, whereas mires have largely been neglected despite their suitability as sources of data over large timescales (Aaviksoo *et al*, 1984). However, the concept of vegetation succession as a Markovian process is severely limited for three reasons. First, there are several mathematical constraints of Markov models which are biologically unrealistic (Usher, 1981), for example no immigration and constant transition probabilities through time. Second, an almost ubiquitous feature of permanent quadrat studies is the importance of spatial effects on the development of vegetation at any one point - this is also shown beautifully by a number of peat stratigraphic studies of pool and hummock development (Walker and Walker, 1961; Moore, 1977; Barber, 1981b).

The dependence of vegetation change on the spatial distribution of species is the greatest factor in restricting the usefulness of Markov models

(Austin and Belbin, 1981; Usher, 1981; Lippe *et al*, 1985). A third limitation has been called 'biological hysteresis' by van Hulst (1980), in that former vegetation states do affect future ones, for example by soil alteration such as podzolisation (see Miles, 1985).

Thus, there is still a great deal required before a rigorously- described model of succession can be applied to the study of mire development over ecologically appropriate timescales (10^1 to 10^3yr). This will need to emphasise the probabilistic nature of succession in which the climax is regarded as a steady-state community. Indeed, the main challenge for the study of succession is the explicit formulation of ideas so that they can be tested by experiment and modelling, and can be extended to the level of whole habitats or landscape units. There have been some developments towards obtaining models of succession more firmly based on biological realism, notably Botkin *et al*, (1972, and subsequent derivates) and van Tongeren and Prentice (1986). Nevertheless, these are concerned with fine-detail invasion of gaps and individual replacement, and it is difficult to relate these to the processes of larger spatial and temporal scales of vegetation change. The unification of succession theory over such differing scales still remains a problem (McIntosh, 1981). In addition, a general theoretical model of succession in mires will need to take into account the influence of vegetation on the mire environment (although this problem is not restricted solely to mires). Wildi (1978) has developed a model of mire development on slopes which attempts to do this and, although unwieldy, it has shown some qualitative success but has yet to be refined. Physical and biological considerations suggest that the steady state mire community is in equilibrium with the drought water level. Ingram (1983) has suggested that drought causes irreversible changes in the hydraulic properties of peat, while Clymo (Hayward and Clymo, 1982; Clymo, 1984) has stressed the importance of wetting and drying cycles to mire plants. Neither of these authors, however, have attempted to define quantitatively the degree of drought conditions thought to be critical. Empirical support for this view also comes from the correlation between vegetation type and climate (essentially net recharge) seen in the stratigraphy of some raised mires (see Barber, 1982 for a review). The more tractable hydrology of ombrotrophic mires continues to make this mire type the most fruitful for the development

of such models.

The transition matrix remains a useful descriptive tool as Walker (1970), Austin and Belbin (1981) and Gittins (1981) have shown, despite the limitations of the models which attempt to manipulate them. Table 5.7 shows the transitions observed in the cores described in this chapter during the Flandrian between six vegetation types identified in the stratigraphy. These are as follows:

SD *Sphagnum* dominated mire

MS *Molinia* - *Sphagnum* dominated mire

MD *Molinia* dominated mire

PF *Phragmites* 'poor fen' (with *Molinia*, *Myrica*, *Sphagnum*)

PC *Phragmites* - carr (*Alnus*, *Betula*, *Salix*)

CA Carr (*Alnus*, *Betula*, *Salix*)

TABLE 5.7 Transition matrix showing the number of transitions observed between six vegetation types (see text) in New Forest valley mire succession during the Flandrian. Direction of transition is from row to column.

TOTAL	SD	MS	MD	PF	PC	CA
SD	5	2				
MS	1	9	3			
MD		2	2	1		
PF		3		4	1	1
PC			1	2		4
CA		1			3	4

In addition to the macrofossil cores, 27 of the cores described in the field were suitable for analysis (out of a total of 34), so that the transition matrix is based on 29 cores, yielding a total of 49 observed transitions. The successional relationships are shown in the linkage diagram (Figure 5.19). About half of all the possible transitions were observed with the likelihood of rarer transitions being missed because of the relatively small sample size. This reflects the problem of obtaining enough data for transition matrices, since the number of

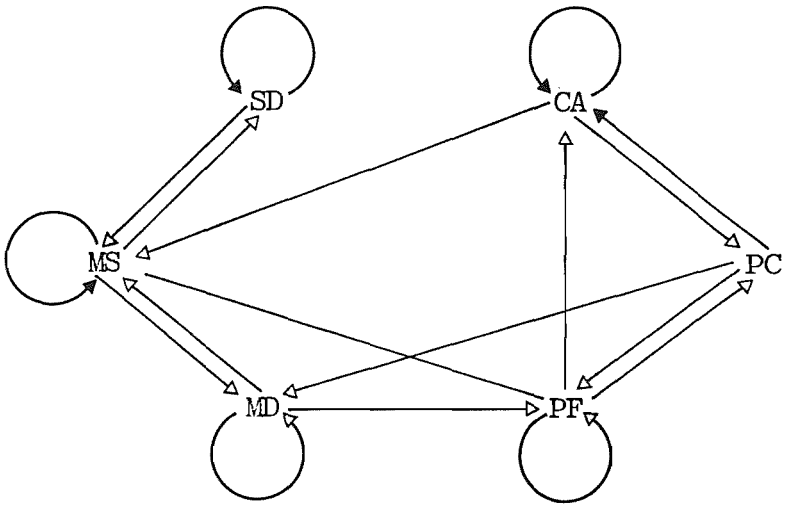


FIGURE 5.19 Linkage diagram showing major and minor pathways of succession from Table 5.9. Arrows denote direction and probability of transitions.

⟶ p > 0.5

⟶ p = 0.1 - 0.49

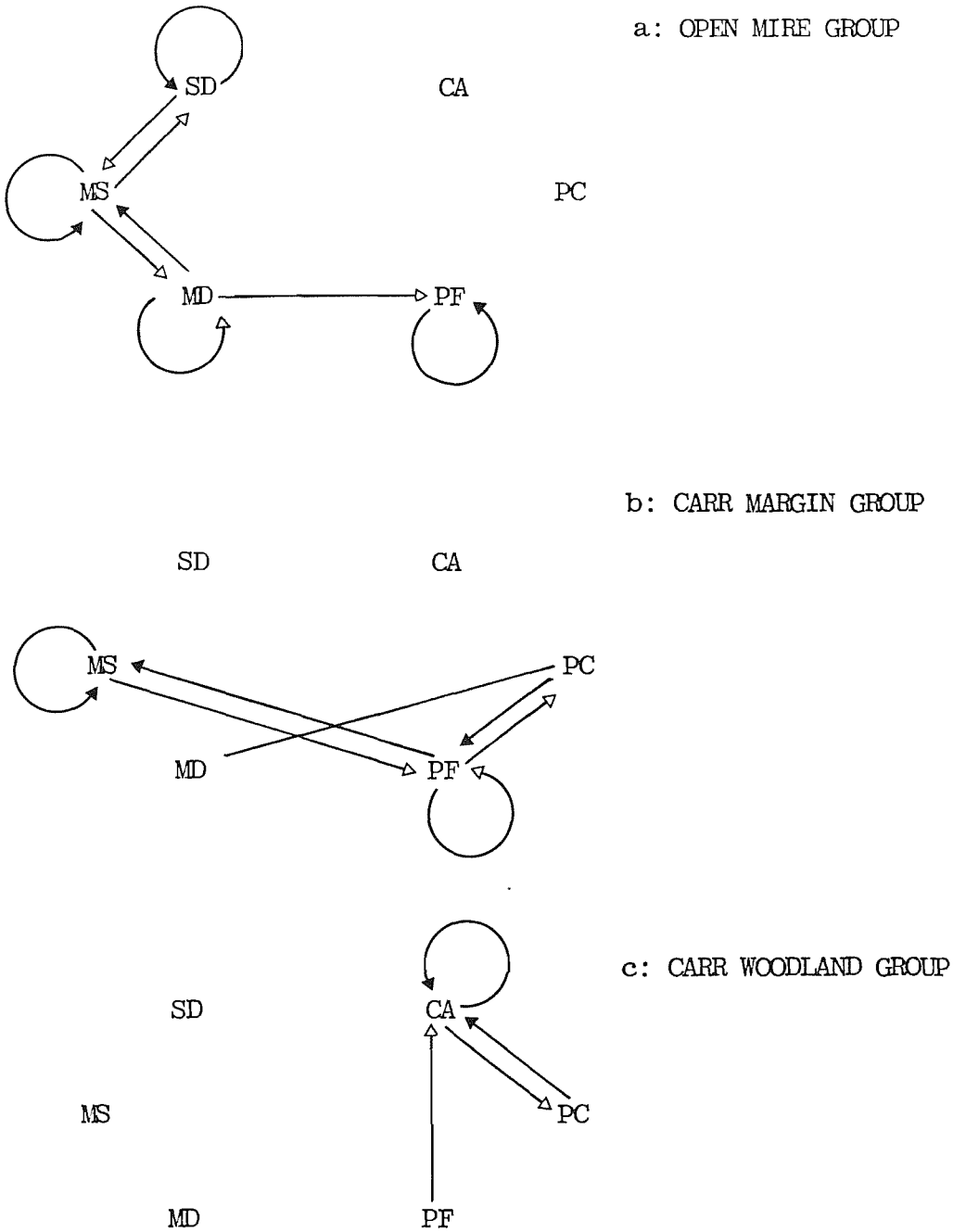


FIGURE 5.20 Linkage diagrams showing major and minor pathways of succession from three habitat groups (see Table 5.10a-c).

⟶ $p > 0.5$
⟶ $p = 0.1 - 0.49$

TABLE 5.8 a-c Transition matrices for subsets of the data in Table 5.7, based on three habitat groups - a: open mire communities, b: communities marginal to carr, c: carr woodland. See text for further details.

a

OPEN	SD	MS	MD	PF	PC	CA
SD	5	2				
MS	1	6	3			
MD		2	1	1		
PF				3		
PC						
CA		1				

b

MARGIN	SD	MS	MD	PF	PC	CA
SD						
MS		3		1		
MD						
PF		3		1	1	
PC			1	1		
CA						

c

CARR	SD	MS	MD	PF	PC	CA
SD						
MS						
MD						
PF						1
PC				1		5
CA					3	5

possible transitions is the square of the number of vegetation states defined by the study. A sampling density of 1.4 observations/transition was obtained in Table 5.7, compared to 1.1 in Walker (1970). Overall, there are no preferred routes showing that valley mire succession is very varied although three community types, SD, MS and MD have a strong effect as 'sinks' with MD and PF also having high probabilities of self-replacement (p = 0.4 and 0.44, respectively). However, if the data are split then a number of 'preferred' routes are more evident showing that not only is succession distinctly non-random, but also that the direction varies in different parts of the valley mire (Table 5.8, Figure 5.20). The cores can be divided into three groups according to the present vegetation pattern - open mire, communities marginal to carr, and carr woodland - which reflects environmental differences in the degree of nutrient flushing (Rose, 1953; Newbould, 1960).

The principle trend of vegetation change in the open mire group (Table 5.8a Figure 5.20a) is in the direction of the *Molinia-Sphagnum* community, which has a high probability of self-replacement (this was the most frequently observed transition in the whole data set). A secondary direction of change towards group PF which, if reached, has a high probability of persisting. A wide variety of transition types were observed in the carr margin group (Table 5.8b, Figure 5.20b) given the number of observations. This may reflect the vegetation heterogeneity of this group but the limited sample size makes it difficult to draw conclusions. Table 5.8c and Figure 5.20c show carr woodland to be a major end-point for valley mire succession but carr often develops without any intervening stages, since most cores contained tree species from the outset. Other sites not included in this analysis also illustrate this point, such as Matley Bog where *Alnus* carr has developed directly on strongly gleyed mineral soil (see Chapter 2). Carr has a high probability of self-replacement and will rapidly re-invade where it has been cut, which is shown by comparison of air photos at sites such as Holmsley Bog and White Moor near Brockenhurst. An oscillation occurs between groups PC and CA but the succession always returns to CA, again suggesting that the *Phragmites*-carr community is due to disturbance (see section 5.6).

The linkage diagrams show there is pronounced differentiation of succession within the vegetation groupings. The probability of self-replacement is high for most communities and this stabilising effect must also reflect a strong environmental determinism in the course of succession within the valley mires. These findings support Grime's (1979) concept of succession in which stress is an important factor in determining the course of succession. A gradient of environmental stress can be identified in which *Sphagnum* is the important element in the successional pathway at one extreme and *Alnus* at the other. In this data set, the *Sphagnum*-dominated community was only stable at Cranes Moor where productivity is limited by a low nutrient flux (see section 5.3). Rimsmoor, a peat-filled doline with little water flow (Waton, 1982), is another site where *Sphagnum* appears to form the climax community in environmentally-limiting conditions. Walker (1970) also found that succession was constrained to *Sphagnum* dominated communities at low nutrient levels. In the rest of the cores, succession is heavily influenced by groups MS and MD, except where the environment appears to be sufficiently favourable for tree growth. Groups MS and MD are distinguished by the degree of *Molinia* dominance, but discrimination of this feature in the cores was very poor, especially in the field samples. These two groups should be regarded, therefore, more as a single ecological unit in which the *Molinia* is the main structural element.

Disturbance has already been recognised as a factor which may account for some of the variations in succession and peat cutting is probably important in this respect, particularly in relation to the secondary pathway to community PF in the open mire group. For example, group PF was prominent in the transitions recorded at Wilverley Bog, a site which is thought to have been heavily affected by peat cutting.

The only transitions between SD and MS occurred at Cranes Moor and there was no evidence in any of the cores to suggest that there is a trend towards the development of *Sphagnum*-dominated or ombrotrophic communities in the other mires. The factors militating against the development of raised mire conditions elsewhere in the New Forest are due to the relationship between vegetation and hydrology and to the topography of most other valley mires. It was pointed out earlier (section 5.3) that the main

variable limiting the formation of a groundwater mound in New Forest mires is the hydraulic conductivity of the peat. In almost all the valley mires, the axial and lateral flow of groundwater from the surrounding catchment creates a high flux of nutrients and aerated water. This supports vegetation dominated by both shrubs and herbaceous plants. As plants decay within the acrotelm the material collapses and reduces the size of pores or spaces within the peat, causing the capillary fringe to rise. However, capillary forces are weak and the main functional result is to decrease the hydraulic conductivity of the peat (Ingram, 1983), but in valley mires the structural elements of uncollapsed vascular plants maintain larger gaps than in moss peat and consequently the thick acrotelm is able to transmit high rates of discharge. This in turn maintains the nutrient status of the mire and the system is self-reinforcing. For a similar degree of humification, the hydraulic conductivity of valley mire, or fen, peat may be up two orders of magnitude more permeable than *Sphagnum* peat (Table 5.5). This mechanism probably accounts for the persistence of many communities and prevents the formation of groundwater mounds elsewhere in the New Forest mires. The potential height of a groundwater mound in the valley mire system is also limited by the two other variables in equation 5.1. Firstly, evapotranspiration from graminoid-dominated mires is some 40% greater than that from *Sphagnum* bogs (Ingram, 1983), so that the net recharge, U, is proportionately less in a valley mire under the same climatic conditions. Second, the width, L, of most mires in the New Forest is less than the dimensions of *Sphagnum* Bog at Cranes Moor. Thus, the potential height is generally limited by the smaller values of L^2 in equation 5.1. The minimum width necessary for the generation of a 1m high ground water mound using the most extreme values calculated for Cranes Moor (i.e. Umax, Kmin in Table 5.6) is 29m but, as has been shown, both these variables will be less extreme in a typical valley mire so that the width required will be larger than this.

The compartmentalised nature of valley mire succession seen in the linkage diagrams and the high probabilities of self-replacement show that there has been a marked stability in the underlying environmental gradient. The cores also suggest that most of the vegetation is now comprised of

equilibrium, or climax, communities and that equilibrium was reached rapidly after peat accumulation began at many sites. In addition to transition probabilities, the radiocarbon-dated macrofossil cores also provide evidence of community stability, in terms of persistence. The estimated duration of vegetation phases in these cores is shown in Table 5.9.

TABLE 5.9 Estimated periods of duration for different vegetation types (see text) in the valley mires from radio-carbon dated cores (to nearest hundred years).

	MIN	MAX	MEAN	n
SD	500	3000	-	2
MS	400	1300	740	6
MD	300	5200	2275	4
PF	4800		-	1
CA	5200		-	1

Although the data are sparse, they do show that most communities have been markedly persistent, in some cases covering a substantial part of the postglacial period. Furthermore, there are sufficient observations to suggest that the *Molinia*-dominated community type is markedly more persistent than the *Molinia-Sphagnum* community. This is of some general significance to considerations of ecosystem stability and complexity. A generally held belief (see review by Pimm, 1984) is that the persistence of communities increases with diversity. Yet *Molinia*-dominated vegetation is one of the most persistent mire communities in the New Forest, as well as being the most species-poor (see Chapter 6). This discrepancy between long-term (palaeoecological) data and theory is again due to the divisions within ecology referred to earlier in this section. There is little direct evidence to support the hypothesis that persistence is dependent on complexity and this notion is easily traced to the ecosystem model approach of May (1973) which, although seminal, was biologically unrealistic (Roberts, 1974; McMurtie, 1975; DeAngelis, 1975; Pimm and Lawton, 1977; Pimm, 1979). The macrofossil evidence, instead, supports Paine's (1980) view based on empirical studies that strong interactions between a few species may determine the stability of the system. Other palaeoecological data also refutes the stability-complexity hypothesis (Boucot, 1983).

The valley mires are characterised during the Flandrian by low species turnover relative to adjacent dry-land habitats, such as the changing forest composition with species immigration (Seagrief, 1960, Barber, 1975, in prep; Scaife, 1980). This is a more general feature of mire succession and reflects the wider geographic distribution of many wetland species compared to other plants. The reason for this may be that the thermal environment is buffered by the presence of a water body, in the form of saturated peat in the case of mires. Davis (1981) has pointed out that the geographic distribution of many species has not been in equilibrium with climate over much of the Flandrian. From this she has argued that the emphasis in studying plant communities should be on those processes permitting rapid change, rather than those acting to maintain stability. However, with regard to mires, many species found in contemporary communities have been present in Britain since at least the beginning of the Flandrian (Godwin, 1975). This is seen in the cores from Church Moor and Cranes Moor, for instance. Undoubtedly the greatest change in community composition of the New Forest mires during the Flandrian has been the expansion of *Alnus*. But population growth is diachronous even across the Forest and there is evidence for a long period of low *Alnus* population densities before this time (see section 5.2). Simple species immigration implies that the New Forest mires comprised non-equilibrium communities before the expansion of *Alnus*. However, a more complex pattern of *Alnus* population growth linked to environmental change appears most probable (section 5.2) and suggests that the mires have been dominated by equilibrium communities during all, or most, of the Flandrian. The question of equilibrium vs non-equilibrium communities is an important one; not only to the understanding of community diversity, but also to the methodological basis of palaeoecology. The latter will be considered in the final part of this discussion.

The Late Devensian and the transition to the Flandrian are, by contrast, marked by a high species turnover. At least five species extinctions occurred at Church Moor during this period, including two, *Homalothecium nitens* and *Betula nana*, which are no longer found in the New Forest. Another moss species present in the region only during this period is *Meesia tristicha*, recorded by Scaife (1980) from Gatcombe Withy Bed, Isle of Wight which, interestingly, was also a sedge-dominated mire during the

Lateglacial. Unfortunately, the poor degree of preservation at Church Moor during the Loch Lomond Stadial and early Flandrian prevents a more exact determination of the timing of the extinction events which took place. However, the evidence suggests that the extinctions are related to the rapid phase of readjustment and immigration following the end of the Loch Lomond Stadial, rather than being a more direct physiological response to environmental change. Firstly, some of the species which became extinct at Church Moor survive elsewhere in the New Forest mires today, notably *Carex rostrata*. Secondly, others show a relict distribution (Holmquist, 1962) in the southern part of their range today. A major contraction in the range of both *H.nitens* and *M.tristicha* occurred well after the beginning of the Flandrian (Dickson, 1973). The phenomenon of relict species is closely linked to the transition from the Late Devensian to the Flandrian (Piggott and Walters, 1954; Rose, 1957) and is particularly evident in the bryophytes on both sides of the Atlantic (Miller, 1980; Birks, 1982). The existence of relict species also suggests that the diversity of communities in the Lateglacial Interstadial is related to the release from interactions with highly-competitive species (sensu Grime, 1977), as was discussed earlier. Indeed, the survival of the 'Teesdale rarities' has been attributed to the effect of heavy-metal toxicity in limiting above-ground biomass (Waugham *et al*, 1983), and thus maintaining a 'high stress - low competition' environment.

5.7.3 Macrofossil analysis : concluding remarks

This study has demonstrated the usefulness of two functional divisions to the study of mire development. First the distinction between mires as peat-accumulating systems and as assemblages of plant species responding to similar environmental factors. Second, the recognition of the two-layered structure of mires (acrotelm and catotelm) with their differing biological and physical properties. But the limitations of macrofossil analysis are also apparent. These are most evident when the surface vegetation is compared with the uppermost samples in the macrofossil cores. There are clear differences in the representation of species within the peat, with a substantial proportion of species almost or totally absent including a number with a high frequency in the present vegetation. For some species, such as sundews and liverworts, this is attributable to high rates of

decomposition. In the case of *Drosera rotundifolia*, the rosette of leaves has usually rotted down almost completely by November in the New Forest. Even the large number of seeds produced by this species were rarely found in the peat deposits (only at Church Moor) despite the fact that *D.rotundifolia* is a highly constant associate of several species which were found in the macrofossil assemblages. There were also differences between the surface peat layer - which can be regarded as the conceptual death assemblage discussed in the previous chapter - and the surface vegetation. This shows that differential recognition is an important factor affecting the representation of species in the macrofossil assemblage. The variability in "identifiability" is not widely acknowledged as a significant problem and most studies emphasise taphonomy and decomposition as the sources of discrepancy between vegetation and macrofossil assemblage. Identification problems become most important in studies of mires dominated by vascular plants rather than in moss-peats; in the New Forest valley mires *Narthecium ossifragum* is the most notable species which is under-represented due to problems of recognition. The roots, in particular, are rather featureless, typical monocotyledon roots with a simple rhomboidal-cell pattern.

Two methods are used in palaeoecology to counter these problems (which are by no means restricted to the interpretation of macrofossil assemblages). The first is the "whole community" approach, whereby the elements of the macrofossil assemblage are compared with present-day communities from which - by analogy - other floristic attributes and environmental conditions are inferred. The other method of interpretation might be described as the "indicator species approach" in which species of characteristic ecological distribution are used to indicate past habitat conditions (many mosses are used in this way, for example). Both approaches are limited in their fundamental assumptions - communities are merely arbitrary assemblages of individually-behaving species populations, while the 'indicator species approach' implies that everything is known about a species' fundamental niche, how it has varied over time and the outcome of all possible species interactions. These points argue for a pragmatic approach to palaeoecology. They may be regarded as weaknesses but no more so than those limitations to other fields of ecology.

The real test of palaeoecology is whether it is able to generate data which

may be used to test hypotheses of general ecological significance. The potential for this is evident from a variety of studies ranging from succession and plant population dynamics to insects in trees and acid rain (Walker, 1970; Barber, 1978; Birks, 1980; Bennet, 1983; Flower and Battarbee, 1983). All of these studies demonstrate the power of palaeoecology to provide data over time-scales far larger than those on which most ecological theory is based.

The principle of uniformitarianism is fundamental to understanding the basis of palaeoecology. But there is good evidence that this method of interpretation is inapplicable to at least one period of the Quaternary, namely the Lateglacial Interstadial of the Late Devensian. The evidence suggests (section 5.2) that the climate ameliorated far more rapidly than the response time of most plants. The resulting non-equilibrium communities during that period are not analogous to the vegetation formations of today which are assumed to be at equilibrium with the environment. The development of non-equilibrium communities during rapid environmental change might also account for the apparently unusual vegetation of some earlier periods, such as the Upton Warren Interstadial (Lowe and Walker, 1984). The failure of uniformitarianism under certain conditions (note also the comments of Davis, 1981, above on Flandrian forest composition), at the level of whole communities or ecosystems, implies that future emphasis in palaeoecology will need to be placed much more on the level of individual species. This will require a synthesis of plant growth strategies, ecotypic differentiation, physiology, biogeography and population genetics; and many of these links have yet to be made within ecology.

5.8 Summary

1. Macrofossil analysis was carried out on 5 cores from 4 contrasted mire systems. The field stratigraphy of a further 7 mires is also described.
2. Valley mire succession is investigated from the earliest phases of the Lateglacial, and is also related to the concept of raised bog development.
3. Evidence for climatic change during the Lateglacial and early Flandrian

is reviewed, but the climatic interpretation of valley mire stratigraphy is limited.

4. Succession is varied with pronounced differentiation in direction of succession between different parts of the valley mire system. Most communities have a high probability of self-replacement and this persistence is related to the stability of the underlying environmental gradients.
5. The limitations and potential of macrofossil analysis, and palaeoecology in general, are critically discussed. The principal of methodological uniformitarianism is challenged in relation to community composition during the Late Devensian and other periods of rapid environmental change.

SECTION THREE PRESENT DAY PLANT COMMUNITIES AND THE CONSERVATION OF THE VALLEY MIRES

CHAPTER SIX: THE COMPOSITION AND STRUCTURE OF THE MIRE COMMUNITIES

6.1 Introduction

The elucidation of the principal factors controlling plant community composition is a major objective of community ecology, which has important consequences for scientific habitat management (Watt, 1971; Dempster, 1977; Ratcliffe, 1976b; Grubb *et al*, 1982). Community composition depends upon individually varying species populations (see Chapter One). The variations in abundance can usually be related to a small number of gradients in the environment (e.g. Whittaker, 1967; Kershaw, 1973; Austin, 1977a; Pignatti, 1980). Hence a few underlying variables can be used to summarise the relations between a large number of species populations. However, the relevant variables - or complexes of variables - are frequently difficult to determine directly, and experimentation on community organisation is often impracticable in complex ecosystems. One of the basic approaches of ecology, therefore, is the analysis of existing ecosystem patterns in order to reveal the ecological processes operating.

The main aims of this chapter are to investigate the variation in the mire communities in order to provide a better understanding of the ecological processes affecting community composition and species distributions. After setting out the framework within which this study is based, community patterns between the mire vegetation and surrounding habitat will be examined before the variation in mire community composition is considered.

6.2 The description and analysis of plant communities

6.2.1 Introduction

A variety of approaches have been developed for investigation of vegetation and habitat relationships, so the selection of appropriate methods should be carefully considered. In this study, several numerical techniques have been adopted because previous research in community ecology has shown

them to be helpful in understanding ecological data. They should be regarded as merely mathematical devices which can be used as analytical tools, and their ecological value should be assessed according to the additional insight they provide into the organisation of real communities.

6.2.2 Ecological data

Community ecology deals with assemblages of species' populations. Plant community data are, therefore, "multivariate" because vegetation samples encompass the simultaneously varying abundances of numerous species. By contrast, the ecological gradients that the vegetation reflects amount to far fewer variables. The correlated changes of a large number of species to a few underlying factors is called "redundancy" because many species within a data set are co-ordinated in their response to the same gradients. This is the "structure" in community data, and without the property of redundancy vegetation science would be unable to detect any order in the patterns it observes. Numerical techniques have the advantage of formally expressing the multivariate nature of ecological data, and allow more precise and explicit formulation of the problems involved (Orloci, 1978). Clymo's (1980) study of Hummell Knowe Moss demonstrates the two basic functions of the multivariate approach in community ecology. Firstly, it helps to reveal the structure in data and generates hypotheses for further investigation and, secondly, it allows effective comparison and communication of results. Multivariate analysis can disclose features which are not revealed by non-numerical methods, because relationships may be too complex to analyse subjectively. The objective is to simplify and order the data, so that the resulting model shows the relationships among species and also reflects the relationships between vegetation and habitat variation (van Grounewoud, 1976).

The multivariate methods used in community ecology fall broadly into three categories, which are complementary and may be used together in an overall investigation. One of these, direct gradient analysis (e.g. Whittaker, 1967), incorporates environmental and floristic data together by relating vegetation to a single (or occasionally two), predetermined environmental gradient. The way in which the abundance of a species changes along the gradient is termed the "species response". In contrast, the other two

methods, classification and ordination, use plant community data alone and leave environmental interpretation to a subsequent, independent step. The identification of the important gradients is often the initial objective of an investigation. In this case, the vegetation itself may be ordered according to the compositional relatedness among samples using classification and ordination, and then various environmental and biotic factors may be compared with the resulting patterns in order to suggest the relevant variables.

The object of ordination is to simplify the pattern of variation in community data with the minimum loss of information, and this is achieved by the spatial arrangement of species or samples such that their position reflects their similarity when they are mapped. More recent ordination methods attempt to extract the directions of variation in vegetation which reflect the underlying ecological gradients, given that species are expected to respond to gradients in certain ways (Noy-Meir, 1974; Grieg-Smith, 1980; Prentice, 1980; Hill and Gauch, 1980).

Classification is fundamental to science and is used in plant ecology to summarise data variation and to generate hypotheses. The aim of all classificatory procedures is to group similar entities together into discrete units, but the method adopted has differed between ecologists. In particular, there is a marked dichotomy between the Braun-Blanquet method used widely in continental Europe and numerical techniques more prevalent among english-speaking workers. The former approach is linked with the Zurich-Montpelier school and was devised by Braun-Blanquet. A review of the vast literature concerning this system and its procedures is given by Westhoff and Maarel (1978). It attempts to erect a hierarchy of vegetation units in a global - or at least regional - framework, progressing from the basic unit, the association, through alliances, orders and classes ultimately to the vegetation circle. Although there is a considerable body of criticism concerning the Braun-Blanquet system, there are few comparative tests between this and alternative, numerical methods (Moore *et al*, 1970; Frenkel and Harrison, 1974). Neither approach is clearly superior, so that the choice of technique inevitably involves a large element of subjectivity based on the investigator's outlook. In one such test, Frenkel and Harrison (1974) concluded that, at the large-

scale or reconnaisance level, the Braun-Blanquet system may be equally cost-effective and informative. National and regional schemes have been proposed for Scottish vegetation (e.g. McVean and Ratcliffe, 1962; Birks, 1973), but numerical methods are also efficient at this large scale, for example the NCC Welsh Lowland Peat Survey (Ratcliffe and Hattey, 1982). Furthermore, the numerical approach creates a data base which is compatible with other analytical techniques and is easily accessed for further investigation (Ratcliffe and Hattey, 1982). This will be of increasing significance in conservation as widely available computer-based information systems become more frequently used with ecological survey data.

On balance, the scale of investigation and a number of methodological objections to the Braun-Blanquet system lead to the rejection of its use here. Firstly, it is difficult to incorporate new data into the existing scheme, apart from possibly the higher units of the hierarchy. Even with these units, some communities may have character species from several different alliances, so that the classification of these communities is uncertain (Hill, 1977). Numerical classification provides a more objective framework for organising data. Secondly, ordering of the raw data tables places great reliance on criteria chosen by the observer, particularly differential species, but also fidelity and constancy. Numerical classification, in contrast, uses the data to indicate the criteria on which they should be organised. Thirdly, the hierarchical framework of the Braun-Blanquet scheme mimics a taxonomic treatment but the two systems differ in the validity of their "end-groups", since community data reflect the vegetation continuum whereas, in systematics, taxonomic units are presumed to reflect an underlying phylogenetic tree - moreover, distance between groups in a taxonomic hierarchy is proportional to phyletic relatedness, but this is not so in communities.

6.2.3 Sampling

The basic sampling unit of vegetation survey is usually the quadrat. Location of quadrats may be by some objective means, e.g. random or systematic distributions, or subjectively within stands of uniform appearance, as in the Braun-Blanquet system where they are often termed "releves".

Two decisions must be made: the size of the quadrat and the type of measurement to be carried out, and the choices made will result inevitably from a trade off between effort expended and information gained. Within the Braun-Blanquet system, emphasis is placed heavily on the concept of the "minimal area", which may be defined as the smallest area within which the species composition of a plant community is adequately represented. Despite many attempts, this concept remains ambiguous on two points (Dietvorst *et al*, 1982; whether it should refer to the abstract plant community or to the concrete stand, and whether it should refer to the qualitative species composition. The homogenous vegetation samples required by the Braun-Blanquet system are also desirable for numerical analysis, if community types are to be represented by the samples or if they are to be related to the environment.

The minimal area requirement of the Braun-Blanquet system has been criticised from Pearsall (1924) onwards, and arises from the fact that organisms and environmental factors are patterned at various spatial scales. The sampling units of community ecology are not naturally delimited and have to be artificially separated from continuous, more or less uniform vegetation (Poore, 1962). Various methods have been proposed for the determination of minimal area and, of these, the interpretation of species-area curves is the original and most frequently recommended method (see Dietvorst *et al*, 1982 for a review). The effect of quadrat size on valley mire samples was investigated in a pilot study. A species-area curve was determined for a series of nested quadrats located within an area of *Molinia* and *Sphagnum* dominated vegetation in Dibden Bog. The results are displayed in Table 6.1 and Figure 6.1, and illustrate the problem frequently encountered in minimal area determinations: the species number does not reach a level of saturation (Hopkins, 1957; Peet, 1974). Goodall (1954), also, could not identify a definite sample mire using a different method and concluded that the minimal area concept was of little value. Although the curve begins to level off above about $4m^2$ (Figure 6.1), there is an inflexion upwards after 4 x 8m as scattered pine trees growing on the mire are encountered. Below about $4m^2$, species frequency is strongly influenced by a *Molinia* tussock within which the first three samples fell entirely. In this context, Putman *et al*, (1982) report a mean diameter of 0.39m for *Molinia* tussocks with a spacing of 0.9m

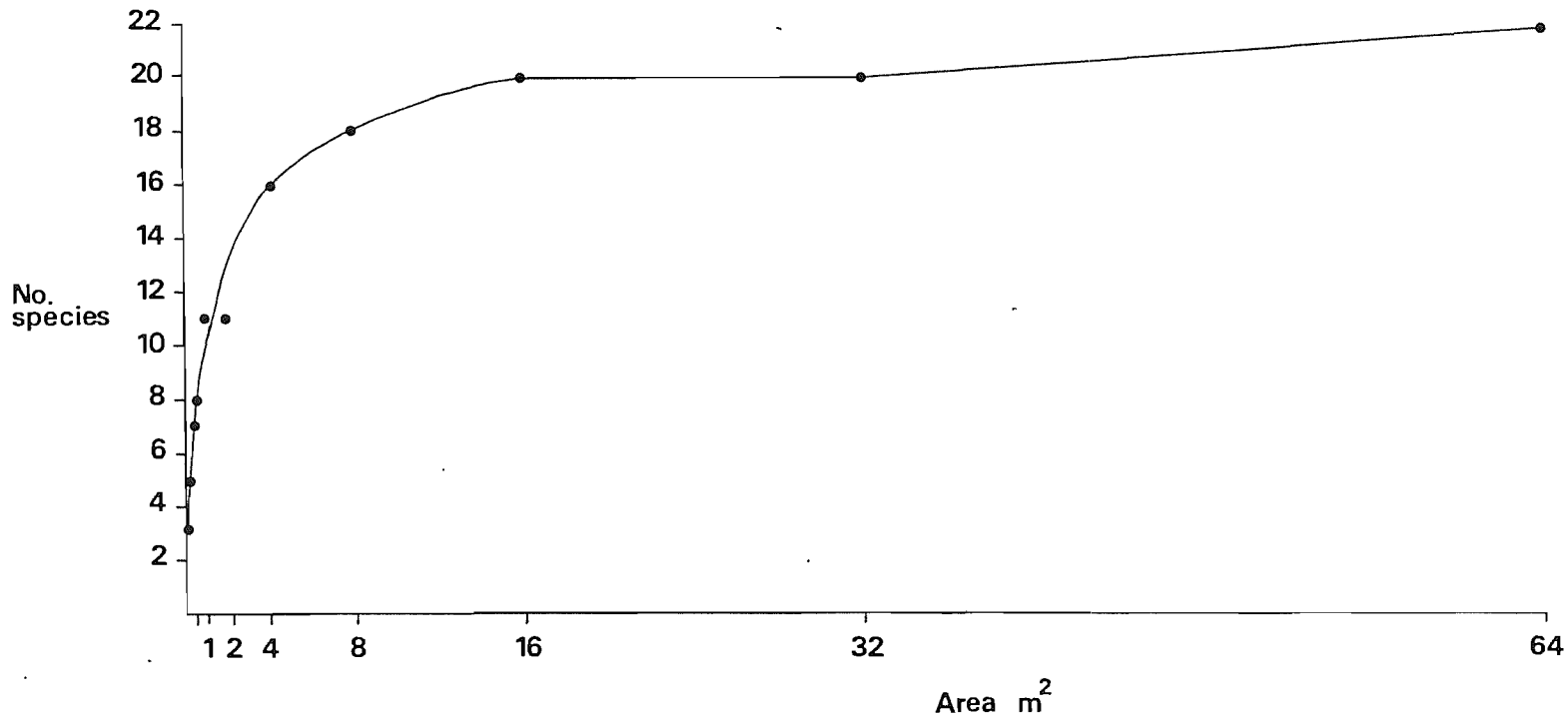


FIGURE 6.1 : The effect of sampling area on species richness from nested quadrats at Dibden Bog.

TABLE 6.1 Species recorded within nested quadrats

Quadrat dimensions (m)	0.125 x 0.125	0.125 x 0.25	0.25 x 0.25	0.25 x 0.5	0.5 x 0.5	0.5 x 1.0	1.0 x 1.0	1.0 x 2.0	2.0 x 2.0	2.0 x 4.0	4.0 x 4.0	4.0 x 8.0	8.0 x 8.0
Quadrat area (m^2)	0.0156	0.0313	0.0625	0.125	0.25	0.5	1	2	4	8	16	32	64
Species Number	3	3	3	5	7	8	11	11	16	18	20	20	22
Molinia caerulea	X	X	X	X	X	X	X	X	X	X	X	X	X
Erica tetralix	X	X	X	X	X	X	X	X	X	X	X	X	X
Juncus acutiflorus	X	X	X	X	X	X	X	X	X	X	X	X	X
Myrica gale				X	X	X	X	X	X	X	X	X	X
Calluna vulgaris				X	X	X	X	X	X	X	X	X	X
Drosera rotundifolia					X	X	X	X	X	X	X	X	X
Hypnum cupressiforme var cupressiforme					X	X	X	X	X	X	X	X	X
Eriophorum angustifolium						X	X	X	X	X	X	X	X
Sphagnum cuspidatum							X	X	X	X	X	X	X
Sphagnum auriculatum var auriculatum							X	X	X	X	X	X	X
Odontoschisma sphagni							X	X	X	X	X	X	X
Lepidozia setacea									X	X	X	X	X
Cephalozia connivens									X	X	X	X	X
Sphagnum palustre									X	X	X	X	X
Sphagnum capillifolium									X	X	X	X	X
Campylopus introflexus									X	X	X	X	X
Betula pendula										X	X	X	X
Potentilla erecta										X	X	X	X
Narthecium ossifragum											X	X	X
Sphagnum papillosum											X	X	X
Pinus sylvestris													X
Sphagnum recurvum													X

elsewhere in the New Forest. An important patterning in the mire vegetation at the scale of *Molinia* tussocks is often evident, and quadrat sizes should be larger to avoid possible artifacts derived from sampling communities below this spatial scale. Quadrat area should be, preferably, greater than $1m^2$ and data from a further seven samples show an increase of 53% in the number of species represented when quadrat size is increased from $1m^2$ to $4m^2$. Throughout this discussion it is important to recognise that the real issue concerns the homogeneity within samples to the overall variation in the data set (Poore, 1962). Obviously, the smaller the between-sample variation, the smaller within-sample variation must be for overall community relationships to emerge. In practice, a 2 x 2m quadrat placed within relatively homogenous vegetation stands has proved adequate for heath and open mire samples in this study. Larger quadrats are necessary for woodland samples.

Measurement of species abundance also entails a cost-benefit decision, since methods such as point-quadrat and biomass sampling are more accurate but are much more time-consuming than visual cover estimates. A number of comparative studies into methods for estimating plant cover have been carried out. A general result is that errors associated with visual estimates are inversely proportional to the cover of the species concerned. The degree of error is also affected by plant morphology. This means that estimates are most reliable for dominant shrub species, rather than graminoids (Floyd and Anderson, 1987; Kennedy and Addison, 1987). Sykes *et al*, (1983) found pronounced differences in the visual estimates of different observers. However, they conclude that the biases involved were relatively consistent between samples, and that there was a worthwhile increase in precision with the use of a single observer. The tolerable level of precision is relative to the aims of the investigation, and criticisms of imprecision are only valid if the conclusions drawn require a greater resolution than the method affords. Visual assessments may be based on percentage or ranked data such as the Domin scale (see Bannister, 1966), and the measurements used here are based on either Domin or percentage scales according to the particular problem under investigation. A quadrat frame sub-divided into 0.1 x 0.1m units was used.

6.2.4 Diversity

Diversity is one of the most important criteria for assessing the conservation value of habitats (e.g. Ratcliffe, 1977a; Usher, 1980) and is a fundamental notion in ecology. There are many ways of expressing diversity, but these can be related to just two components of overall diversity, which are conventionally called alpha and beta diversity after Whittaker (e.g. Whittaker, 1967 : see also MacArthur, 1965; Peet, 1974; Cody and Diamond, 1975 and Southwood, 1976 for reviews). They may be related to each other as follows:

Components of overall diversity	(alpha -	Number of species in a community
	(beta -	Species turnover between communities
Overall diversity -	gamma -	Total number of species in all communities.

Diversity within communities (alpha) is usually concerned with the distribution of observable units (individuals) between categories (species) in a sample, and is often the only measure of diversity used in many investigations. Two parameters are required to describe alpha diversity, relating to (i) how many kinds of organisms there are in a sample (species richness), and (ii) how evenly their abundances are distributed (equitability: the proportions of common and rare species). Attempts to produce a comparative measure of diversity (e.g. for conservation assessment purposes) use one of two methods; the first approach (diversity indices) derives a single index which reflects both species richness and equitability. The second (distribution fitting) fits a statistical distribution to the data, and then uses the parameters of this statistical distribution as a measure of diversity. Both approaches are faced with difficulties, however. Most diversity indices do not respond in a regular way to changes in total species number and equitability, and they are often too sensitive or too insensitive to extremes in species richness and abundance (e.g. Shannon-Weiner and Simpson's diversity indices). Distribution-fitting methods, on the other hand, require very important assumptions concerning the biological mechanisms underlying the distributions and these are often too unrealistic.

In the light of these difficulties, it is scarcely surprising that species

number alone remains the principal criterion of diversity for conservation assessment. In addition to expediency due to the uncertainty surrounding other diversity expressions, it may be argued that there are also theoretical reasons why species richness alone is a suitable measure for assessment. This follows from two simple observations on living organisms (May, 1975a); firstly, since all species increase geometrically rather than arithmetically (their numbers multiply), the natural variable of abundance is the logarithm of population density and, secondly, all organisms are distributed between conventionally distinct categories or species, i.e. they are distributed according to the Poisson distribution. Thus, common logic suggests that the frequency distribution for N individuals (which vary logarithmically) in S species (which is a Poisson variate) is a log-normal type (Preston, 1948). The log-normal distribution is characterised by two parameters, S (species richness) and J (i.e. total no. of individuals/no. of individuals in rarest species). If a further empirically-based assumption is made as to the details of the log-normal distribution for natural communities (Preston, 1962), then it is reduced to a special one-parameter family of "canonical log-normal distributions"; the distribution is then specified by either S or J alone. Given that a measurement of J requires a detailed census to discover the abundance of the rarest species, S, or species richness, becomes the most readily estimated parameter from field surveys.

However, the log-normal distribution has been increasingly under attack (e.g. Platt *et al*, 1984; Hughes, 1986). Both in terms of field evidence for this distribution of abundance, and in terms of its biological relevance since it is based purely on the central limit theorem of statistics. Nevertheless, these theoretical considerations and the difficulties of estimating diversity parameters in the field combine to make basic species richness the most suitable and practicable measure of alpha diversity for conservation purposes. The objection (e.g. Usher, 1983) that species richness provides an inflated measure of alpha diversity, due to rare species, is less important for conservation assessment. This is because the rarer species (in the particular community) are often those which are more highly valued.

In contrast, beta diversity has received scant attention despite the

recognition of its importance by animal and plant ecologists (e.g. MacArthur 1972, Whittaker, 1972). Beta diversity reflects either the variety in the communities present at a site, i.e. habitat heterogeneity, or species turnover along an ecological gradient from one sample site to another, in which case the length of the gradient is measured by beta diversity. It is a useful community measure for at least three reasons (Wilson and Schmida, 1984): (i) it measures habitat-partitioning by species, (ii) it is a component of the overall biotic heterogeneity of an area, (iii) most importantly for conservation assessment, it can be used as a comparative measure of habitat diversity between different sites.

Measurement of beta diversity can be based upon species abundance data or simply presence and absence information. Many of these measurements express the degree of similarity between samples, so that they indicate the ecological distance between communities along ecological gradients. A relationship can be seen between the beta diversity of ecological gradients and some ordination techniques, because in ordination samples are separated geometrically on the basis of their similarity and gradients of major variation are then extracted from their distribution. Although workers, such as Whittaker, have proposed a variety of indices for beta diversity, a comparative evaluation has only been carried out for measures based on presence and absence, and was reported recently by Wilson and Schmida (1984). The main index to be considered in this study, was devised by Whittaker (1960) and is related in a simple manner to the species richness of individual samples, i.e. to alpha diversity:

$$B_w = \frac{\text{(total number of species in all samples)}}{\text{(means species number in the samples)}} - 1$$

This is the total number of species divided by the average and is based on presence and absence data. Wilson and Schmida (1984) found it to be one of the most satisfactory measures of beta diversity, fulfilling all the criteria of their evaluation. Whittaker's index is independent of any gradients in the data. A second measure is obtained by ordination and will be described later for the sake of clarity.

6.2.5 Ordination and classification methods used

6.2.5.1 Methodology

Selection of appropriate multivariate techniques requires a working under-

standing of the properties of community data in the form of a species-by-sample matrix. The dichotomy between ordination and classification is no longer controversial and it is recognised that classification can usefully partition a continuum and ordination can reveal discrete groups. The mathematical concepts underlying multivariate analysis are more readily visualised geometrically, rather than being expressed algebraically (for a general treatment see Gauch, 1982; and also Orloci, 1978).

Consider a given vegetation sample: it is characterised by the abundances of the species it contains. If the various species are represented by different axes in a conceptual "space", then the sample can be located within this space as a point whose position corresponds to the abundance of each species along its axis - this is shown in Figure 6.2a for two samples, a and b, each comprising three species, 1, 2 and 3, and is a spatial representation of the species-by-samples data matrix in Table 6.2 (from Gauch, 1982)

Table 6.2 Species-by-samples community data for Fig. 6.2 (after Gauch, 1982)

		Sample	
		a	b
	1	6	20
Species	2	5	10
abundance	3	7.5	15

This conceptual space (Fig. 6.2i) is known as "species space", and the three species can be located, alternatively, within "sample space" where the samples are now the axes and species are located along the axes according to their abundance in each sample (Fig. 6.2ii). It will be seen that samples which share similar species composition will be distributed close together in the species space and dissimilar samples will be far apart. Equally, those species occurring together in the same samples occur in the same region of sample space. When many species are present there will be many axes in the species space, so that vegetation can be regarded as a multidimensional continuum. Thus, a typical data matrix from a vegetation survey can be thought of as a cloud of points in a space made up of many dimensions (each point representing a sample in the species space and vice versa for sample space).

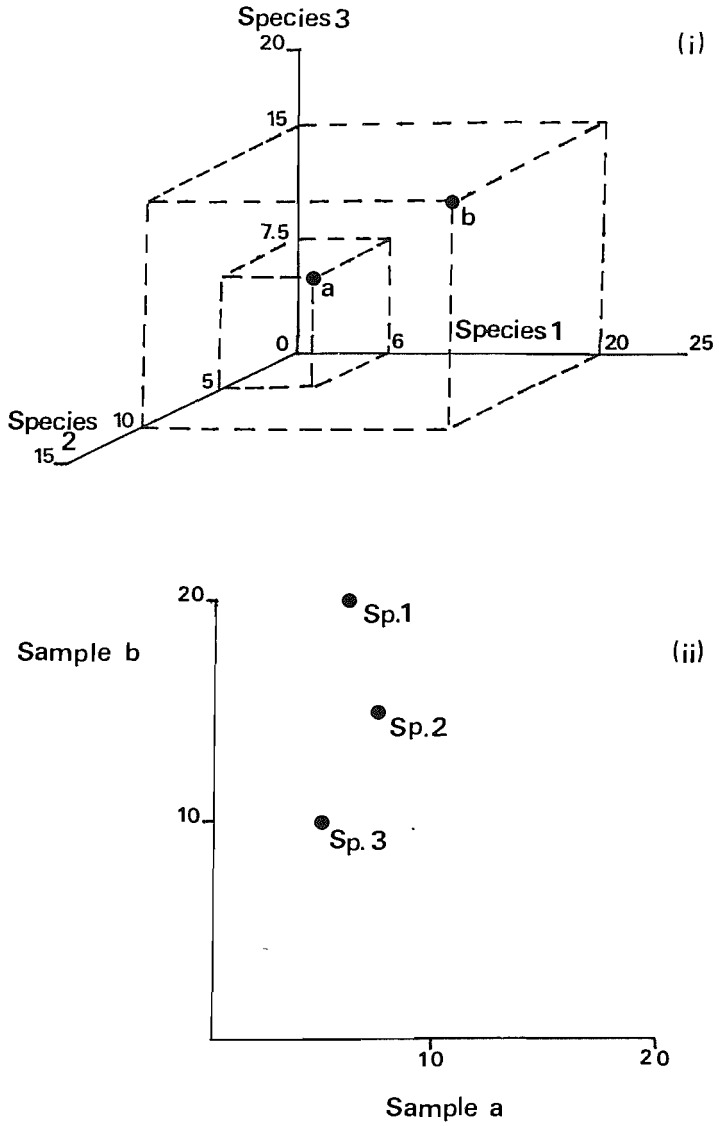


FIGURE 6.2 : Geometric representation of the community data matrix in Table 6.2, (i) is species space and (ii) is sample space (after Gauch, 1982).

Ordination operates on samples (or conversely species) by projecting the cloud of points in the highly dimensional species space onto a space with far fewer dimensions, which can then be mapped and displayed graphically. If all species were distributed randomly between samples there would be a vast number of different possible projections. However, the distributions of species tend to be correlated so that the main structure of the cloud of points occurs in few dimensions. Ordination seeks to identify these principle axes of variation in the cloud, and so the resulting projection onto just two or three dimensions, say, thereby retains the maximum amount of information concerning the relationships between points, i.e. the ecological distance between samples. In this way, ordination summarises data structure by a reduction in dimensionality. In order to understand fully how the results from ordination can be interpreted ecologically, it is necessary to introduce yet another conceptual space, termed "ecological space" (Austin, 1976a), which has ecological gradients as axes. The points occurring within ecological space can be varied and include species, samples and other community characteristics (e.g. physiognomy or diversity). Typically, there are only a small number of dimensions in ecological space - most communities are principally affected by very few ecological gradients. The object of ordination is to derive the ecological space from the species-by-samples data. Direct gradient analysis (see above) ordinates species in a very simple ecological space, where just one ecological gradient is displayed.

The development of suitable multivariate techniques has been advanced by the study of the response of species to environmental gradients and by testing techniques against simulated data for which the underlying pattern (the ecological space) is known. One of the most important conclusions to emerge from studies using direct gradient analysis in the 1960's was that the distribution of a species' population along an environmental gradient (the species response) is in the form of a "bell-shaped curve" (e.g. Whittaker, 1975). This mathematical model of community structure is intended only as an approximation, and its theoretical and empirical basis is a source of continuing debate (see Austin, 1976a, 1987; Hill, 1977; Greig-Smith, 1980), although it has had utility in the development of techniques.

6.2.5.2 Detrended correspondence analysis (DCA)

The fact that species do not exhibit a linear response has serious implications for ordination methods, since measures of sample similarity in terms of composition are not, therefore, direct linear functions of separation along an environmental gradient. This has been called the "nonlinearity problem" and was demonstrated clearly by Swan (1970), who first used simulated data to evaluate ordination methods. Simulated data are useful for testing multivariate techniques because, unlike real data, the expected result is known precisely beforehand and the effects of variations in the data can be examined easily.

It was rapidly realised (Swan, 1970; Noy-Meir and Austin, 1970) that ordination by principal components analysis produced a "horseshoe" or "arch" effect in the results because of this non-linearity: if data arranged along a single gradient are analysed by principal components, the gradient is distorted into an arch so that, instead of one axis, it requires two or more axes to recover the gradient. Further distortion may occur so that interpretation becomes very difficult. This effect has been recognised as a major problem, also, in other techniques (Austin, 1976a) and has led to alternative methods being sought that are less susceptible to distortion, particularly non-metric multidimensional scaling (Fasham, 1977; Prentice, 1977) and detrended correspondence analysis (Hill, 1979a).

Following comparative tests in the late 1970's (e.g. Austin, 1976b; Fasham, 1977; Prentice, 1977, 1980; Gauch *et al*, 1977),it soon became clear that DCA was a significant advance over other ordination methods. This has led to a wide acceptance of DCA by many ecologists, which is not unrelated to the availability and convenience of the computer program DECORANA. The technical advantages of DCA are two-fold. Firstly, it systematically removes the arch distortion and compression of ends of a gradient relative to the centre, referred to above. Second, in doing so it scales the axes in standard units. This is important for interpretation since the axes - reflecting ecological gradients - are scaled in natural, meaningful units measuring beta diversity. Thus, unlike other ordination techniques, the results of DCA from one investigation are directly comparable to another because the units are standardised. Beta diversity is measured along

gradients as the "average standard deviation of species turnover" or s.d. This is because the average (root mean square) species abundance profile has a standard deviation of one (Hill and Gauch, 1980). Since most of a normal distribution is contained within four standard deviations, a species range will occur over approximately four s.d. Consequently a full turnover in species composition will also take place in about four s.d. - i.e. samples which are more than four s.d. apart will have virtually no species in common. A half-change, which is a 50% change in sample composition is equal to 1.39 s.d. for noise-free data and approaches 1 s.d. for field data (Gauch, 1982). An alternative method for measuring beta diversity along gradients has been described by Wilson and Mohler (1983), but as yet no comparative tests have been published.

The principal disadvantage of DCA lies in the assumption that species exhibit bell-shaped response curves to environmental gradients. This still remains a largely untested hypothesis. Field evidence does not support the hypothesis in particular cases, but there is insufficient direct evidence for a general model to be developed yet (Austin, 1987). DCA is less successful where response functions are more complex, and distortion may also arise from the detrending and rescaling operations (Minchin, 1987). The performance of DCA may also be impaired by trends in species richness (Dargie, 1986; Minchin, 1987), although the problem is not restricted to this technique alone.

The discrepancy between theory and methodology in vegetation science (Austin, 1987) is far from being resolved. Current trends indicate that non-metric methods of ordination may be preferable, in that they make less assumptions about species response curves (Prentice, 1980; Minchin, 1987). There is, however, a third advantage of DCA. This is its close relationship to the classification method TWINSPAN, and the widespread use of both techniques as tools which provide ecologically meaningful results, in practice. This has allowed for greater compatibility and cross-comparison between studies (such as the recent peatland surveys of Ratcliffe and Hattey, 1982; Alcock, 1985 and Rodwell, in prep.).

6.2.5.3 Two-Way Indicator Species Analysis (TWINSPAN)

Numerical classification involves the identification of clusters from a cloud

of points in multidimensional space. If community variation is discontinuous and points exist in discrete groups, then classification is a relatively straightforward process. When there is more or less continuous community variation, classification is more arbitrary but provides a useful summary of community patterns, as discussed above. A "cluster" is a somewhat diffuse term, but can be defined by a number of precise parameters, such as those outlined by Sneath and Sokal (1973). Numerical classification is particularly useful when cluster boundaries have to be imposed on a continuous distribution of points. Methods differ in several features, according to (i) their similarity measures, (ii) whether they are hierarchical or not, (iii) whether they start by splitting the whole data set into smaller units (divisive) or treat each item as an end-point and fuse similar clusters together (agglomerative), and (iv) whether they create sample clusters using a single species (monothetic) or many species (polythetic). The theory and techniques of ecological classification are considered by a number of authors including Shimwell (1971), Orloci (1978) and Whittaker (1978).

Like ordination, numerical classification must take into account both the purpose of the analysis and the underlying model of community structure; in this respect the bell-shaped species response curve means that classification requires a dissection of more or less continuous variation (Hill, 1977). Thus, Hill argues that, in vegetation classification, the overall pattern is more important than the identification of deviant stands. Theoretically, classification techniques which are hierarchical, polythetic and divisive are the most suitable for the highly-dimensional nature of most community data (Lambert *et al*, 1973; Gauch and Whittaker, 1981). Hierarchical classification can be displayed by a dendrogram and produces a data summary which effectively expresses sample relationships. Polythetic, divisive techniques place emphasis on overall sample relationships and make the most use of available data.

Among available techniques, two-way indicator species analysis (TWINSPAN) meets these requirements and has proved to be robust and effective for a variety of community data (Hill, 1979b; Gauch and Whittaker, 1981). The term "indicator species analysis" is somewhat misleading since the method is based upon the division of an ordination, and the identification of

indicator species is a secondary step. A series of ordinations (by reciprocal averaging) are split in half and the resulting groups are the basis of the next set of ordinations, with the resulting dichotomies arranged into a hierarchy. The sequence involved in making the dichotomies is discussed by Hill (1979b). TWINSPAN carries out an integrated classification of both samples and species and arranges the output in a two-way ordered table of species and samples. The resulting table and the emphasis on indicator species (and their fidelity) show some similarities to the Braun-Blanquet approach. The success of TWINSPAN stems partially from its ability to take account of the vegetation-environment model of community structure through the incorporation of ordination in the method of analysis.

6.3 Previous vegetation research on the New Forest valley mires

Following Rankin's (1911) early description of the New Forest mires, little investigation of the plant communities was carried out until after the Second World War. However, compared to upland and northern mires there has been relatively little research on the productivity, hydrology and species autecology of valley mires. The first systematic survey was carried out by Rose (1953), whose observations on valley mires included the New Forest and were based upon 122 sites. Rose synthesised the general structure of these mires as a cross-valley zonation (Figure 6.3) which highlighted the important hydrological distinction between raised and valley mires, stressing the functional relationships between water movement, nutrient supply and floristic variation. Most sites were within heathland areas with nutrient-poor lithology, consequently progression downslope results in increasing soil wetness and concentration of water flow and nutrients, which are reflected by the vegetation zonation.

Below the dry heath communities (7 and 8 in Fig. 6.3), damp heath (6) is found on gentle slopes developed over gleyic podzols with seasonal waterlogging, *Calluna vulgaris* is variably co-dominant with *Erica tetralix* and *Molinia caerucea*. Where the water table remains relatively close to the surface with gleyed soils, the wet heath zone (5) occurs, in which *Erica tetralix* is an important component of the shrub-layer associated with

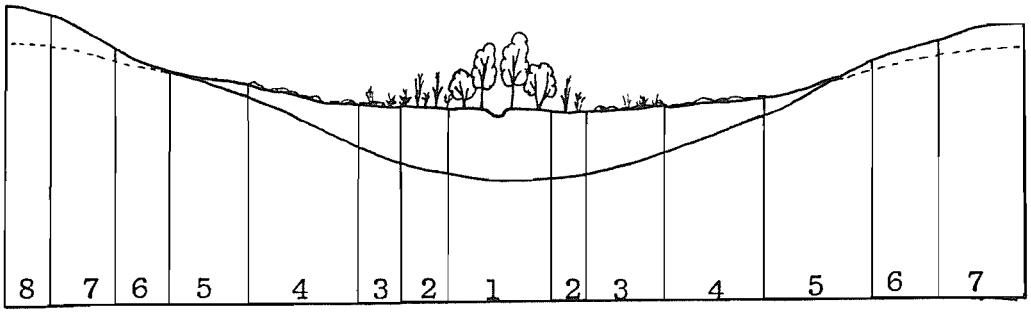


FIGURE 6.3 Generalised zonation of a lowland valley mire of the New Forest type (after Rose, 1953).

Zones: 1 = Carr or swamp carr

2 = Poor-fen or reed swamp

3 = *Sphagnum pulchrum* - *Eriophorum angustifolium* - *Juncus acutiflorus* - *Molinia* association

4 = *Sphagnum* hummock complex

5 = Wet heath

6 = Damp heath

7 = Dry heath over a thin peat layer

8 = Dry heath or bracken, freely-draining

Pecked line denotes the water table.

Sphagnum compactum and *S. tenellum*. This heathland community shows affinities to the mire zones downslope. The *Sphagnum* hummock complex (4) has a high water table with oligotrophic conditions similar to some raised mire communities. A *Sphagnum pulchrum* - *Eriophorum-Juncus* association (3) occurs over relatively liquid peat with stagnant water allowing formation of a *Sphagnum* carpet, *Molinia* tussocks may form where drier conditions are present. The final two zones (1 and 2) reflect higher nutrient levels and base-status, but differ in the degree of water supply and flux of solutes. The poor-fen or reedswamp (2) develops in conditions marginal to a central stream or flush and the more stagnant conditions reduce the vigour of tree growth. The dominants vary with base-status and shade tolerant *Sphagna* may be present. The central carr (1) is sometimes absent and this may be attributable to insufficient water and nutrient flux in small catchments. When present, *Salix cinerea* is usually dominant except where there is an innermost zone of *Alnus glutinosa*. Variation in this sequence occurs due to topographic variability and total water supply and, where perched water tables occur on the valley sides, seepage terrace mires (zones 4 and 5) are present. Within the New Forest, Rose (1953) gave Matley and Wilverley Bogs as examples of the typical full zonation.

Newbould also took the view that the distribution and ionic status of water flow was the most important factor controlling plant distribution in these mires (Newbould, 1960; Newbould and Gorham, 1956). His work suggested that the typical zonation was simply a reflection of a drainage network centred along the main valley axis and in more complex basins, such as Cranes Moor, the distribution of plant communities followed a more complex spatial pattern of water chemistry (Newbould, 1960). These investigations followed research on mire vegetation by Gorham (1950) and pioneered particularly in Sweden (e.g. Du Rietz, 1949; Sjors, 1950), which was based on the relationships between pH and specific conductivity measurements for both individual species and communities. On Cranes Moor four communities were distinguished by Newbould (1960): *Molinia* - *Myrica* and *Rhynchospora* - *Sphagnum* variants of a "general bog community", a *Schoenetum* and wet heath. A correlation between the distribution of the communities on Cranes Moor and the pattern of pH, specific conductivity and the flow of water was demonstrated. This relationship was explained by response of individual species to gradients in solute concentrations observed from species ranges

on Cranes Moor (Newbould and Gorham, 1956). Bellamy (1967) drew similar conclusions from his analysis of mires from eight regions of Europe, including the New Forest and elsewhere in the Hampshire Basin. He was further able to demonstrate the general applicability of Kulczynski's (1949) main thesis, that water quality and the hydrological regime are the most important factors governing mire type.

Few autecological studies have been carried out within valley mire communities, and these were conducted principally elsewhere and are discussed in Section 6.4. Most of this research has been linked to comparative studies of heathland species, particularly on the effects of waterlogging and Rutter's work on wet heaths, followed by Loach (1966) and Sheikh (1969a,b) is notable in this respect. The New Forest provided sites for McVean's (1955a,b) investigation of *Alnus glutinosa*, and Giles (1977) has studied the rooting ecophysiology of *Eriophorum angustifolium* on Cranes Moor.

More recently Atkinson (1984) has described some vegetation types in a survey of the New Forest mires (for fuller details see Atkinson,1978). Atkinson (1984) placed emphasis on large scale environmental pattern between sites rather than the phytosociological features at a more local scale. A wide range of vegetation was sampled from a variety of sites. His analysis identified a highly varied set of communities which incorporated dry woodland, acid grassland, dry heath, alluvial lawns and swamp developed over mineral substrates, in addition to 13 major noda occurring in the valley mires whose main attributes are summarised in Table 6.3. Ecological interpretation was inferred from species constancy and fidelity in each nodum, and indicator species are those with both high constancy and fidelity. Although the objective was to describe habitat variability at a high level of generalization, these noda reflect fine macrohabitat differences and measurement of the relevant environmental variables is needed to clarify the vegetation-environment relationship.

An agglomerative form of nodal analysis was developed by Atkinson to produce a two-way table of sites and species from which the noda were identified. This approach is similar to TWINSPAN (Hill, 1979b) and its precursor, indicator species analysis (Hill *et al*, 1975), in that the clustering procedures are based on an initial ordination (see Section

TABLE 6.3 Atkinson's (1984) major valley mire noda

Nodum		Main indicator species	Habitat features
Wet heath	G	*Zygogonium ericetosum* *Trichophum cespitosum*	Upper slopes
	H	*Drosera intermedia* *Sphagnum tenellum*	Lower slopes
Seepage slopes	I	*Sphagnum cuspidatum* *Cladopodiella fluitans*	Micro-hollows
	J	*Sphagnum capillifolium* *Cephalozia connivens*	Micro-hummocks
	K	*Lepidozia setacea* *Odontoschisma sphagni* *Rhynchospora alba*	Smooth gentle gradients
Mire expanse	L	*Myrica gale* *Sphagnum subnitens*	Tussocks and moderate flow
	M	*Sphagnum auriculatum* *Cirsium dissectum*	Impeded and dispersed flow
	N	*Potamogeton polygonifolius* *Juncus bulbosus*	Open flowing water
	O	*Drepanocladus revolvens* *Scorpidium scorpioides* *Campylium stellatum* *Pedicularis palustris*	Base-rich water
Central carr	T	*Sphagnum recurvum* *Aulocomnium palustre*	Carr margin and lawn
	U	*Salix cinerea* *Frangula alnus*	Shrub thicket
	V	*Carex remota* *Mnium hornum*	Groundflora
	W	*Alnus glutinosa* *Fraxinus excelsior*	Carr

6.2.5), but the methodology differs radically. Agglomerative nodal analysis (Atkinson, 1984) proceeds by ordinating species using principal components analysis followed by agglomerative clustering of the output. Considering the heterogeneity of Atkinson's data set, principal components analysis is not the most appropriate ordination technique. Given the long community gradients within the data, reciprocal averaging would be more effective on theoretical (Hill, 1973) and empirical (Gauch *et al*, 1977) grounds. Furthermore, the "arch problem" (e.g. Swan, 1970) discussed in Section 6.2.5 is particularly severe in principal components analysis, where displayed gradients may be involuted so that opposite ends are brought together (Gauch *et al*,1977). Interpretation of the patterns produced are severely restricted under these circumstances (see Austin 1976a). Agglomerative clustering begins by examining small distances between similar samples and, in community data, these small distances are mainly a reflection of "noise" so that agglomerative techniques tend not to be robust (Hill *et al*, 1975). Where overall relationships in the pattern of variation are most important divisive methods are preferable (e.g. Lambert *et al*, 1973; Hill, 1977) for ecological studies. Atkinson's classificatory scheme for mire vegetation also emphasises the importance of hydrology and a downslope progression in community types, but some of his noda are not easily equated with the communities of other workers (see also 6.5.6).

Other recent vegetation studies include the NCC England Field Unit survey (Alcock, 1985), which is discussed in Section 6.5, and which forms the basis of analysis here. Wheeler (1980a,b,c) incorporated some New Forest samples in his study of rich-fen communities of England and Wales, but most mire vegetation is not included, or is mentioned only briefly, since it was outside the scope of his investigation. Wheeler (1984) also reviews valley mires of the New Forest type in relation to other "mixed mire" and valley fen communities.

In conclusion, the common strand to the phytosociological research described here is the importance of water movement and nutrient status which, in turn, depends upon topography and geology. The production studies of Newbould (1960) and Giles (1977) reinforce the functional significance of these factors in relation to plant community composition of the valley mires.

6.4 Gradient analysis of the mire-heath transition : a case study

6.4.1 Introduction

The distribution and area of New Forest valley mires depends upon the vegetation response to waterlogging. The causes and extent of waterlogging were discussed earlier, and here the changes in community composition due to a soil wetness gradient will be investigated.

6.4.2 Methods

Hive Garn Bottom was selected as a study site for the reasons outlined in Section 3.2.3. The distribution of mire and heath communities in a 1ha sampling grid was compared with soil profile characteristics in co-operation with R.H.Allen of the Soil Survey of England and Wales. The grid location and sampling design are also discussed in Chapter 3. Soil profile morphology provides evidence for the long term behaviour of the water regime and indicates the extent of the capillary fringe (Ingram, 1983), or saturated zone, above the water table.

Thirty-seven vegetation samples were collected and the data were classified by TWINSPAN to permit comparison with the soil information, and ordinated using DCA to summarise community patterns in order to facilitate environmental interpretation (Clarke and Allen, 1986).

6.4.3 Results

Four community types were identified by TWINSPAN (Clarke and Allen, 1986). The primary division of the classification reflected a physiognomic distinction between the ericoid- and graminoid - dominated communities of the heath and mire, respectively. At this level, *Sphagnum papillosum* and *Eriophorum angustifolium* were indicator species identifying the mire samples, which subsequently split almost exactly into communities occurring on the seepage step and in the valley bottom. The heathland was divided into a group in which *Pteridium aquilinum* was the dominant, or was co-dominant with *Calluna vulgaris*, and which occurred mainly on the terrace edge. Below, on the valley side, the other heathland group approximated to the "triple heath" community (Williams and Lambert, 1961; Lambert and Williams, 1966), dominated by *Calluna*, *Molinia caerulea* and *Erica tetralix*.

The distribution of plant communities identified at the second level of the TWINSPAN hierarchy corresponded closely to the soil map units in Table 3.1 (Clarke and Allen, 1986).

Ordination of the edited matrix by DCA revealed a single major axis (eigenvalue = 0.601) of floristic variation (Fig. 6.4). The position of the four community types identified by TWINSPAN showed this axis to correspond to a moisture gradient (Clarke and Allen, 1986). This gradient is reflected by the soil profile data. Two features of soil profile morphology can be combined to give an index of soil wetness (Clarke and Allen, unpublished). These are depth of humose and peaty horizons and depth to gleyed horizons (Avery, 1980). The soil wetness index is closely correlated to the scores along axis 1 of the ordination (r_s = 0.766, $p<0.001$). The classical valley mire zonation occurs where the spatial variability in soil moisture is principally in one direction, parallel to the slope, so that both the major environmental and vegetation gradients can be represented directly by a linear cross-valley section. There is not, however, a simple catena at Hive Garn Bottom, due to the variable lithology, and here the main floristic and edaphic gradients are represented by axis 1 in the ordination (Figure 6.5).

Further insight into community composition can be obtained by plotting species abundance along axis 1, which is the ecological response of species to the moisture gradient rescaled in units of beta diversity. This is an alternative approach to direct gradient analysis where the species response curves are plotted directly against an environmental factor. Instead, the principal axis of the ordination has been used to represent the ecological gradient (this is sometimes referred to as "indirect gradient analysis"). The axes of DCA are scaled in units of beta diversity, and gradients rescaled in this way permit clearer interpretation of the width and overlap of species distribution curves (Wilson and Mohler, 1983).

In common with most direct gradient studies, the raw data are "noisy" and so curves must be smoothed to reveal relationships more clearly (Gauch, 1982), this has been done by pooling every four consecutive points. The results are shown for the soil wetness index (Fig. 6.5) and for selected species occurring in the various communities (Fig. 6.6). Of all the species,

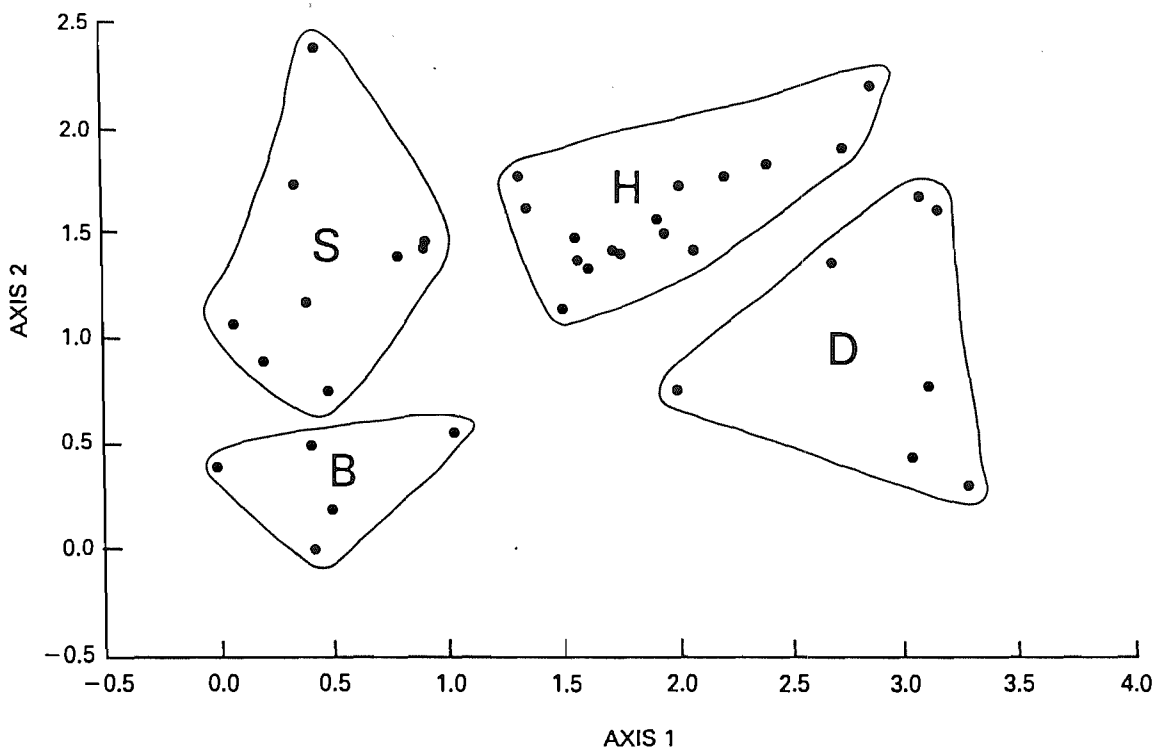


FIGURE 6.4 : DCA ordination of Hive Garn Bottom vegetation samples.
H = Humid heath, D = Dry heath, S = Seepage mire,
B = Valley bottom mire.

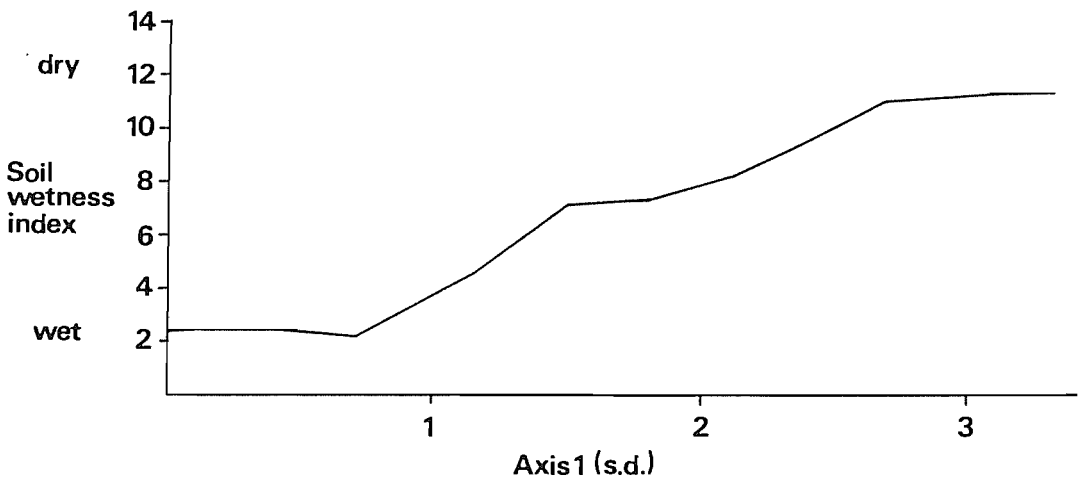


FIGURE 6.5 : Environmental interpretation of the primary gradient in the Hive Garn Bottom vegetation data revealed by DCA. A smoothed curve for the soil wetness index (arbitrary units) is plotted against axis 1.

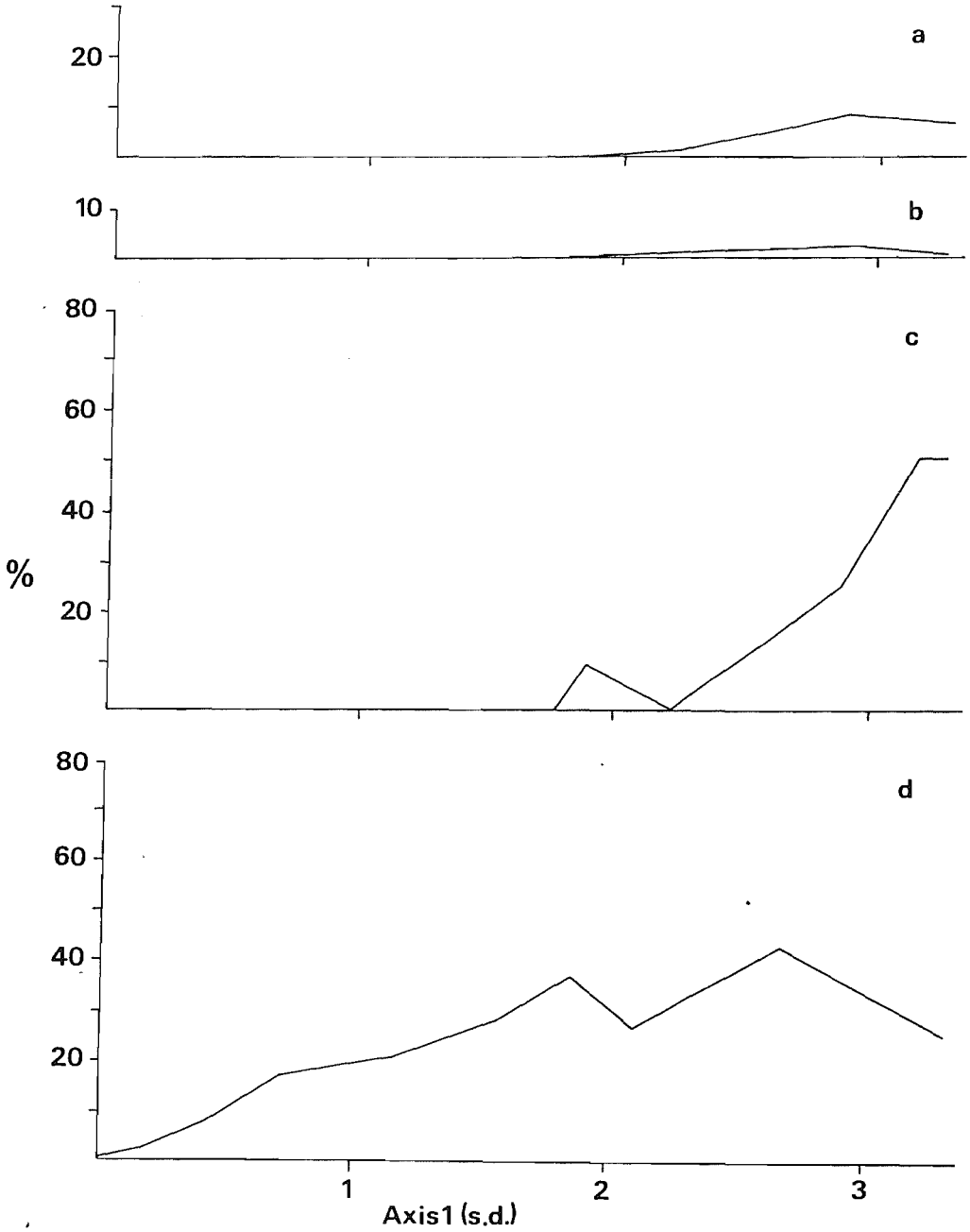


FIGURE 6.6 : Species response curves along the primary DCA gradient, reflecting soil wetness (data smoothed by pooling every four points).
a) *Erica cinerea* b) *Agrostis custisii*
c) *Pteridium* d) *Calluna* e) *Erica tetralix*
f) *Molinia* g) *Trichophorum* h) *Sphagnum compactum*
i) *S. tenellum* j) *S.papillosum* k) *Narthecium*.

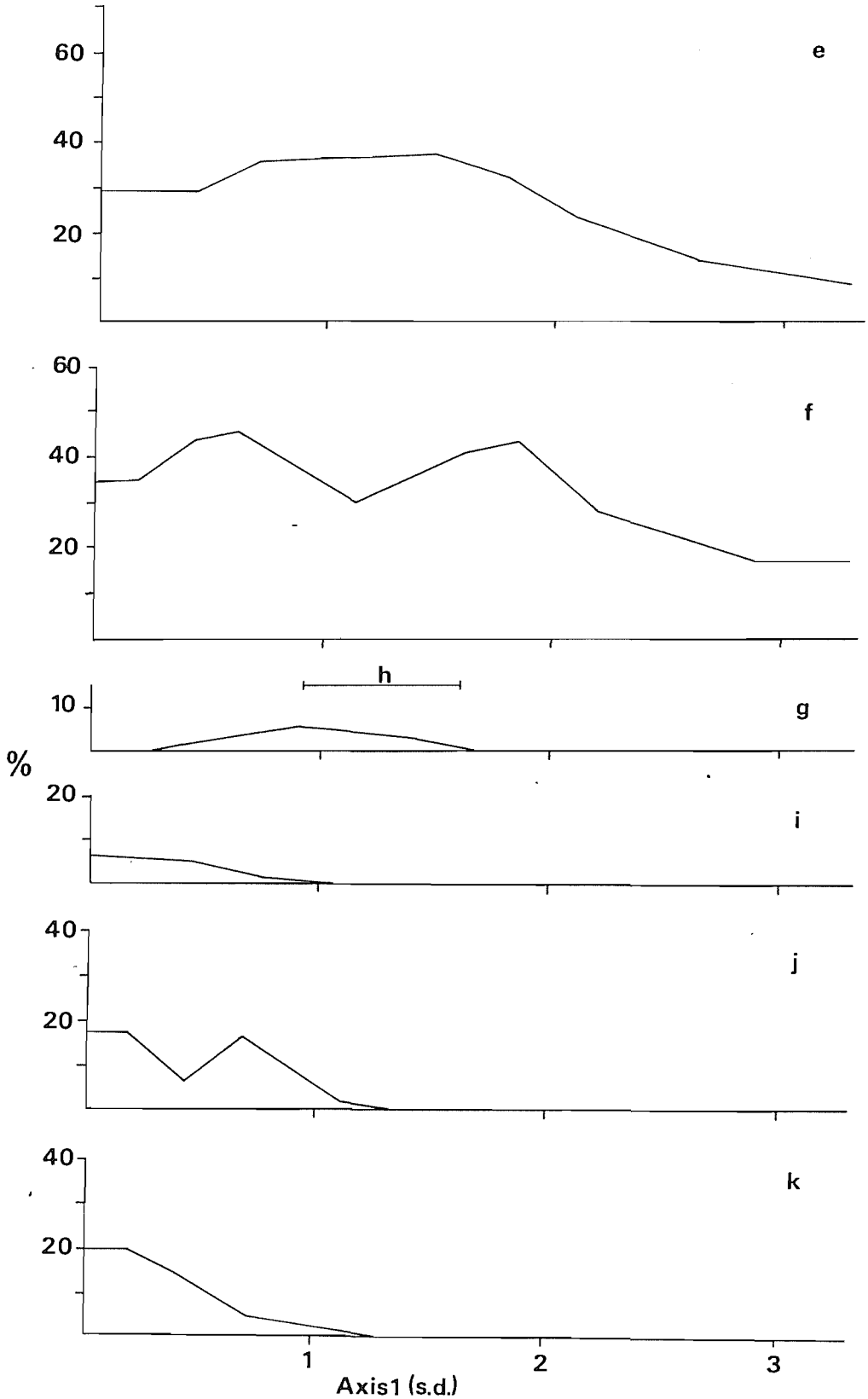


FIGURE 6.6 (continued)

the co-dominants of the "triple heath" grouping show the greatest ecological amplitude and variations in their relative abundances account for much of the overall floristic variation.

The ecological response of a plant species, and hence community composition, is determined by its physiological response and biotic interactions such as competition (Wuenscher, 1969; van Grounewoud, 1976). The distribution of species along the wetness gradients compares well with the results of comparative physiological studies of tolerance to waterlogging by heathland and mire species. Both *E.cinerea* and *Calluna* (6.6i and ii) show declining abundance with increasing soil wetness, but *Calluna* occurs over a wider range of conditions. *E.cinerea* readily succumbs to waterlogging (Bannister, 1964a; Jones and Etherington, 1970; Davies, 1984) since it requires a high level of relative turgidity to be maintained. This depends upon sustained root activity (Bannister, 1964a) which is inhibited by waterlogging due to the anaerobic conditions, in which reduced Fe^{2+} (and also Mn^{2+}) becomes an important toxin (Jones, 1971), possibly by decreasing the membrane permeability of the root system (Armstrong, 1981). Bannister (1964b) attributed the greater ecological amplitude of *Calluna* to its ability to tolerate low levels of transpiration and a wide range of relative turgidities or water deficits.

Erica tetralix displays the opposite distribution (Fig. 6.6iii) and is sensitive to any water deficit (Bannister, 1964a). *E.tetralix* is more tolerant of Fe^{2+} and Mn^{2+} and this appears to be attributable to amelioration of the rhizosphere by internal ventilation, so that iron is immobolised both inside and outside the roots through oxygen enrichment (Jones, 1971), this is a common strategy in wetland plants (Armstrong, 1981). The tolerance of *Calluna* to waterlogging leads to reduced assimilation in wetter areas and *E.tetralix* is able to maintain a higher growth rate than *Calluna* in these environments (Bannister, 1964b). Gloaguen (1987) has shown that these three ericaceous species (and also *E.ciliaris*) have relatively similar physiological amplitudes with respect to soil wetness and all respond best to moist but well aerated soils. From this, Gloaguen suggests that the differing ecological distributions of these species are shaped largely by competition.

Molinia (Fig. 6.6vi) has a similar response curve to *Erica tetralis* and is

abundant over a wide range of conditions, but is limited to those soils with lower moisture status. It has long been known that *Molinia* performs best in situations with moving ground water (e.g. Jefferies, 1915; Pearsall, 1950; Gore and Urquhart, 1966; Armstrong and Boatman, 1967), but the underlying reasons are not clear. Rutter (1955) found *Molinia* growth was correlated with water-table fluctuation and offered two alternative explanations for his observations, both of which stressed the importance of aeration. He proposed that the water-table fluctuation may act directly by providing periodic oxidation, or it may indicate moving groundwater which not only increases the rate of oxygen supply, but also lowers toxin concentrations and provides a higher nutrient input. Subsequent research has shown that *Molinia* will only tolerate mildly reducing conditions (Gore and Urquhart, 1966; Armstrong and Boatman, 1967) and its productivity is related to nutrient supply (Loach, 1966; Sheikh, 1969a). Thus, *Molinia* abundance increases with soil wetness, but it is restricted from waterlogged sites with low flow due to high concentrations of CO_2 and H_2S (Armstrong and Boatman, 1967; Sheikh, 1969b). The relatively steep slopes at Hive Garn Bottom ensure high rates of water movement for *Molinia* growth (Fig. 6.6vi).

A group of species were recorded mainly from the transition zone between the heath and mire, notably *Trichophorum cespitosum* and also *Sphagnum compactum* (Fig. 6.6Vii). (A wet heath community was not identified at Hive Garn Bottom and the possible reasons for this are discussed below). Comparison with the soil wetness index in Figure 6.5 shows that both these species have their centres of distribution along the moisture gradient away from the main mire species, and where there is relatively rapid change in the soil water regime. In this respect, *Trichophorum* shows an interesting relationship to *Molinia*.

The ecological response curve of *Molinia* (Fig. 6.6vi) is bimodal with the trough corresponding to the curve for *Trichophorum*. This feature is commonly a result of interspecific competition (e.g. Fresco, 1982, but see Ernst, 1978). Both species are similar tussock-forming graminoids and this is a particularly successful life-form (Grime, 1979). However, the tussock-forming ability of *Molinia* is negatively correlated to the mean water table depth (Rutter, 1955) and decreases along axis 1, especially in the mire-heath transition zone. Furthermore, the

Trichophorum mire communities of upland Britain (e.g. Birks and Birks, 1974; Rodwell, in prep.) are developed on drier surfaces than many valley mires, often associated with species less tolerant of waterlogging, such as *Calluna*. The distribution of *Trichophorum* in the New Forest and other southern heathlands is very distinctive, occurring along seepage zones, in wet heath and on interfluves where there is impeded drainage and seasonal waterlogging. This distribution, therefore, may be the result of *Trichophorum's* superior ability, compared with *Molinia*, to develop competitively-advantageous tussocks in a narrow ecological zone of slightly drier soil moisture conditions.

In addition to *E.tetralix* and *Molinia*, the other frequent mire species, *Sphagnum tenellum* (Fig. 6.6viii), *S.papillosum* (Fig. 6.6ix) and *Narthecium ossifragum* (Fig. 6.6x), all show increasing abundance with higher levels of soil wetness. Interestingly, *S.tenellum* shows a similar distribution to *S.papillosum* and does not occur in drier conditions as might be expected.

Physiological investigations by Hayward and Clymo (1982) suggest that water table fluctuation may also be an important control of or the distribution of *Sphagnum* species, in addition to the well known species zonation in relation to water table depth (e.g. Ratcliffe and Walker, 1958). This arises from a hysteresis effect in *Sphagnum* water content when plants undergo cycles of wetting and drying due to changes in evaporation and water availability. A *Sphagnum* plant may not reach full water content after it has dried because of the way water is conducted up the stem and branches, and will remain in this state until rainfall occurs. Species exhibit this feature to varying degrees, and a small initial difference in water content between competing species may become catastrophic during repeated cycles in times of drought, so that one species remains wet while the other dies due to dehydration. Hayward and Clymo (1982) suggest that this process will be most significant during more extreme summers.

Autecological studies of *Narthecium* suggest that its species response curve has some relationship to *Molinia*, particularly with respect to the oxygenation of water (Daniels, 1975; Miles, 1976). Summerfield (1973) and

Summerfield and Rieley (1975) conclude that the growth of *Narthecium* in Britain is limited by nutrient supply, but Daniels (1975) and Miles (1976) do not support this assertion. Miles (1976) provides evidence to suggest that the performance of *Narthecium* is affected principally by soil aeration and other factors including toxins, such as Fe^{2+}.

6.4.4 Discussion

Classification by TWINSPAN revealed a well-defined division between seepage step and valley mire communities at Hive Garn Bottom. *Sphagnum tenellum* had a much higher constancy (V1) on the seepage step, as had *Narthecium* (V), and *Trichophorum* and *Juncus conglomeratus* were present in many samples. The two mire communities were also separated by DCA along axis 2 of the ordination (Figure 6.4), but ecological interpretation of this axis is hampered by the similar positions along the axis occupied by both mire and heath samples. It may be that two or more variables are confounded with this axis, or it may be due to the method used in DCA to remove any systematic relationships between axes (Hill and Gauch, 1980). Analysis of the mire samples alone showed the seepage step and valley bottom communities to be separated along the main gradient in the vegetation (Clarke and Allen, 1986).

Soil morphology shows there to be seasonal fluctuations in soil waterlogging on the seepage step, but prolonged waterlogging in the valley bottom mire (Clarke and Allen, 1986). This is consistent with the autecological studies and differences in community composition discussed above, which indicates that it is an important environmental distinction between the two mire types. Greater fluctuation in waterlogging on the seepage step should be reflected by more humified peat. In order to test this prediction, humification values were calculated for cores from a stratigraphic survey of the seepage step and valley bottom mires based on the Troels-Smith (1955) system. In this scheme, material resulting from decomposition is termed "substantia humosa" (Sh), and this category was used as an index of humification rather than the alternative "humicity", because it is thought to be more reliable for sediments with varied inorganic elements (Troels-Smith, 1955). The amount of a particular element in a stratigraphic horizon is measured in six categories: 0

(absent), +, 1, 2, 3 and 4. In order to compare cores, an average figure for Sh has to be calculated for each core. This was done by allocating a score to the abundance category of Sh in each horizon (Sh0 = 0, Sh+ = 1, Sh1 = 2, Sh2 = 3, Sh3 = 4, Sh4 = 5). A single mean value for each core was then obtained by multiplying the Sh score of each horizon by its thickness, adding these values together and then dividing by the total thickness of the whole core.

On this basis, average humification values were calculated for 20 cores from the seepage step mire and for 12 cores from the valley bottom mire, and were compared using the Mann - Whitney U-test for ranked data. The mean humification for the seepage step (2.01) was significantly greater (p 0.025) than that of the valley bottom (1.33), and the seepage step peat was shallower and discontinuous laterally compared to the valley bottom. Although seasonal fluctuations in water table depth are known to influence community composition (e.g. Rutter, 1955), it is possible that more extreme events are responsible for a large proportion of peat humification in the seepage zone. In 1984, for example, the whole peat column in the seepage step mire at Hive Garn Bottom was exposed to the air during the summer drought. In this respect, the acrotelm-catotelm division of Ingram (1977) and others is only partially valid for seepage step mires because the catotelm is absent during very dry periods, when the peat is no longer waterlogged. The periodic absence of a catotelm may actually provide a good functional criterion for distinguishing ecotones, such as shallow seepage mires or wet heath, from mires *sensu stricto*, even though they are closely related floristically.

In summary, the change in community composition between heath and valley mire is largely a function of individual species' responses to a wetness gradient. At Hive Garn Bottom, the soil moisture status has a complex spatial distribution and, by using detrended correspondence analysis (DCA), the species zonation for mire and heath samples can be represented by the primary axis of the ordination. When the mire samples are analysed in isolation, floristic variation is correlated to fluctuations in soil waterlogging which is interpreted as the major environmental gradient. Differences in valley bottom and seepage step mire community composition are, therefore, not so much related to waterlogging *per se*,

but more to the degree of watertable movement. This finding can be related to autecological studies, such as those of *Molinia* (e.g. Sheikh, 1969a,b) and *Narthecium* (Daniels, 1975), and also to comparative physiological investigations of *Sphagnum* (Hayward and Clymo, 1982).

6.4.5 Mire and heath community structure : changes in diversity

The mire and heathland samples at Hive Garn Bottom display contrasted attributes in terms of the two components of community diversity discussed in Section 6.2.4. These are related to concepts concerning (i) the diversity within a particular sample or community (alpha diversity), and (ii) the variation between communities within a habitat (beta diversity). The relationship between these components for the vegetation at Hive Garn Bottom is shown in Figure 6.7, where the species richness of samples is plotted against the position of samples along the major gradient revealed by DCA. The units of this gradient are scaled according to species turnover and hence provide a measure of beta diversity along it (Hill and Gauch, 1980). The DCA axis in Figure 6.7 has been split into a mire and heath segment according to the first division of the classification hierarchy.

The mire communities are clearly more species-rich than the heath (Mann-Whitney U-test, $p < 0.001$), but the heathland communities span a greater length along the beta diversity gradient. This is important in relation to ecological assessment criteria, since the heath is more varied but the mire communities are more species-rich at Hive Garn Bottom. The reason for the difference in habitat variation can be seen more easily by examining Whittaker's index of beta diversity for the two habitats (Table 6.4), which is independent of any gradients in the data.

Table 6.4 Calculation of Whittaker's beta diversity index for mire and heath communities at Hive Garn Bottom

	Total number of species (A)	Mean species no. per sample (B)	Beta diversity (=A - B)
Heath	30	6.13	3.89
Mire	38	13.79	1.76

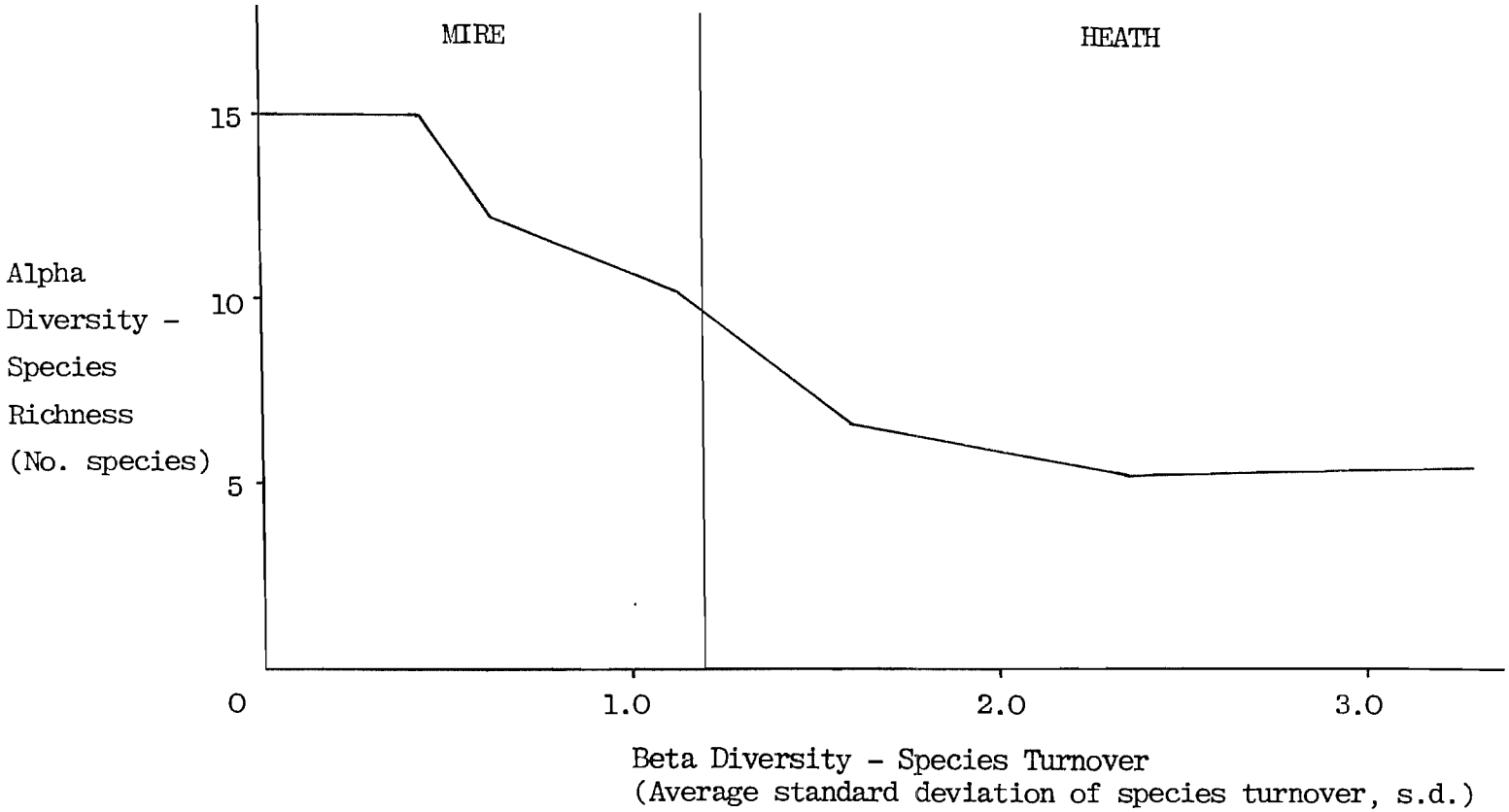


FIGURE 6.7 Changes in alpha and beta diversity at Hive Garn Bottom
Species richness is plotted against species turnover, along the primary ecological gradient revealed by DCA. The graph shows how the heath contains a greater range of communities but is relatively species-poor compared to the mire.
Species richness data smoothed as described in the text.

This table shows that the mire communities share many species in common whereas the heath is partitioned into a number of communities of low species diversity.

Although most lowland heaths are intrinsically poor in species (Gimingham, 1972), the contrast between these two habitats may be exacerbated in the New Forest by frequent burning (see Gimingham, 1972 and Gill and Groves, 1981 for reviews of the effect of fire). For example, the development of lichen-rich heathland requires the establishment of mature and degenerate age stands of heather (Tubbs, 1974), but the Hive Garn Bottom area has a preponderance of younger, even-aged stands due to management objectives, this site having been last burnt in 1979 (Forestry Commission, pers. comm.). The importance of the burning regime is also indicated by the widespread occurrence on the terrace of the introduced moss *Campylopus introflexus*, a post-fire coloniser (Richards, 1963; Richards and Smith, 1975). The development of *Pteridium*-dominated stands is also favoured on more freely draining soils, creating additional heterogeneity within the heathlands, increasing beta diversity, even though the species richness of such stands can be very low.

A notable feature at Hive Garn Bottom is the absence of a species-rich wet heath, particularly in relation to the bryophyte and lichen ground flora. This is a relatively well-defined community that has been described variously as *Ericetum tetralicis* Schwickerath 1933, *Ericetalia tetralicis* Moore 1968, the wet heath of Rose (1953) and the *Erica tetralix* - *Sphagnum compactum* wet heath of the National Vegetation Classification (Rodwell, in prep.). Seepage step mires, such as at Hive Garn Bottom, are closely related floristically to this wet heath association. In particular, *Sphagnum tenellum* and *Trichophorum cespitosum* are important constants and other infrequent associates, such as *S.molle*, are distinctive in both communities (Rodwell, in prep.). The boundary between wet heath and seepage step mire communities is inevitably arbitrary, as Ivimey-Cook *et al*, (1975) point out in their investigation of a similar small heathland valley in east Deven (see also Ivimey-Cook and Proctor, 1967), although the absence of *S.compactum* from the seepage step mire at Hive Garn Bottom could be regarded as a diagnostic

feature. The lack of *Ericetum tetralicis* wet heath below the seepage step at Hive Garn Bottom is surprising in relation to soil profile characteristics, where gleying almost reaches the surface due to slowly permeable subsoils and lateral flow of water from the surrounding catchment. Instead, the heath is species-poor and dominated by *Erica tetralix* with *Molinia* and *Calluna*. Similar stands were noted by Ivimey-Cook *et al*, (1975) and are also described in the National Vegetation Classification (Rodwell, in prep.), where the development of such species-poor heaths is attributed to the effect of frequent burning on *Ericetum tetralicis* communities. It is argued that a number of originally species-rich heath types may converge on an impoverished *Molinia* - *Erica tetralix* - *Calluna* community, through fire depleting the moss layer and favouring *Molinia* (Rodwell, in prep.). The tendency for fire to occur will also be increased due to the abundant leaf litter of *Molinia*. Burning acts on community composition by affecting successional processes, particularly species regeneration and establishment. In a survey of the east Dorset heathlands, Prentice and Prentice (1982) found fire to be an important factor. Analysis by DCA revealed a primary wetness gradient and a secondary gradient for the drier heath samples reflecting the time since burning.

6.5 The classification of New Forest valley mire vegetation and its interpretation

6.5.1 Aims and methods

Community ecology proceeds by a series of steps in which a working hypothesis, such as a particular model of vegetation variation, is progressively revised. It is no different from other branches of science in this respect except, perhaps, that revision is often based on observation rather than direct experimentation. This process has been termed 'successive approximation' following Poore (1955) or 'successive refinement' (e.g. Gauch, 1982). Successive approximation has been a basic tenet of post-war phytosociology, including numerical approaches. Poore (1962, p.38) describes successive approximation as an inductive method based on a "series of inferences each closer to the truth" leading to the formulation of "inductive generalisations". In practice it has similarities to the scientific method of Popper (1963), and successive

approximation is entirely compatible with the hypothetico-deductive approach.

The aims of this section are twofold; they are to describe the variation in the present vegetation of the mires and to put forward hypotheses which may explain the ecological causes of the patterns observed. To this end, certain questions will be addressed specifically:

What are the main plant community types present?
How are these communities related to one another in terms of composition?
What are the important environmental and biotic factors affecting community composition?

A series of analyses were carried out using detrended correspondence analysis (DCA) and two-way indicator species analysis (TWINSPAN), which have been discussed in section 6.2.5. This strategy is based on the successive refinement principle and allows the major facets of the data to be fully expressed. Despite the apparent objectivity of multivariate analyses at one level, the results are heavily determined by the investigator's choice of technique and editing. The advantages of this approach are lost if the methods used and the reasons for selection are not stated clearly. A subsidiary aim, therefore, was to evaluate the options available from DCA and TWINSPAN and the ecological usefulness of these techniques. For convenience, some technical details are omitted here, and are included in Appendix 5.

The data were collected by the England Field Unit of the NCC, in conjunction with Southampton University Department of Geography, during a survey of the mires in 1981 (Alcock, 1985). Twenty-three sites were selected by C.R.Tubbs and K.E.Barber to represent the principal range of site variation (Table 6.5). A stratified sampling scheme was adopted and species were recorded on the Domin scale, site inventories were also made (see Alcock, 1985, for further details). Environmental factors were noted, including measurement of pH and conductivity (mhos cm^{-1}) where possible. In all, 184 quadrats were sampled and 247 species were recorded. A classification, using a single analysis by TWINSPAN, was carried out by Alcock (1985). The aim here is to analyse community variation in more detail, and to evaluate the stability of the groups

identified by TWINSPAN and the ecological relationships within the classification. This provides a descriptive framework for the analysis of environmental factors using ordination.

6.5.2 Environmental data : acidity and corrected conductivity

Acidity and corrected conductivity measurements for the valley mires are plotted in Figure 6.8, based on data collected by the England Field Unit. The distribution of points suggests that there may be a weak negative relationship between pH and conductivity. However, although this relationship can be demonstrated to be statistically significant ($r = -0.205$, $p<0.05$), analysis shows that the five highest corrected conductivity values and the exceptional 7.6 pH sample have a particularly large influence in the correlation. When these samples are excluded, no relationship can be discerned and it would appear that pH and corrected conductivity are essentially independent of one another in the New Forest mires. Hydrogen ions are often a major component of mire waters with low salt content (Sjors, 1950), but these conditions ($K<50$ mhos cm^{-1}) are almost completely absent from the Forest.

Newbould and Gorham (1956) found that under acid conditions in the New Forest mires sodium was predominant over calcium and sulphate was the most abundant anion, whereas in circumneutral water calcium and bicarbonate ions had the highest concentrations. When sodium was added to acid peat, it had little effect on the pH but the corrected conductivity increased markedly (Newbould and Gorham, 1956). By contrast, pH increased rapidly when they added calcium with a relatively minor effect on corrected conductivity. This leads to the suggestion that the high pH sample (with a low corrected conductivity) shown in Figure 6.8 is due to a relatively higher concentration of calcium, and that the high corrected conductivity values associated with low pH are due mainly to the sodium concentration.

Small-scale variations are frequently encountered in valley mires (and other types of mire) in a number of water quality parameters, such as pH, conductivity and redox potential. This presents an inherent problem to the community approach when significant variation occurs at a smaller scale than the sampling unit (e.g. the quadrat). But, it does not invalidate community-level investigation - the now classic post-war

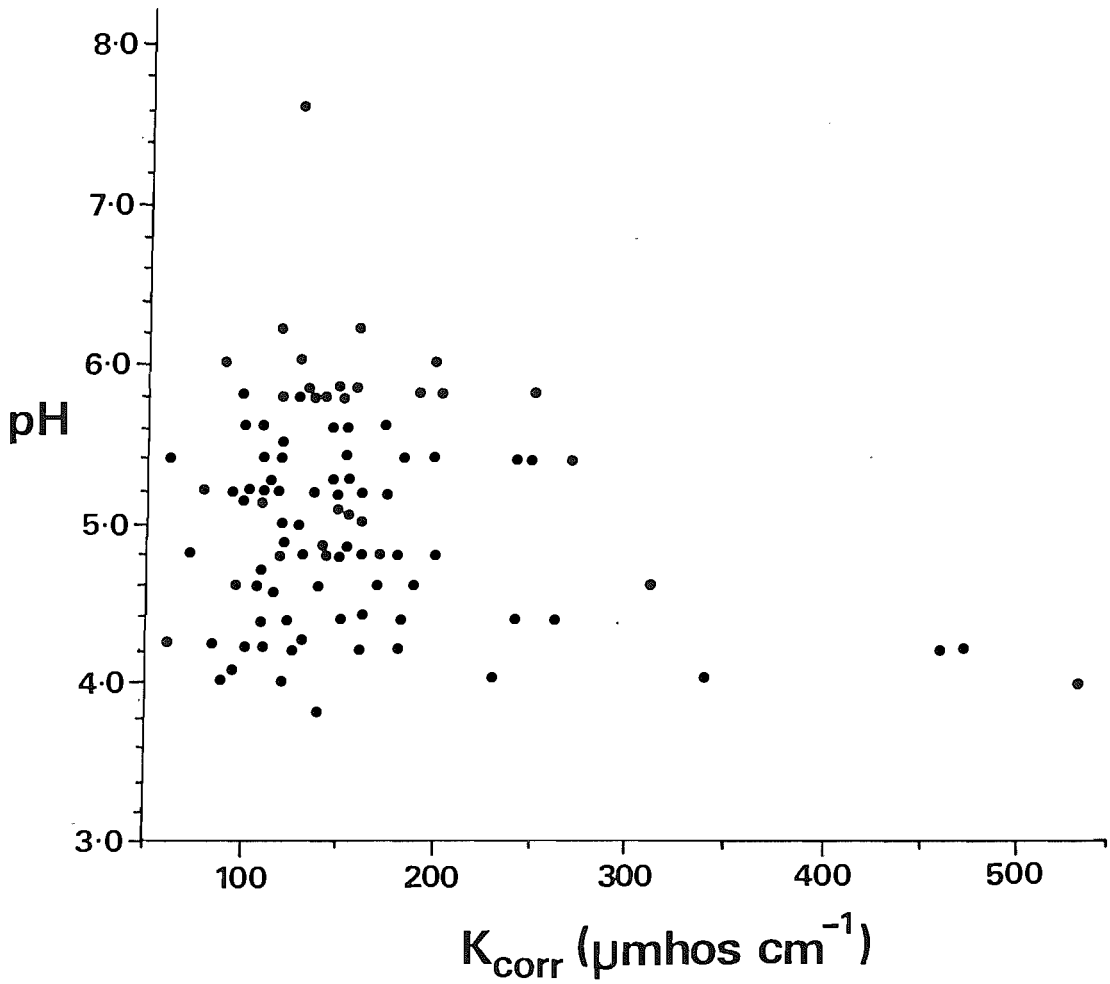


FIGURE 6.8 : Acidity and corrected conductivity measurements for mire water samples (n = 96). Mean pH = 5.1 (standard deviation = 0.67), mean K_{corr} = 156 μmhos cm^{-1} (sd = 80 μmhos cm^{-1}).

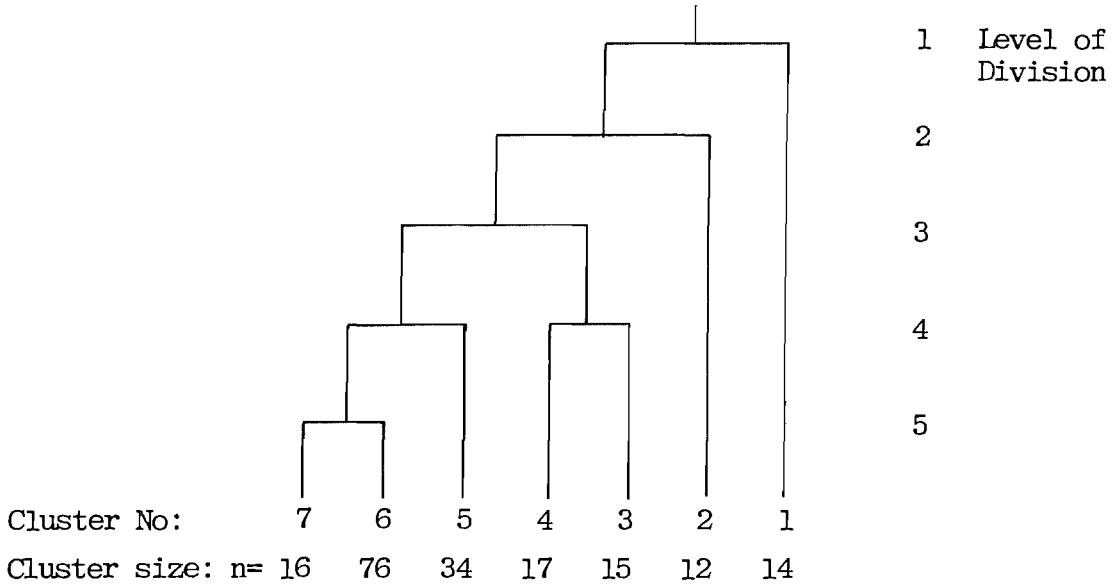
research in mire ecology (see section 6.3) demonstrates the success of this approach in understanding the vegetation - environment relationship. However, it is important to recognise that the community-approach involves a degree of generalisation in its methodology, which means that an exact relationship, or 'fit', between vegetation and environmental data is unlikely.

6.5.5 TWINSPAN vegetation classification

This technique may be carried out with differing degrees of emphasis placed on the relative abundance of the species present. The characteristics of the community can be altered in the analysis by varying the semi-quantitative abundance scale used in TWINSPAN. Three alternative scales were adopted in order to give a variable weighting to dominance in the classification of the mire communities (see Table 1 in Appendix 5): (i) The default option recommended by Hill (1979b), which lays relatively equal emphasis on dominants and species present at low abundance values; (ii) A widely-used alternative scale (e.g. Rodwell, in prep.) that gives more emphasis to the dominants in the sample; (iii) An intermediate between these two scales approximating to a geometric series. In addition, a series of analyses were carried out in which rare species were deleted (corresponding to a frequency of 5% or less for all samples). This is often desirable on technical grounds (e.g. Gauch, 1982) because rare species may distort the analysis but, at the same time, this is counter-productive to the ecologist since these species frequently have distinctive habitat requirements.

An initial classification was used as a base-line against which the other analyses could be compared. For reasons of compatability, the abundance scale (ii) was chosen and rarities were included in the initial analysis, since this corresponds to the National Vegetation Classification and Alcock (1985).

The results of TWINSPAN are similar to those produced by Braun-Blanquet methods, in that a table is produced in which an ordered arrangement of species and samples is made. The concept of constants is a useful summary of the main features of each community type identified by TWINSPAN.



1: Carr canopy
2: Fen carr groundflora
3: Shaded acidic mire
4: Flushed mire
5: *Molinia*-dominated mire
6: *Sphagnum* lawn and hummocks
7: Wet *Sphagnum* lawn and pools

FIGURE 6.9 TWINSPAN classification hierarchy, for the initial analysis

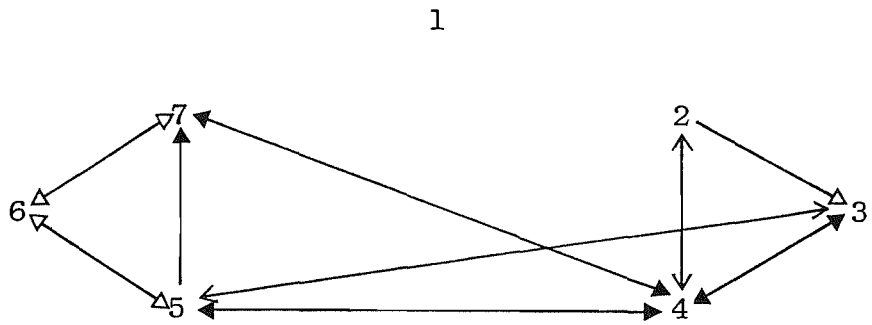


FIGURE 6.10 Relationship between communities as shown by reclassification of samples between clusters using different options in TWINSPAN

——→ low rate of reclassification
——▷ moderate rate of reclassification
——▶ high rate of reclassification

The notion of differential species is also relevant to TWINSPAN. Differential species are those whose occurrence is restricted to certain community types, and are central to Braun-Blanquet phytosociology. The term 'differentiating species' will be used here, instead, for character species in order to avoid implying that they have the same significance as in Braun-Blanquet classification. The following constancy classes will be used for a given species in a particular community type:

I = present in 0-20% of samples
II = 21 - 40%
III = 41 - 60%
IV = 61 - 80%
V = 81 - 100%

6.5.3.1 The initial classification

All species were included in the initial trial. Division of the data set was continued until the clusters obtained were of reasonable size (around 10 - 20 samples) and homogeneity. The dendrogram in Figure 6.9 shows that the classification hierarchy is strongly affected by 'splintering' (Frenkel and Harrison, 1974), whereby clusters are progressively split away from the main body of samples due to almost continuous variation. As a consequence, cluster boundaries were determined at different levels since further division of each cluster identified did not produce more ecologically meaningful groups.

Level 1 : Cluster 1 - Carr canopy

The carr canopy community forms a very discrete cluster with subsequent division separating *Alnus* dominated samples from *Salix* - *Betula* - *Myrica* stands.

Constants :	*Alnus glutinosa*	IV	*Quercus robur*	III
	Salix cinerea	IV	*Ilex aquilinum*	III
	Frangula alnus	IV	*Betula pendula*	III
	Lonicera periclymenum	IV		

Level 2 : Cluster 2 - Fen carr groundflora

This groundflora community is relatively species rich (mean = 23.7 species per quadrat) and is associated with both carr canopy types. It is distinguished particularly by the presence of *Mnium hornum*, *Carex remota* and *Galium palustre*.

Constants:	*Mnium hornum* V	*Calypogeia fissa* III	*Pellia epiphylla* III
	Carex remota IV	*Ranunculus repens* III	*Juncus effusus* III
	Mentha aquatica IV	*Sphagnum palustre* III	*Lonicera periclymenum* III
	Carex paniculata IV	*Athynium filix-femina* III	*Ranunculus flammula* III
	Galium palustre IV	*Eurhynchium praelongum* III	
	Dryopteris dilatata IV		

Differentiating species: *Mnium hornum, Carex paniculata, C.remota, Galium palustre, Athyrium filix - femina*

Level 3

Both clusters 3 and 4 are characterised by the presence of *Agrostis canina* and the absence or low frequency of several species associated with clusters 5, 6 and 7, such as *Sphagnum papillosum, Erica tetralix, Drosera rotundifolia,* and *Narthecium ossifragum.* In addition, *Hypericum elodes, Hydrocotyle vulgaris* and *Juncus effusus* are all distinctive of clusters 3 and 4.

Level 4 : Cluster 3 - Shaded acidic mire

High cover values of *Sphagnum recurvum* are characteristic of this community coupled with very low species richness (mean = 12.2). Other dominants include shade tolerants such as *S.palustre,* and *Juncus acutiflorus* may be particularly abundant in light gaps. This community occurs as a groundflora stand beneath mainly *Salix - Betula - Myrica* carr canopy or marginal to carr and other woodland (e.g. Barrow Moor in Mark Ash Wood). The classification dendrogram indicates that this community is more closely related to the flushed mire community (cluster 4) than to the fen carr groundflora (cluster 2). On the whole, it lacks the differentiating species of either of these two other communities and it may represent a species-poor, shaded variant of the flushed mire community.

Constants:	*Sphagnum recurvum*	V	*Sphagnum palustre*	III
	Juncus acutiflorus	V	*Calliergon stramineum*	III
	Molinia caerulea	V	*Juncus effusus*	III
	Agrostis canina	V		

Level 4 : Cluster 4 - Flushed mire

Most samples in which flushing was observed were classified in this cluster which also includes some samples from mire pools. It is distinguished from the shaded acidic mire (cluster 3) by the presence of *Eriophorum angusti-*

folium, *Cirsium dissectum* and *Carex panicea*, also *Potamogeton polygonifolius* is often abundant.

Constants:		
	Molinia caerulea V	*Juncus bulbosus* III
	Cirsium dissectum V	*Potentilla erecta* III
	Eriophorum angustifolium IV	*Agrostis canina* III
	Myrica gale IV	*Anagallis tenella* III
	Potamogeton polygonifolius IV	*Carex panicea* III
	Juncus acutiflorus IV	*Ranunculus flammula* III
	Carex echinata IV	
	Hypericum elodes IV	

Differentiating species: *Hypericum elodes* and *Carex nigra* are weak differentiating species

Level 4 : Cluster 5 - *Molinia*-dominated mire

This community is species-poor (mean = 14.8) and dominated by *Molinia caerulea*, which characteristically exceeds 25% cover and is often in excess of 50%. *Erica tetralix* and *Myrica gale* are also important components of the community. Some species more tolerant of shading are often present, such as *Sphagnum palustre*, *S.recurvum* and *Juncus acutiflorus*, whereas others have reduced frequency and abundance compared to clusters 6 and 7, including *Drosera rotundifolia*, *Narthecium ossifragum* and *Rhynchospora alba*. This tussocky community occurs in a contact zone with wet heath and in wetter areas of the mire expanse.

Constants:		
	Molinia caerulea V	*Cephalozia machrostachya* III
	Myrica gale V	*Sphagnum palustre* III
	Erica tetralix V	*Sphagnum recurvum* III
	Juncus acutiflorus V	*Narthecium ossifragum* III
	Eriophorum angustifolium IV	*Calypogeia fissa* III

Level 5 : Cluster 6 - *Sphagnum* lawn and hummocks

High abundance values of *Sphagnum papillosum*, the presence of *Lepidozia setacea*, *Cephalozia connivens* and *Erica tetralix* distinguish this community from the wet *Sphagnum* lawn and pools (cluster 7), as does the absence of *Menyanthes trifoliata* and low abundance of *Potamogeton polygonifolius*. Hummocks and tussocks of this community often form a mosaic with stands of the wetter cluster 7.

Constants:			
	Eriophorum angustifolium V	*Rhynchospora alba* IV	*Odontoschisma sphagni* III
	Narthecium ossifragum V	*Myrica gale* IV	*Calluna vulgaris* III
	Molinia caerulea V	*Cephalozia machrostachya* IV	*Cladopodiella fluitans* III

TABLE 6.5 Sites in the England Field Unit vegetation survey (Alcock, 1985) analysed here. See Appendix 1 for O.S. grid references

1. Church Moor
2. Barrow Moor
3. Warwickslade Bog
4. The Noads
5. Gritnam Bog
6. Avon Water East
7. Cranes Moor
8. Rakes Brakes Bottom
9. Fawley Bog System
10. Linwood Bog/Digden Bottom
11. Holmsley Bog
12. Hincheslea Bog
13. Denny/Shatterford Bog System
14. Crockford Bottom
15. Bramble Hill Bog
16. Cadnam Common
17. Row Hill Bog
18. White Moor
19. Fort Bog
20. CrabTree Bog
21. Wilverley Bog
22. Vales Moor
23. Matley Bog

TABLE 6.6 Classification stability of the mire communities identified by TWINSPAN in six different trials

Cluster	Community	No. of samples	Mean % of samples reclassified due to: Abundance scale used	Effect of rare species	Average rate (% of reclassification)
1	Carr canopy	14	0	0	0
2	Fen carr groundflora	12	17	8	11.6
3	Shaded acidic mire	15	13	11	11.8
4	Flushed mire	17	26	23	24.2
5	*Molinia*-dominated	34	13	13	13.0
6	*Sphagnum* lawn	76	11	4	6.8
7	Wet *Sphagnum* lawn and pools	16	28	19	22.6

Sphagnum papillo-sum V	*Lepidozia setacea* IV	*Sphagnum cuspidatum* III
Drosera rotundifolia V	*Sphagnum auriculatum* IV	*Eleocharis multicaulis* III
Erica tetralix V		

Differentiating species: *Sphagnum tenellum*, *S.capillofolium* and *Lepidozia setacea* are weak differentiating species as is *Pinus sylvestris*

Level 5 : Cluster 7 - Wet *Sphagnum* lawn and pools

This community shows some similarities to the flushed mire community (cluster 4) despite the differences discussed at level 3 of the classification hierarchy. *Menyanthes trifoliata* and *Carex rostrata* are more frequent than in the flushed mire. Liverworts are almost absent and the wet conditions are reflected by the absence of *Calluna vulgaris*.

Constants:	*Potamogeton polygonifolius* V	*Juncus acutiflorus* IV	*Rhynchospora alba* III
	Molinia caerulea V	*Sphagnum papillosum* IV	*Drosera rotundifolia* III
	Eleocharis multicaulis V	*Sphagnum auriculatum* IV	*Riccardia pinguis* III
	Myrica gale V	*Carex panicea* III	*Menyanthes trifoliata* III
	Eriophorum angustifolium V	*Phragmites australis* III	
	Narthecium ossifragum V	*Cirsium dissectum* III	

6.5.3.2 The effect of relative abundance and rarities on the classification

Each of the three abundance scales were run on TWINSPAN with and without rare species (frequency 5%) included in the data set. The variations produced in the classification are instructive, since they reveal relationships between the community types that are not shown in the dendrogram and they indicate the main sources of variation between these clusters. In all cases, not surprisingly, the carr canopy cluster was split off first. However, although the main features of the classification were consistant, approximately 30% of all samples (excluding the carr canopy) were reclassified in the six different trials. The flushed mire and the wet *Sphagnum* lawn and pools communities (clusters 4 and 7) were particularly unstable, (Table 6.6) and samples oscillated between these two groups and also the *Molinia*-dominated community (cluster 5). Other interactions were

weaker but reclassification of samples was relatively frequent between the shaded acidic mire (cluster 3) and the flushed mire (cluster 4). The relationship between clusters is summarised in Figure 6.10. Most of the differences in classification can be attributed to the presence of two species-poor communities which are strongly dominated by *Sphagnum recurvum* (cluster 3) and *Molinia caerulea* (cluster 5), respectively. In this case, the composition of clusters very much depends on the emphasis given in TWINSPAN to dominance versus presence or absence, and whether species of very low frequency (usually present in the species-rich communities) are included. The major changes in sample classification arose from variations in the construction of the classification hierarchy. This is because TWINSPAN tends to split the reciprocal averaging ordination space into equal volumes at each stage of the hierarchy (see Appendix 5). For example, when the wet *Sphagnum* lawn and pools community was split off at level 4 instead of level 5 of the dendrogram, it was larger and incorporated a wider variety of samples (which were included in other clusters when this community was split off at level 5).

6.5.3.3 Changes in the classification due to the exclusion of rare species

In this trial, the abundance scale of the initial classification was retained but rare species were deleted prior to analysis. The changes in classification are as follows.

1. Carr canopy. This group remained unchanged although the division differed between the *Alnus*-dominated and *Salix - Betula - Myrica* community types.

2. Fen carr groundflora. There was little change except that *Galium palustre* was more diagnostic than in the initial classification.

3. Shaded acidic mire. This was very similar with high cover values of *Sphagnum recurvum* and *Juncus acutiflorus*, and with *Agrostis canina* and *Molinia caerulea* as associates, but there were fewer constants.

4. Flushed mire. *Hydrocotyle vulgaris* (III) and *Carex nigra* (III) differentiated this community more clearly from the wet lawn and pools community (7). Other additional constants were *Aulocomnium palustre* (III) and *Sphagnum auriculatum* (III).

5 & 6. *Molinia*-dominated mire and *Sphagnum* lawn. There was negligible change in these communities

7. Wet *Sphagnum* lawn and pools. This group was distinguished from the flushed community (4) by the presence of *Sphagnum papillosum*, *S.subnitens*, *Erica tetralix*, *Drosera rotundifolia* *Narthecium ossifragum*.

6.5.3.4 Changes in the classification due to less emphasis on dominance

The original default abundance scale used in TWINSPAN (Hill, 1979b) places less emphasis on dominance. Comparison of the clusters obtained using the default scale with the initial classification showed that 15% of all samples were reclassified. The principal difference was that the *Sphagnum recurvum*-dominated community (3) and the *Molinia*-dominated community (5) included samples which were excluded previously because the cover values of these dominant species had been too low. This altered the composition of the other three herbaceous communities:

2. Fen carr groundflora. *Galium palustre* was, again, a more diagnostic differentiating species. *Athyrium filix-femina* showed reduced constancy, while the constancy of *Scutellaria minor* (III) and *Lysimachia vulgaris* increased.

4. Flushed mire. This cluster included samples previously placed in the wet *Sphagnum* lawn and pools community, so that the difference between these two groups was less distinct.

The default abundance scale was found to be less robust with respect to rarity than the scale used in the initial classification - there was a much higher rate of reclassification where rare species were omitted from the analysis. This is because the default cut-levels of Hill (1979b) place relatively more emphasis on the mere presence of a species in a sample.

6.5.3.5 Conclusions from TWINSPAN

The main conclusion to emerge from these results is that, while some of the mire communities are relatively discrete, others grade almost continuously into each other. Consequently, the delimitation of community types is particularly arbitrary for some components of the valley mire

vegetation. However, although differences in the TWINSPAN classification were induced by varying the parameters of analysis, the clusters identified were approximately equivalent which indicates that these groupings do reflect ecologically meaningful communities. The precise location of cluster boundaries is unimportant, the significant point is that a classificatory framework of the valley mires must incorporate some community types which are easily-identified, discrete components of the vegetation and some which cannot be so precisely defined. This working flexibility is a recognition of the irregular community variation in the valley mires, and such variation is best explored by ordination.

6.5.4 Detrended correspondence analysis

Ordination may be used as a data exploration tool - to suggest ecologically-important environmental variables - and as a method by which hypotheses concerning community variation may be tested. In the first case, species are used as indicators whereby their known ecology allows the major directions of variation in the data to be interpreted. In the second instance, it is predicted that certain ecological factors are correlated with the main axes of the ordination, if they are important variables in the community-environment relationship. This requires that the relevant factors are selected at the outset; frequently these will be complexes of factors and particular variables must be chosen as surrogates by which they can be measured. In this way, a community-based approach can be coupled with direct gradient analysis and ecophysiological studies, in order to understand the relationship between vegetation and its environment.

Three main factors may be postulated as important environmental controls of vegetation variation in valley mires of the New Forest type (Rose, 1953; Newbould and Gorham, 1956; Newbould, 1960, Bellamy, 1967; Daniels and Pearson, 1974), as follows:

(i) acid-base status,
(ii) nutrient supply,
(iii) hydrology

It is suggested here that in the New Forest a fourth factor, grazing, may also be added. It has been shown that *Molinia caerulea* is significant

dietary component of commoners' ponies and cattle in the New Forest (Putman *et al*, 1983), and the impoverished flora of *Molinia*-dominated stands in mire vegetation is well known (e.g. Clapham, 1940). An initial prediction of this hypothesis, therefore, is that the abundance of *Molinia* should be correlated to a major component of community variation.

The practicality of direct measurement varies considerably between these factors, and is compounded by spatial and temporal variability. In particular, water flow often takes place through the peat matrix, is diffuse and occurs at very low velocities (see Daniels and Pearson, 1974). Furthermore, nutrient supply is dependent on the rate of water movement, supply area, etc. which may not be easily estimated. The following variables recorded by the England Field Unit were correlated with the results of DCA ordination: pH conductivity (μmhos cm^{-1}) and the cover of *Molinia caerulea* (Domin scale). A visual assessment of the water flow was also made by the England Field Unit, but the reliability of such estimates is unknown beyond gross differences in hydrology (see Daniels and Pearson, 1974 in relation to evidence from field measurement).

6.5.4.1 Results

Detrended correspondence analysis was carried out using all species but rarities were downweighted according to their frequency and abundance. The effect of this and other analytical options is considered along with other technical aspects in Appendix 5. Where possible, the community types identified by the TWINSPAN classification were used to partition DCA ordination space in order to facilitate interpretation.

The first two axes of the ordination are displayed in Figure 6.11. The separation of the carr canopy (cluster 1) from all other communities is very clear. The length of axis 1 and the associated eigenvalue are considerably greater than those of the other axes (see Table 6.7). These features of the ordination show that the presence of carr woodland is the largest source of habitat diversity in the valley mires. Further interpretation is difficult because of the disjunct distribution between

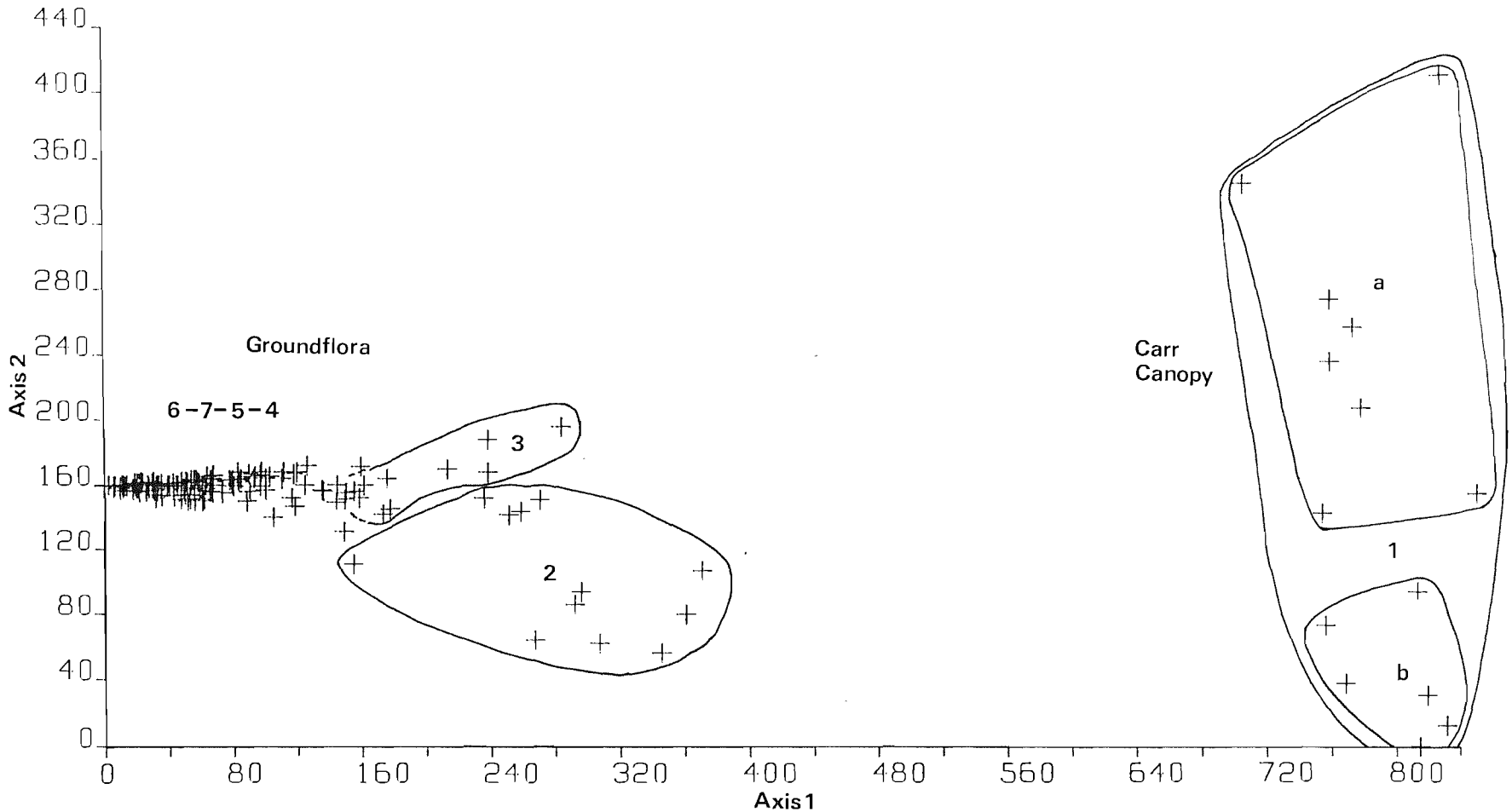


FIGURE 6.11 : DCA ordination of the complete data set with TWINSPAN clusters superimposed (see text and Table 6.10). Axes = s.d. x 100.

the carr and the remaining samples. The second axis displays the variation of the carr community fully but the open mire samples are compressed into a cloud of points little more than 0.4 sd wide.

Table 6.7 Ordination details for the complete data set

	Axis 1	Axis 2	Axis 3	Axis 4
Axis length (s.d.)	8.52	4.12	2.83	4.09
Eigenvalue	0.924	0.344	0.221	0.153

The carr canopy is separated into *Alnus*-dominated and *Salix - Betula - Myrica* communities (indicated as 'a' and 'b' on Figure 6.11). The two canopy types were compared for differences in water quality using measurements from the corresponding groundflora samples. Unfortunately, it was not possible to obtain conductivity measurements for most samples, so that a meaningful comparison of conductivity could not be made. The mean pH for *Alnus*-dominated stands was 5.4 (range 5.0 - 6.0) compared to a mean of 5.14 (range 4.7 - 5.8) for the *Salix - Betula - Myrica* carr, but the statistical significance of this difference was very low ($U = 10$, $p = 0.172$). However, the separation along axis 2 of the fen carr groundflora and acidic shaded mire communities corresponds to the separation of the two canopy communities. Also, within the fen carr groundflora community, those samples associated with *Alnus* stands have lower scores along axis 2 compared to samples occurring under *Salix - Betula - Myrica* stands. This suggests that axis 2 reflects a gradient of increasing base status and nutrient supply within the carr communities.

The overall wedge-shaped distribution of sample points was found to be a distinctive feature of DCA when markedly different communities were included in the analysis. This artefact may be due to the methods used in DCA (see Appendix 5).

The environmental variables were all correlated with the higher axes (especially axis 3 and 4), but these represented composite gradients which confounded interpretation. The variation in the data due to these variables is 'forced' into the higher axes because of the dominant

influence of the disjunct carr canopy group on the ordination. The next stage of analysis, therefore, is to exclude the carr canopy community and re-ordinate the remaining samples, so that the variation in this data can be more fully expressed. The main conclusion from the first ordination of the data emphasises the significance of the carr woodland in enhancing the habitat diversity of the valley mires. It is an important environmental factor in its own right because it creates shade. The presence of carr affects the species richness of a site by generating a new habitat niche for shade-tolerant species to exploit, in addition to the presence of the carr canopy species themselves.

Removal of the carr canopy samples from the analysis leads to a major expansion in the distribution of the rest of the data set on ordination. The variation in the open mire communities (clusters 4 - 7), in particular, is expressed more fully. Figure 6.12 shows the first two DCA axes and correlations with the measured environmental variables are summarised in Table 6.8. There are two main features of this ordination to be considered; (i) the relationship between the distribution of communities in ordination space and the classification obtained by TWINSPAN, and (ii) the ecological gradients reflected by the ordination.

The TWINSPAN classification of the vegetation data can be understood much more fully if the distribution of clusters in the ordination (Fig. 6.12) is compared to the classification dendrogram (Fig. 6.9). Furthermore, the frequent reclassification of samples (Figure 6.10) can also be explained by reference to this distribution. The "splintering" effect in the dendrogram, discussed in section 6.5.3 is due to the continuous distribution of points in ordination space; TWINSPAN progressively splits the ordination as shown in Figure 6.13. The fen carr groundflora is a relatively distinct community but the other communities grade smoothly into one another. The relationship between the flushed community (cluster 4) and the wet *Sphagnum* pools and lawn community (cluster 7) is also much clearer. Whereas the classification hierarchy of TWINSPAN suggests that these are quite separate communities, DCA reveals that they are closely related ecologically. This explains the frequent reclassification of samples between these groups.

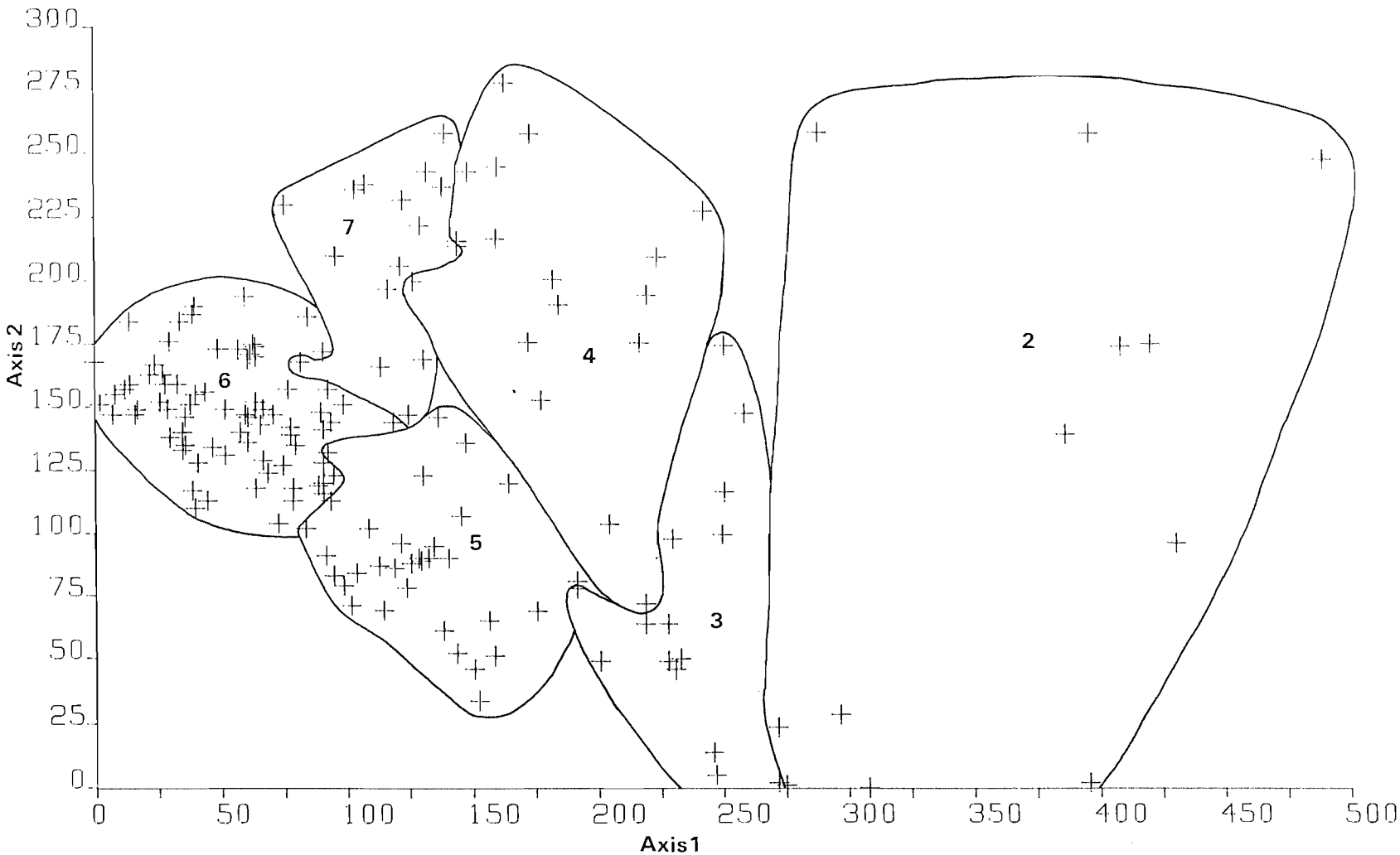


FIGURE 6.12 : DCA ordination of the groundflora communities (see text and Table 6.10). Axes = s.d. x 100.

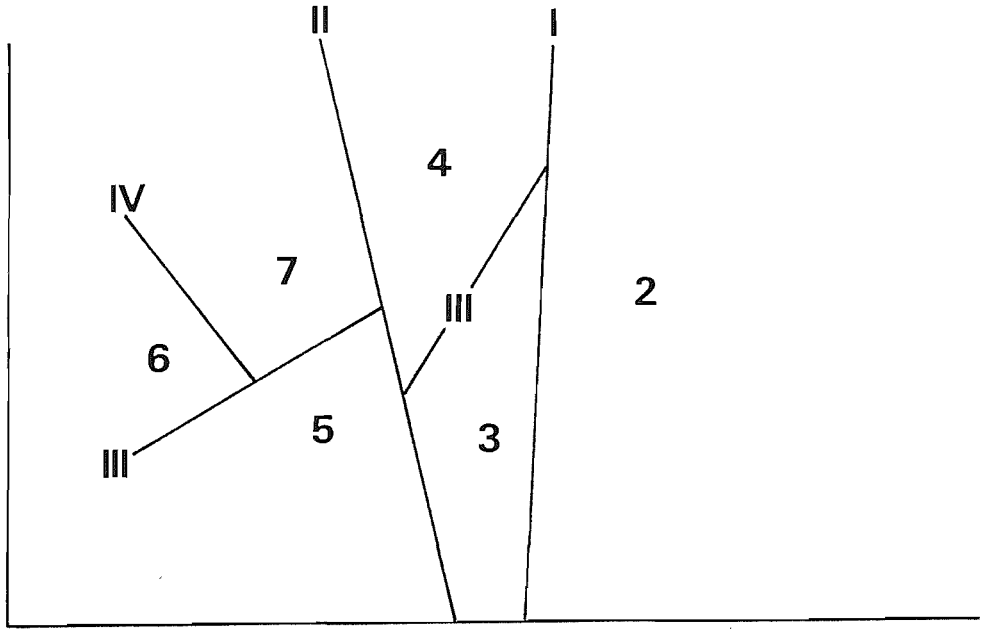


FIGURE 6.13 : Schematic diagram showing the divion of DCA ordination space (Figure 6.12) by TWINSPAN. Each division is numbered according to the level in the classification dendrogram (Figure 6.9), i.e. I = first division.

Ecological interpretation of the ordinated data is greatly facilitated by the exclusion of the carr canopy samples, but the axes still reflect complex composite gradients (see Table 6.8). The primary axis describes a gradient of increasing pH with the *Sphagnum* lawn and fen carr groundflora communities at opposite ends of the gradient. However, it is clear that shade, also, must be an increasingly important environmental factor at the higher end of this axis. The gradient along axis 2 is associated with increasing cover abundance of *Molinia* and *Sphagnum* (especially *S.recurvum*) in one direction, and with increasing species richness in the other. This is essentially a gradient of community diversity and separates those communities which cannot be distinguished solely along the acidity gradient of the first axis.

A further refined ordination was carried out in order to exclude carr canopy shade as an ecological factor, in which samples from the open mire were analysed in isolation from the carr and shaded groundflora communities. Three principal directions of variation were identified for this subset of the data, and these were more readily interpretable compared to the relatively complex and composite gradients of the entire data set (Table 6.9). The first was correlated with pH, increasing wetness and water flow (axis 1, Figure 6.14), while the second axis was closely correlated to the abundance of *Molinia caerulea*. The third gradient shows a strong relationship with the corrected conductivity of the mire water (Figure 6.15). The fourth axis contributed very little to the overall variation in the data and was not easily interpreted (see Table 6.9). In general, only those axes whose eigenvalues are of a similar magnitude to the first, or top, eigenvalue are likely to be of significance (Hill, 1979a). From this, it can be concluded that these three environmental gradients are the most significant source of variation in the plant communities in open areas of the valley mire, and a decreasing order of importance can be attached to them from the first to the third axis. It is interesting to note that most high pH values were associated with flushing, yet corrected conductivity values did not show the same relationship. Similarly, Newbould and Gorham (1956) found that there was a greater difference in acidity between flushed and non-flushed vegetation than compared to corrected conductivity. The concentration of

TABLE 6.8 Correlation of environmental variables with the ordination of the mire groundflora (shown in Figure 6.12). Asterisks denote level of significance (.05, .01, .001). Product moment correlation, except for *Molinia* where Spearman's rank correlation corrected for ties.

	Axis 1	Axis 2	Axis 3	Axis 4	n
pH	0.303***	0.117	-0.311***	-0.257***	138
Corrected conductivity	0.246*	-0.019	0.222*	0.232*	101
Molinia cover	-0.034	-0.465***	-0.102	-0.327***	159
Axis length (s.d.)	4.90	2.78	3.65	2.84	
Eigenvalue	0.495	0.248	0.150	0.124	

TABLE 6.9 Correlation of environmental variables with the ordination of the open mire vegetation (shown in Figures 6.14 and 6.15)

	Axis 1	Axis 2	Axis 3	Axis 4	n
pH	0.483***	0.00	0.248**	0.003	110
Corrected conductivity	0.172	0.042	-0.400***	0.188	88
Molinia cover (r_s)	0.049	0.666***	0.201*	0.009	136
Axis length (s.d.)	2.69	2.41	2.21	1.86	
Eigenvalue	0.308	0.161	0.114	0.099	

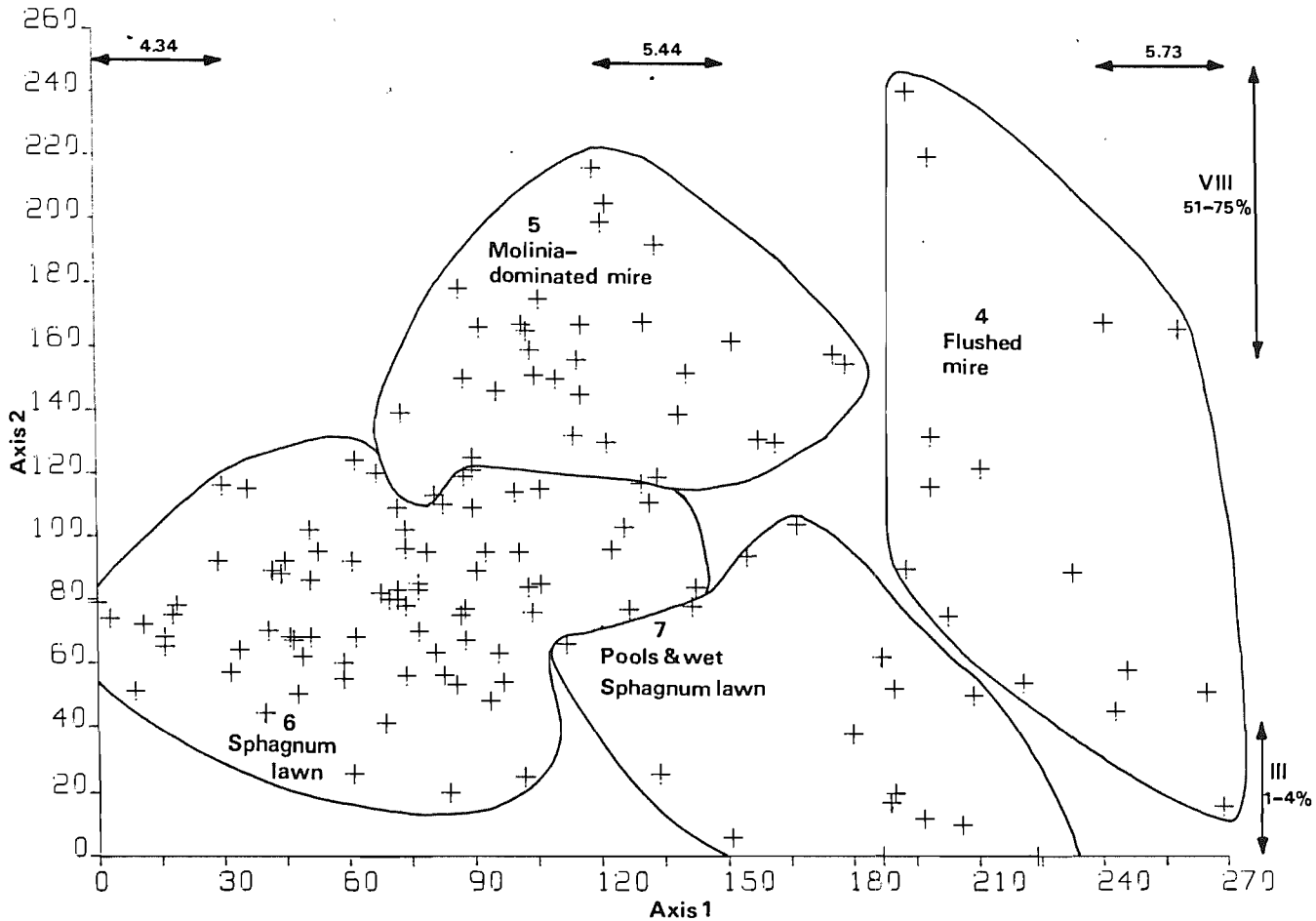


FIGURE 6.14 : DCA ordination of the open mire communities, with mean pH values superimposed on axis 1 and median *Molinia* cover (Domin) on axis 2 (see Table 6.9 and text).

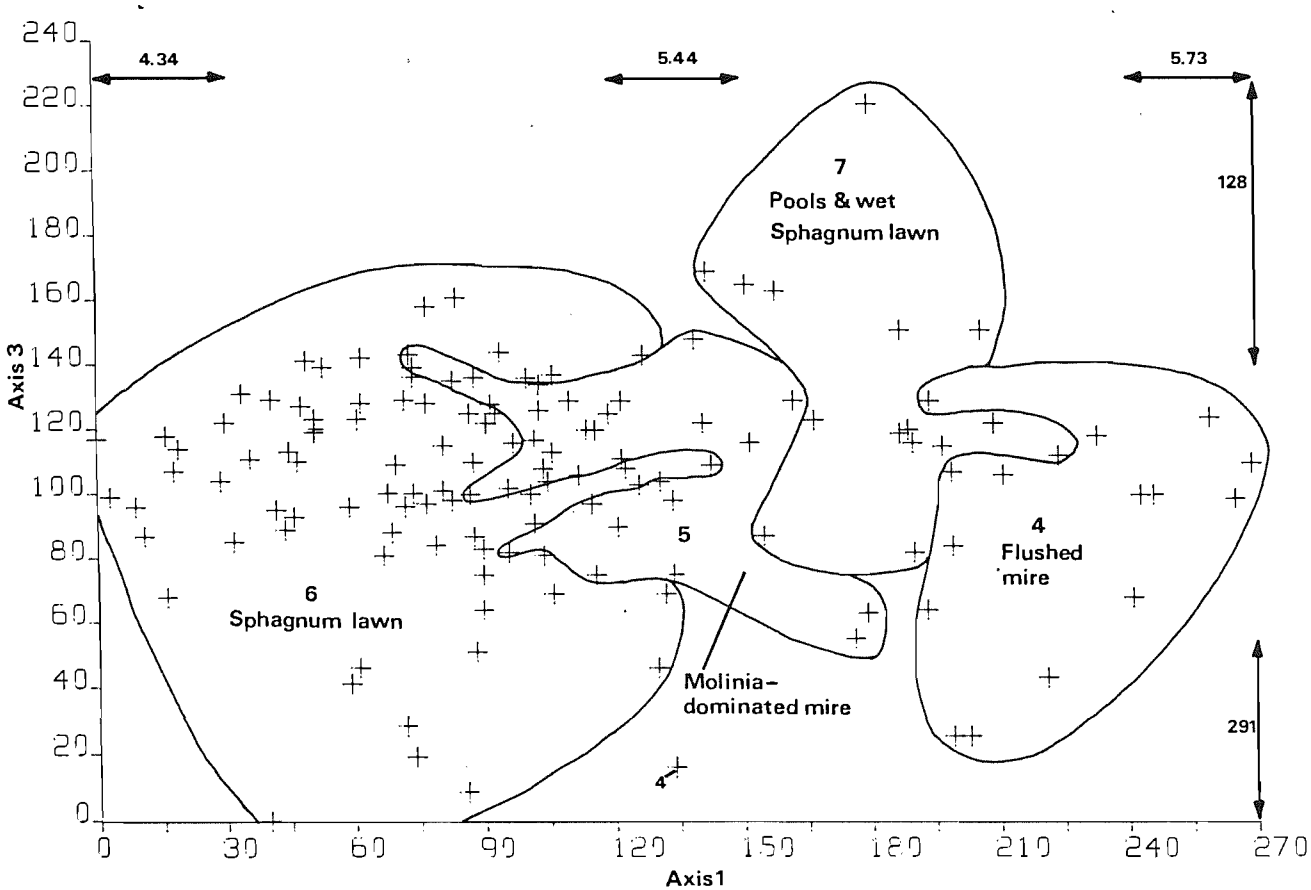


FIGURE 6.15 : DCA ordination of the open mire communities, with mean pH and corrected conductivity values superimposed on axis 1 and 3 (see Table 6.9 and text).

specific ions also appears to be more or less unrelated to water movement. At Roydon Common, Daniels and Pearson (1974) were able to demonstrate a clear correspondence between pH distribution and rates of water movement, but were unable to demonstrate such a pattern for other chemical elements. The rate of water movement, therefore, appears to be the key factor in determining the nutrient flux available to plants in the valley mires.

Detrended correspondence analysis has proved particularly successful in displaying the irregular variation in the valley mire vegetation. In this respect, it has proved superior to TWINSPAN. Mapping of the TWINSPAN groups in ordination space (Figures 6.11 - 15) suggests that a more effective clustering of community types can be made. Furthermore, the analysis by DCA has provided more information on the relationships between communities and on the ecological factors responsible for community differentiation.

6.5.5 A refined classification of the plant communities and ecological interpretation

Gauch and Whittaker (1981) propose a series of division criteria for the optimal classification of continuous community variation into a set of clusters. They suggest that the identification of clusters should ideally, (i) place most emphasis on obtaining an equal range of variation within each community type (the degree of within-cluster similarity); (ii) give less weight to obtaining equal numbers within each cluster; and (iii) attempt to divide the clusters obtained so far along zones where there is maximum separation of the clusters (i.e. regions in space where there is a sparse distribution of points). Classification of the mire vegetation by TWINSPAN showed that, although the carr canopy and the associated fen carr groundflora were relatively discrete communities, the other community types were not naturally clustered. Ordination by DCA demonstrated these findings more clearly. For a given level in the hierarchy, TWINSPAN was effective at partitioning DCA space into roughly equal volumes but cluster boundaries were not necessarily optimally positioned. Also the characteristics of some communities were dependent on the editing options used in TWINSPAN, such as the flushed mire and wet *Sphagnum* lawn and pools. One solution is to adjust the TWINSPAN

cluster boundaries visually, so that they pass through regions of DCA space in which sample points are sparsely distributed. (Gauch and Whittaker, 1981; Gauch, 1982). Where alternative boundaries are equally suitable, borderline samples may be assigned to clusters on the basis of site details and inspection of species composition. This approach is consistent with an emphasis on overall community relationships and makes use of information on community structure expressed by ordination to refine the classification, so that it reflects the major directions in habitat variation more clearly.

This procedure was carried out for the vegetation data. Firstly, the carr canopy and fen carr groundflora communities were excluded from the analysis, because they are ecologically well-defined units in which several differentiating species have a high constancy. However, it should be noted that they occupy disproportionately large volumes of DCA space, and hence encompass a relatively large range of within-community variation. The remaining samples were ordinated by DCA and the TWINSPAN clusters were used to partition DCA space. Several trials were conducted in which dominance and rarity were accorded varying degrees of emphasis, yielding variable cluster boundaries (Figure 6.16a, b, c). Finally, the configuration of the clusters was adjusted as discussed above (Figure 6.16d).

The clusters identified by this method were used to construct a constancy table for the main community types (Table 6.10). The arrangement of species is based on the initial TWINSPAN species classification. Distinctive groupings of species within and between communities are indicated by solid and pecked lines respectively. Table 6.11 summarises the water quality and species richness data for these communities. The main pattern in the vegetation reflects an ecological gradient ranging from almost eutrophic to relatively oligotrophic conditions which is related to mire hydrology, principally the concentration of water flow due to topography. Superimposed upon this pattern are intrinsic, structural features of the vegetation - mainly the carr canopy and the *Molinia* tussocks - which exert a strong influence on community composition by shading.

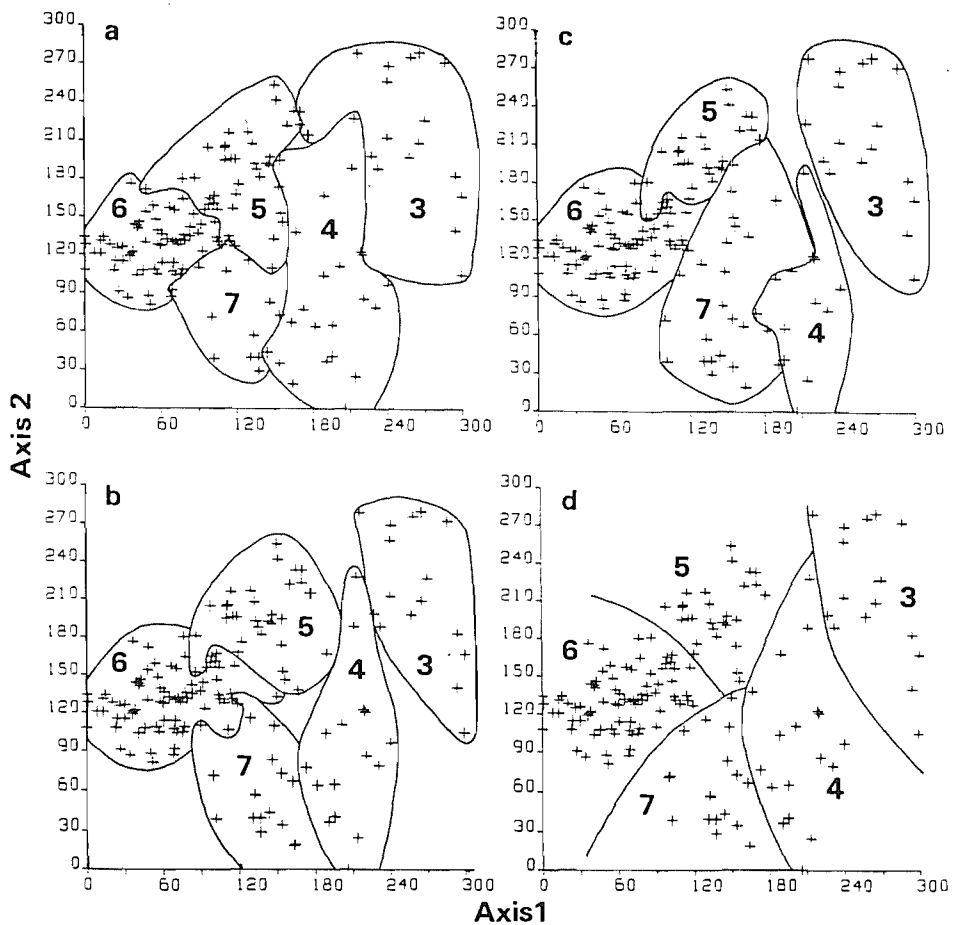


FIGURE 6.16 : Classification of mire vegetation by partitioning of ordination space (see text). Carr canopy and fen carr groundflora communities excluded. a - c are different trials of TWINSPAN: a = low weighting of dominance, b = high weighting c= as b with rare species omitted.

TABLE 6.10 Constancy table for the major New Forest valley mire communities, as classified by TWINSPAN and DCA space partitioning. Order of species is based on the TWINSPAN species classification. Community numbers refer to TWINSPAN clusters

1a : *Alnus* carr
1b : *Salix - Betula - Myrica* carr
2 : Fen carr groundflora
3 : Shaded acidic mire
4 : Flushed mire
7 : Pools and wet *Sphagnum* lawn
5 : *Molinia* - dominated mire
6 : *Sphagnum* lawn

Community group	1a	1b	2	3	4	7	5	6
Sample size	6	8	11	16	19	16	29	79
Alnus glutinosa	V	IV						
Hedera helix	IV	+	I					
Ilex aquifolium	IV	III						
Ionicera periclymenum	V	IV	III					
Frangula alnus	III	IV	III					
Salix cinerea	III	V	+	+	II		I	+
Quercus rober	+	IV	I	+			+	
Betula pubescens	+	IV	II	I	+		+	
Myrica gale		IV	+	II	IV	V	V	IV
Mnium hornum			IV					
Carex remota			V					
Ranunculus repens			III	+				
Athyrium filix-femina			III					
Equisetum palustre			II	+	+	I	+	+
Hypnum cupressiforme			I	+	+		+	+
Carex paniculata			IV	I			+	
Galium palustre			V	+	I			
Lysimachia vulgaris			II	I	+			
Calliergon cuspidatum			II		I	+		
Eurhynchium praelongum			III	+	+			
Pellia epiphyllum			III		+			
Dryopteris dilatata			IV	II			+	
Glyceria fluitans			II	+	+			
Dicranella heteromalla			+	I	+			+
Rubus fruticosus			II	I				
Scutellaria minor			II	II	II			+
Mentha aquatica			IV	+	II			
Ranunculus flammula			III		III			
Juncus effusus			II	III	II		I	
Juncus bulbosus			I	I	III	II	I	I
Calliergon stramineum			+	II	I		+	I
Agrostis canina			I	V	III	I		+
Sphagnum palustre			III	III	II	I	III	I
Carex nigra				I	II		I	
Polytrichum commune				II			+	+
Hypericum elodes				II	IV	I		
Lotus uliginosus				I	I	+		
Hydroctyle vulgaris			+	II	II			
Sphagnum recurvum			II	V	II	I	III	II

TABLE 6.10 (continued)

Community group	1a	1b	2	3	4	7	5	6
Sample size	6	8	11	16	19	16	29	79
Potentilla erecta				I	III	I	I	II
Aulocomnium palustre				I	I	I	II	I
Juncus acutiflorus			+	V	IV	IV	IV	II
Pedicularis palustris					II	I		
Sparganium erectum					II			
Anagallis tenella				+	III	II		I
Carex panicea					IV	III		I
Cirsium dissectum					IV	III	+	I
Potamogeton polygonifolius				I	III	V		I
Carex echinata				I	IV	III	I	+
Carex rostrata					II	II	I	I
Menyanthes trifoliata					II	III	+	
Calypogeia fissa			III	I	II	II	III	II
Cephalozia connivens			I	II		I	II	II
Sphagnum auriculatum			I	+	III	III	I	III
Hypnum ericetorum			I	II		I	II	II
Phragmites australis			I		I	III	II	I
Molinia caerulea			II	V	V	V	V	V
Sphagnum subnitens			+		II	III	II	II
Eleocharis multicaulis					III	V	I	III
Erica tetralix					III	II	V	V
Calluna vulgaris					I	+	III	III
Odontoschisma sphagni			I		+	I	III	III
Sphagnum cuspidatum			+		I	II	II	III
Cladopodiella fluitans			+	I		I	I	III
Narthecium ossifragum					II	V	III	V
Drosera rotundifolia				+	II	IV	II	V
Sphagnum papillosum			+	+	I	III	III	V
Lepidozia setacea						+	II	IV
Cephalozia machrostachya				I	+	I	III	IV
Sphagnum magellanicum						+	I	II
Sphagnum capillifolium			+			I	I	II
Eriophorum angustifolium				+	IV	V	III	V
Riccardia multifida						II		I
Schoenus nigricans						+		I
Drosera intermedia						II	+	I
Utricularia minor						I		+
Cladonia impexa								I
Polygala serpyllifolium								I
Pinus sylvestris							+	I
Sphagnum tenellum								III
Rhynchospora alba						III	+	III
Riccardia pinguis						II		II

TABLE 6.11 Acidity, corrected conductivity and species richness data for the major valley mire communities

[1]NB: Mean = 5.3, when 7.6 pH value removed, range = 4.8 - 6.4

	Community type	pH				Conductivity				Mean No. of species
		Mean	Stan. dev.	Range	n	Mean	Stan. dev.	Range	n	
1	Carr canopy	5.28	0.4	4.7 - 6.0	12	175	-	150 - 200	3	9.1
2	Fen carr groundflora	5.40	0.4	4.8 - 6.0	10	175	-	150 - 200	3	23.8
3	Shaded bog community	5.04	0.6	4.0 - 6.1	14	206	-	150 - 374	5	12.8
4	Flushed open mire	5.33	0.7	4.0 - 6.3	10	221	-	150 - 560	8	19.1
7	Pools and wet *Sphagnum* lawn	5.68[1]	0.5	4.8 - 7.6	14	148	28	104 - 256	12	20.2
5	*Molinia*-dominated	5.09	0.7	4.2 - 6.3	21	139	38	81 - 478	15	14.5
6	*Sphagnum* lawn	4.79	0.6	3.8 - 6.0	63	158	75	70 - 500	41	18.2

The carr communities, aligned along the axis of valleys, are associated with relatively high rates of water flow in water tracks or distinct channels. Acidity is relatively low (Table 6.11) but corrected conductivity values are comparable with most other communities, although the sample size is very small. In terms of nutrient flux, the rate of water flow appears to be much more significant than differences in the instantaneous concentration of solutes. The carr canopy may be split into *Alnus*-dominated and *Salix* thicket communities (Table 6.10, 1a and 1b); *Myrica gale* is characteristic of the latter. Differentiation of the carr canopy corresponds to lower pH and reduced rates of water flow in the *Salix* community. Shade is an important factor in the composition of communities marginal to the carr as well as for the carr groundflora itself. The shaded acidic mire community can be found along the carr edge and adjacent to drier woodland areas, as well as beneath the carr canopy. In contrast, the fen carr groundflora is restricted to areas within the carr. As the names imply, the distribution of the fen carr groundflora is related to significantly higher pH values than the species-poor, shaded acidic mire (Table 6.11, $U = 37$, $p = 0.05$).

Two of the unshaded communities exhibit a similar range of pH and corrected conductivity values to the carr communities. The flushed mire is associated with minerotrophic flushing, often below seepage lines and in water tracks. The shaded acidic community has a number of floristic affinities with the flushed mire (Table 6.10) and lacks any distinct differentiating species. This suggests that it may effectively be a shaded "variant" of the flushed mire, through species impoverishment and enhanced dominance of shade-tolerant species. Although the shaded acidic mire exhibits a lower mean pH than the flushed mire, it is difficult to distinguish between external environmental factors and the modifying effect of large cover values of *Sphagnum* or acidity through cation exchange (Clymo, 1984). The wet *Sphagnum* lawn and pools community develops in zones of slower water movement, frequently forming mosaics with tussocks of the *Molinia*-dominated mire and drier *Sphagnum* lawn. Natural pools are relatively rare in the New Forest mires and peat cutting in the past is probably the most significant cause of the pools present today. The distribution of patterned mires and ombrotrophic hummock-hollow complexes has been related to the interaction of

topography and the hydraulics of ombrotrophic mire systems (e.g. Ivanov, 1981; Ingram, 1983; Boatman, 1983; Foster *et al*, 1983). Compared to ombrotrophic mires, the hydrology of valley mires and fens is poorly understood (Ingram, 1983). However, the permeability of the acrotelm and factors controlling the potential groundwater profile are likely to be important in determining the pattern of surface wetness.

Molinia achieves dominance in a wide range of environmental conditions, from dry marginal areas in a contact zone with wet heath to very wet, central water tracks. *Myrica gale* is most vigorous as a co-dominant in the latter, more nutrient-rich conditions. The *Sphagnum* lawn is the most oligotrophic community with several *Sphagna* virtually restricted to it, such as *S.magellanicum*, *S.capillofolium* and *S.tenellum* (also in wet heath). The hepatics are also most prominent in this community.

6.5.6 Vegetation classification of the New Forest mires : an overview

Table 6.12 shows the relationships between the classification schemes proposed for the New Forest mires. Newbould's communities on Cranes Moor (Newbould, 1960) are included, although he treats the Forest mires as a whole within Rankin's (1911) framework (Newbould and Gorham, 1956). It is convenient to divide the communities of Table 6.12 into two groups; (a) those which show clear similarities to one another and (b) those which are not so directly comparable on a one-to-one basis. Despite the variety of methods used by these authors, a relatively consistent pattern is evident almost throughout. Group A comprises communities at the extremes of habitat variation in the mires (see Figures 6.11 and 6.12) - the carr with associated groundflora communities and the *Sphagnum* dominated open mire. Also included in this group is the *Molinia* - *Myrica* community which was recognised in all classification schemes. The vigorous tussocks of *Molinia* and low species richness make this an ecologically distinct community, despite quite close similarities to other communities solely on floristic composition (Table 6.10, Figure 6.10). The relationships between communities in group B are also made clearer by reference to the ordination results. This group encompasses vegetation in which the boundaries between communities are more arbitrary, because of the continuous variation in the vegetation. For

TABLE 6.12 The relationship between classification schemes for the New Forest valley mires. A = clear one-to-one similarity, B = inter-related but not comparable.

	Moss, Rankin, Tansley 1910 and Rankin 1911	Rose 1953	Newbould 1960 Cranes Moor only	Mussett 1964	Atkinson 1984	This study (Table 6.10)
A	Alder thicket	Carr		*Alnus* carr	Carr	*Alnus* carr
				Salix thicket	*Salix* - *Frangula* thicket	*Salix* carr
	Carr groundflora	Carr field layer			Carr groundflora	Fen carr groundflora
	Molinia association	*Molinia* variant of (3)	*Myrica-Molinia* variant	*Myrica-Molinia* community	*Myrica-S.subnitens-Molinia* tussocks (approx)	*Molinia* - dominated mire
	Sphagnum moor	*Sphagnum* hummocks and hollows	*Rhynchospora-Sphagnum* variant	*Sphagnum* community	3 seepage slope noda and parts of noda M and N	*Sphagnum* lawn
B	Reed swamp associations	Poor fen zone		*Phragmites* community	*S.auriculatum* - *Cirsium dissectum* (nodum M)	Flushed mire
		Sphagnum - *Eriophorum* - *Juncus* Association (3)			*Potamogeton* - *Juncus bulbosus* (nodum N)	Wet *Sphagnum* lawn and pools
					Carr margin and *Sphagnum* lawn	Shaded acidic mire
			Schoenetum	*Schoenus* community	"Brown moss" nodum	

TABLE 6.13 Comparison with national classification schemes for mire communities

PRESENT CLASSIFICATION TABLE 6.10	RATCLIFFE (1977a)	DANIELS (1978)	PETERKEN (1981)	WHEELER (1980a,b,c)	RODWELL (in prep.)
Alnus carr	*Alnus* - *Salix* carr		Alder woodland Stand 7B	*Osmundo-Alnetum glutinosae:typicum*	*Alnus glutinosa -Carex paniculata* woodland
Salix - *Betula-Myrica* carr				*Salix cinerea* carr	*S.cinerea-B.pubescens Phragmites* woodland *Sphagnum* sub-community
Fen carr groundflora		*Betula-Dryopteris/ Galium palustre* noda			
Shaded acidic mire		*Betula-Sphagnum recurvum* nodum			
Flushed mire					*Littorelletea* alliance *Hypericion elodis*
Molinia-dominated mire	*Molinia-Myrica* marginal mire	*Molinia-Myrica* marginal mire		*Molinia-Myrica* community	*Molinia-Myrica* communities
Wet *Sphagnum* lawn and pools		*Eriophorum angustifolium* nodum			*Drosera intermedia -Sphagnum auriculatum* Association (Western type, Hants)
Sphagnum lawn	*Sphagnum*-dominated community	*Molinia-Erica tetralix* nodum			*Narthecio-Sphagnetum Eulanticum*

example, the flushed mire community and the pools and wet *Sphagnum* lawn community were the most difficult to consistently separate by TWINSPAN. This may account for the different, but inter-related communities identified by various workers for vegetation on the open mire or adjacent to the carr, in which there are relatively wet conditions and a high nutrient supply rate.

Valley mire classification in the New Forest is related to national mire vegetation schemes in Table 6.13, using the classification carried out in this study (Table 6.10) as a framework for comparison. Difficulties in adequately sampling community variation at a national level limit the resolution at which these schemes can be compared. Very few systematic surveys of British mire types have been carried out. Daniels (1978) sampled 56 sites in a far-ranging survey and provides a key for assigning quadrats to his noda. Although several valley mire sites were included in his study (including Cranes Moor and Wilverley from the New Forest), it is still difficult to incorporate many community types into his system because they were not sampled in the original survey, e.g. there is no herb-rich alder carr groundflora community. However, Table 6.13 shows that most New Forest mire communities are distinguishable at a more regional scale. The *Molinia - Myrica* and *Sphagnum* communities are recognised by several authors, as are the variants of the carr communities.

Much of the community variation in the New Forest mires falls within the *Narthecio - Sphagnetum eulacticum* of the National Vegetation Classification (Rodwell, in prep.), which is also utilised in TWINSPAN. The NVC recognises two variants of this association, a northern one in which *Sphagnum recurvum* assumes dominance and a southern one, centred on the New Forest and the Poole Basin, in which *S.papillosum* and *S.auriculatum* are the most important *Sphagna* with *S.pulchrum* and *Erica ciliaris* locally dominant. In addition, a bog hollows community is described, for which a "western type" *Drosea intermedia - Sphagnum auriculatum* association is recognised. The Hampshire Basin variant of this association has wet carpets of *Sphagnum* with open water (*S.auriculatum* is very constant), and associates including *Drosera intermedia, Eleocharis multicaulis, Potamogeton polygonifolius,* and *Utricularia minor.* This

association has affinities with the *Littorelletea* communities of shallow acid pools and runnels, including the *Hypericion elodes* association. The NVC scheme, therefore, identifies similar communities with similar affinities as the classification carried out here, but at a coarser, more regional scale.

Communities in which *Schoenus nigricans* is prominent have been included together in group B of Table 6.12. However, there are important differences in the composition and floristic affinities of the communities which have been identified. *Schoenus* is restricted to the southern parts of the Forest, with a concentration of sites in the west but extending in range as far east as Dibden Bottom. It occurs either in nutrient-rich, central water tracks or in valley-side seepages along calcareous outcrops of the Headon Beds. This distribution probably reflects the interaction of nutrient status and local climatic factors (Sparling 1967, 1968). *Schoenus* tussocks often replace *Molinia* as a major structural element of the mire vegetation.

Schoenus is an associate of Atkinson's (1984) "brown moss" nodum (O, Table 6.3), which has *Drepanocladus revolvens*, *Scorpidium scorpioides*, *Campylium stellatum*, and *Pedicularis palustris* as indicator species. This nodum was only recorded by Atkinson (1978) at Thorney (or Stony Moors), and this site is probably the location of the *Schoeno - Juncetum subnodulosi* association of Wheeler (1980b), although a precise site reference is not given. Stony Moors is described in Ratcliffe (1977a) and in an unpublished report by Rose (1959). Seepage from the Headon Beds maintains low acidity in parts of the site. The pH range on 14 August 1983 was 5.9 - 7.8 for surface water in the mire, and 3.2 - 7.1 at 10cm depth in peat.

Less extensive stands of "rich fen" or "brown moss" communities occur at a number of other sites, and species compositional data are given in Table 6.14. In addition there is limited development of this vegetation at Hincheslea (see Alcock, 1985), Widden Bottom (see Newbould and Gorham, 1956) and Little Wood near Hatchet Pond. Goater (1961) describes a brown moss community on Matley Heath, east of the railway, but this has not been relocated and may have been destroyed by forestry plantation.

TABLE 6.14 Species occurrence in "brown moss" or "rich fen" communities in New Forest valley mires.
HB = Holmans Bottom, AD = Acres Down, BH = Boundway Hill, SM = Stony Moors, MG = Magpie Green, LHB = Little Holmsley Bog, CB = Crockford Bottom, HR = Hampton Ridge, LH = Lodge Heath, GR = Godshill Ridge (f = frequent, l = locally, o = occasional, r = rare)

	HB	AD	BH	SM	MG	LHB	CB	HR	LH	GR
Isolepis setacea		o								
Pinguicula vulgaris		lf								
Epipactis palustris			lf							
Gymnadenia conopsea			r							
Briza media			lf							
Plantathera bifolia				r						
Triglochin palustre		r	f	o						
Cratoneuron commutatum		o		o						
Hammarbya paludosa	o					r				
Eriophorum latifolium				lf		o				
Drosera anglica						lf				
Carex nigra	o	r	r			o		r		
Carex pulicaris		o		o						
Carex hostiana		f		o						
Hydrocotyle vulgaris	o	o	lf	o				o		
Cirsium palustre	o	o	o	r				o		
Succisa pratensis	o	r	o	r		o		r		
Drepanocladus revolvens	o		f	f	o	lf		o		
Schoenus nigricans				f	f	f				
Utricularia minor			lf	o	f	o	r			
Calliergon cuspidatum				o	o		o	o		
Ranunculus acris			r							
Holcus lanatus			r							
Anthoxanthum odoratum			o					o		
Agrostis canina			r					r		
Trifolium repens			r					r		
Galium palustre			r					o		
Riccardia pinguis					o	o	o	r		r
Juncus effusus								f		
Pedicularis palustris		lf	o	lf	o	o	o	r		
Drosera intermedia		o	o	r	f	r		f	f	
Carex demissa	f	f	f	f		f	o	f		o
Campylium stellatum	f	f	f	f	f	f		f	f	f
Anagallis tenella	f	f	f	o	f	f	f	f	f	f
Eleocharis multicaulis	f	f	f	o	f	f	lf	f	f	f
Carex panicea	f	f	f	f	o	f	f	f	r	o

TABLE 6.14 (continued)

	HB	AD	BH	SD	MG	LHB	CB	HR	LH	GR
Molinia caerulea	f	f	f	lf	f	f	f	f	f	r
Narthecium ossifragum	f	f	o	r		f	lf			r
Cirsium dissectum	o	f	o	f	o	f	o	r		
Carex echinata	f	lf	o	f	f	f	o	f		
Pinguicula lusitanica		o	r		o	o				r
Eriophorum angustifolium		r	o	r	f	f	f	lf	f	o
Potamogeton polygonifolius	o	lf	o	o	f	f	f	o	r	f
Rhynchospora alba	r	lf	o	r	f	f	o			r
Drosera rotundifolia	lf	f	f	o		f	o	o		f
Juncus acutiflorus	f	f		f	f	f	r	f	lf	f
Juncus articulatus		f				f				
Phragmites australis										
Ranunculus flammula	f			r			r	o		
Equisetum palustre			o				r	f		
Sphagnum subsecundum	r				o					
Sphagnum subnitens				o	f		f			
Juncus bulbosus	f	lf		lf		o	r	r		o
Menyanthes trifoliata			lf	o					o	
Hypericum elodes			r			o	o	f	o	
Aulocomnium palustre	o	r	lf		o	o	o	r		
Myrica gale		f	r		o	f	f	lf	o	r
Potentilla erecta	f	f	o				r	o		
Erica tetralix		f	f			f	o			r
Sphagnum papillosum	lf	o	o			f	o	r	r	r
Sphagnum palustre	lf	o			f		r			
Sphagnum auriculatum var auriculatum					f		o			
Sphagnum capillifolium	r	o	o					o	r	
Sphagnum tenellum		o								
Sphagnum cuspidatum					o		r			

These communities are a minor component of New Forest mire vegetation, in terms of area, but are of immense floristic interest and nature conservation importance.

The sites in Table 6.14 are unified by the joint-occurrence of *Campylium stellatum*, *Anagallis tenella*, *Eleocharis multicaulis*, *Carex panicea* and, to a slightly lesser extent, *Carex demissa*, *Drosera intermedia* and *Pedicularis palustris*. This species grouping is particularly abundant in areas of bare mineral substrate with groundwater upwelling, often forming runnels between more oligotrophic and acidic tussocks or hummocks. Grazing occurs at all these sites and is probably important in maintaining the diversity of these communities (including poaching). By the end of the winter, there may be very little standing crop at some sites (e.g. Stony Moors and Boundway Hill) apart from a short herb and bryophyte layer.

The most well-developed examples of this vegetation occur in valleyside or valley head seepages of the Avon Water catchment (the Stony Moors - Magpie Green complex, Boundway Hill, Little Holmsley Bog and Holmans Bottom), and at Acres Down which is the northernmost outlier of the Headon Beds to outcrop in the Forest. The communities at all these sites are the most species-rich of all the open mire vegetation in the Forest, and include a large number of rarities, although there is great variation in species representation between sites. The latter may reflect historical factors and local isolation by less suitable (i.e. acidic) habitats. Wheeler (1984) has described such mires as "base-rich, low productivity valley fens", since they are generally rich in calcium, but have low levels of dissolved nitrogen and phosphorus. The species richness of these mires is thought to be linked to the low productivity of the communities. In this respect, it may be significant that in the New Forest this mire type is relatively rich in insectivorous plants, including three species of *Drosera*, two species of *Pinguicula* and at least one species of *Utricularia*. In the case of *Pinguicula vulgaris* the insectivorous habit is thought to be in response to a requirement for phosphorous (Karlsson and Carlsson, 1977). The two most extreme sites, Stony Moors and Boundway Hill, are also notable in having water snails (*Limnaea* sp) and earthworms, possibly suggesting marked differences in the structure of the invertebrate communities compared to more typical

mires in the Forest (see Chapter 7). The distribution of the rare damselfly *Coenagrion mercuriale* is strongly associated with this plant community in the New Forest.

Intermediate examples between this and a number of other mire community types occur at several sites. Vegetation at Hincheslea (*Campylium stellatum* rate/absent) and Buckherd Bottom (*Anagallis* rare) shows close relationships with the flushed mire community, such as frequent *Hypericum elodes, Mentha aquatica, Agrostis canina* and *Potamogeton polygonifolius*. Vegetation along the margins of a small *Salix* thicket at Long Bottom includes *Anagallis tenella, Carex panicea, Eleocharis multicaulis, Carex pulicaris, Cirsium palustre, Galium palustre, Lotus uliginosus* and *Carex pallescens*, and shows relationships to flushed mire and shaded acidic mire/fen carr groundflora communities. The England Field Unit stands from Crockford Bottom, which included fen elements, were variously classified by TWINSPAN within the *Sphagnum* lawn community and the pools and wet *Sphagnum* lawn community, which also contained *Schoenus* stands from Cranes Moor.

The vegetation in Table 6.14 also includes a major component of more typical valley mire species (cf Table 6.10), which are most abundant where they are relatively isolated from base-rich water in runnels. This mixture of more "oligotrophic" and "eutrophic" elements (sometimes referred to as "mixed mire") is a distinctive feature and is one reason against classifying New Forest mires as "bog" or "fen". A very similar stand has been described by Ivimey-Cook *et al*, (1975) from Aylesbeare Common, Devon. Wheeler (1980b) places these communities in his *Ericetosum* sub-association of the *Schoeno - Juncetum subnodulosi* (Allorge, 1922), which forms a rather variable grouping.

The National Vegetation Classification (Rodwell, in prep.) recognises a *Schoenus - Juncus subnodulosus* and a *Schoenus - Narthecium* community. The latter is regarded as synonymous with the *Schoenus* stands of Ivimey-Cook *et al*, (1975), the *Schoenus - Juncus subnodulosus* samples of Daniels and Pearson (1974) and the *ericetosum* sub-association of Wheeler (1980b). The sites in Table 6.14 may be placed within this category of the NVC. However, the *Schoenetum* of Newbould (1960) at Cranes Moor is

also included in the *Schoenus - Narthecium* community (Rodwell, in prep.). The *Schoenus* vegetation at Cranes Moor, and a number of other sites, differs in several respects from those in Table 6.14. Floristically, the former is closely linked to *Molinia* and *Sphagnum* dominated vegetation, and are less species-rich with many of the characteristic "fen" species of Table 6.14 absent. This vegetation occurs in central water tracks in the valley bottom, in contrast to valleyside, base-rich seepages which rapidly become more oligotrophic downslope. This suggests that there are important differences in the underlying nutrient dynamics of the two vegetation types.

The *Schoenus - Juncus subnodulosus* mire of the NVC is a much larger grouping (Rodwell, in prep.). This includes much of the vegetation of calcareous flushes and seepage fens in lowland England and Wales (Bellamy and Rose 1961; Wheeler, 1980b, 1984; Ratcliffe and Hattey, 1982). The *Campylium stellatum - Anagallis - Eleocharis multicaulis - Carex panicea* vegetation and other *Schoenus* communities of the New Forest mires do not fit easily into the national classification schemes, and further research is required to clarify the phytosociological relationships between these communities.

On the European scale, there has been little integration of British mire vegetation into continental classification schemes, particularly that of valley mires. Part of the reason is probably due to methodological differences, but also certain "key" species in continental systems are scarce or absent in Britain, such as *Scheuchzeria palustris* (Tallis and Birks, 1965). Moore (1968) includes British and Irish data in his classification of European mires and wet heath, but unfortunately the only releves from the New Forest and similar mires are four wet heath samples from Newbould's (1960) study of Cranes Moor. Dierssen (1982, cited in Atkinson, 1984) includes samples from Cranes Moor and Hincheslea Bog in the *Erico - Sphagnetum magellanici* (Osvald, 1923) Moore 1968. However, although this alliance has *Molinia caerulea, Eriophorum angustifolium* and *Rhynchospora alba* as differential species, it essentially refers to the low hummock vegetation of the classical raised bog (Moore, 1968). The New Forest mires differ in that *Sphagnum magellanicum* is rarer and much less prominent than is typical for this alliance (Moore, 1968),

despite other similarities such as the high frequency of *Narthecium* recorded in the sub-atlantic race of the alliance (at Tregaron Bog, for example).

Duvigneaud (1949) makes reference to the valley moors, described by Rankin (1911), in a comprehensive classification of continental mires but virtually no community data is included from lowland British sites. However, related sites in north-western France are considered in more detail by Duvigneaud. Some of the New Forest mire communities can be matched, to varying degrees, with his classification. The main *Sphagnum* community corresponds closely to the *Narthecio - Sphagnetum acutifolii euatlanticum* (Duvigneaud, 1949). The abundance of hepatics amongst the *Sphagna* is a distinctive feature of this association. Duvigneaud (1949, pp. 74 - 75) gives the following change in dominants for the transition from euatlantic valley mires to continental and then boreo-alpine mires:

Euatlantic:	*Molinia* depauperata *Narthecium ossifragum - Sphagnum subnitens - acutifolium* var *Erica tetralix - Sphagnum papillosum* *Calluna vulgaris - Sphagnum magellanicum* *Eriophorum vaginatum - Sphagnum recurvum* *Empetrum - Ledum - Sphagnum fuscum*
Boreal - alpine:	*Chamaedaphne - Ledum - Sphagnum magellanicum*

The *Molinia* dominated community has similarities with the *Sphagneto - Molinietum* (Smith 1911) Zumpfe 1929, and with the *Sphagneto - Myricetum Gale - molinietosum* Almquist 1929. The herb layer of the latter is described by Duvigneaud (1949, p.111) as "... dominée par des touradons de *Molinia* servant de support aux broussailles de *Myrica*". The wider phytosociological amplitude of *Myrica gale* in the British Isles creates some difficulties for the continental classification schemes, so that the *Myricetum Gale* becomes less well-defined when these "transgressive" elements are incorporated. The shaded acidic mire community is the only other group for which clear affinities can be seen, both with the *Agrostideum caninae euatlanticum* (Gadeceau 1909) Lemée 1938 in which *Juncus effusus* is abundant and *Galium debile* is a characteristic associate, and with the *Juncetum acutiflori - Sphagnetum recurvi* (Schwick, 1938) Duvigneaud 1943. Atkinson (1984) concludes that the phytosociological relationships between New Forest and European mire communities can only be provisional, because of the rigidity of the latter classification

which is dependent on Central European species. A classificatory scheme for mire vegetation for the whole of western Europe requires the incorporation of more data from northern and western regions (e.g. Duvigneaud, 1949), including the British Isles (Atkinson, 1984). In order to do this, a number of methodological and linguistic difficulties will also have to be overcome.

6.5.7 Conclusions

The plant communities identified here (Table 6.10) have been related to five habitat factors. Ordination by DCA has shown that these factors interact to produce composite gradients in ecological space which underly the main directions in community variation. The correlation of environmental measurements with the results from DCA suggests that these factors may be tentatively arranged in order of their importance as controls of community composition:

1) Acidity,
2) Water flow,
3) Shade from the carr canopy,
4) Cover-abundance of *Molinia caerulea*
5) Corrected conductivity (i.e. solute concentration).

This ordering should be qualified by emphasising that the individual effects of each factor cannot be separated, in practice, in the field. For example, as has been discussed above, the effects of water flow and solute concentration are not independent in relation to the nutrient flux. This analysis uses the vegetation data itself to indicate the principal environmental gradients in the mires, and emphasises the importance of internal, structural features of the vegetation in controlling the species composition of the community. In particular, the carr canopy and the *Molinia* tussocks are shown to be almost equally significant habitat factors as mire hydrology and water quality. Other species in the community perceive this structural component of the habitat as a major environmental influence on their performance and hence their ability to compete. The fact that *Molinia* is an important control of community composition is a necessary condition for the hypothesis that grazing has a significant impact on the mires in the New Forest, which is tested in the next chapter.

The community level approach to the vegetation - environment relationship

is limited, however, by virtue of the very scale of the investigation. For example, there may be significant environmental changes within the sampling unit, so that species within a community may be responding to quite different conditions. By way of illustration, acidity in the New Forest mires may vary by up to 3.2pH units between the surface and a 10cm below the surface in the peat. Summerfield (1974) has also demonstrated notable small spatial variations in the water quality of mires. Although less important in the regeneration phase of plants, this will affect mature plants rooting at different levels (compare, say, *Phragmites*, *Drosera* and bryophytes). Despite the statistical significance of correlations between environmental measures and the results of DCA, the correlation coefficients seldom explained more than 50% of the variance. This phenomenon is conventionally regarded as "noise" (Gauch and Whittaker, 1981), but a large part of this unexplained variance is due to small-scale spatial heterogeneity in the environment which cannot be expressed in the biologically abstract concept of the community.

The differential variation in the soil environment with depth may account for the continuous floristic variation within some components of the mire vegetation. This phenomenon is probably a common feature in mires, for example Adam *et al*, (1975) found that although some units of vegetation at Malham Tarn were distinct, the "general bog communities" showed no discernible structure. Clearly, this presents a problem to the classification of mire vegetation since arbitrary diviision is imposed on continuous variation and the communities obtained will depend on the classification technique. It is not surprising, therefore, that all the classification schemes for the New Forest mire vegetation include a group of communities which are not directly comparable between schemes (Table 6.12). Detrended correspondence analysis was particularly successful in dealing with the discontinuous variation in the vegetation of the mires. Classification using both TWINSPAN and DCA was the most satisfactory since it enabled communities to be partitioned in relation to the principal ecological gradients. In terms of ecological interpretation, DCA was particularly effective where only four communities were described in three dimensions. With more than this number of communities the axes tended to represent complexes of factors. Although there are many approaches to the problem of vegetation classification, the methods used

here have the advantage that the floristic variation is displayed objectively by a technique which is based on ecologically explicit assumptions, and that the subsequent identification of clusters (communities) is made in relation to the important habitat factors.

6.6 Summary

1. Analytical methods in community ecology and previous vegetation research on the New Forest mires are both reviewed.
2. The transition between mire and heathland is examined in a case study by indirect gradient analysis.
3. Classification of the mire vegetation is carried out using TWINSPAN and DCA. The community types obtained are compared with other peatland classificatory schemes for the New Forest and elsewhere. It is concluded that certain vegetation units are distinctive partly due to physiognomic characteristics, other mire community types are dependent on the methods used to partition more or less continuous floristic variation.
4. Community composition is related to environmental factors. This study confirms earlier research but also highlights the importance of internal, structural features of the vegetation in determining the main gradients.

CHAPTER SEVEN THE CONSERVATION OF NEW FOREST VALLEY MIRES

7.1 Introduction

As part of the New Forest, the valley mires benefit from a degree of legislative protection (see Chapter One). This has shielded the mires from the direct losses to human population growth which have occurred elsewhere in the Hampshire Basin, notably in south-east Dorset. However, the open Forest still represents the "least-cost option" in many cases to service industries and other infrastructure developments, which often enjoy their own facilitating legislation. In the 1980's, proposals affecting the New Forest mires have included: (i) several pipelines for the petrochemical and water industries; (ii) water reservoir drainage and discharge outlets (including discharge of flushing agents containing biocides); (iii) storm water storage facilities; (iv) oil and gas exploration sites; (v) road development. Within the Forest itself, the mires are subject to management demands which centre on artificial drainage.

This chapter will first consider the nature conservation significance of the valley mires and will review what is known of the ecological characteristics that are used in site evaluation of the mires. This is of relevance to the present management of the Forest, since management consultations frequently require assessments to be made of the nature conservation importance of the mires that are affected. There is also a need to assess the impact of management practices on the mires. Today, this is restricted to grazing by commonable stock, drainage and burning. However, there are also several other practices which have died out only in the recent ecological past, and their effects on the present mire communities also need to be examined, as far as is possible. It is also important to understand the ecological processes which underly these management impacts. This particularly relates to the interaction between *Molinia* and grazing, since this species plays a major role in structuring the vegetation of the open mire, as was shown in the last chapter. The final part of this chapter will attempt to identify the biological principles which are important to the present management of the valley mires and their future conservation.

7.2 Ecological evaluation of the New Forest mires

7.2.1 The nature conservation significance of the New Forest valley mires

The New Forest mire type is closely associated with the Anglo-Norman heathlands (see Chapter 1). Together these habitats form an ecosystem which is restricted to the lowland, littoral regions of southern England and northern France. The fate of both habitats has been shaped largely by the population pressures and agricultural changes which have taken place in these regions since the nineteenth century.

The decline which has occurred in the area of heathlands, and with them the valley mires, is now well-known and has been relatively well quantified, compared to many other habitats. This provides the backcloth against which the present- and future- significance of the New Forest to nature conservation has to be judged. Several studies of lowland heath habitat loss have been carried out in S.England, following the now classic work of Moore (1962). Tubbs (1985) reviews the situation and concludes that more than 75% of heathland has been lost in S.England since about 1800. About half of what remains occurs in the New Forest. Together with this decline, there has been a massive increase in the fragmentation of the surviving area (e.g. Webb and Haskins, 1980). The decline in lowland heath and mire in north-west France has probably been greater; perhaps as high as 95% over a similar period and no more than about 15000ha survives in total, mostly as small and fragmented areas (Noirfalisse and Vanesse, 1976; Nicholson, 1979; Goodwillie, 1980). Many of the rarer valley mire and wet heath species are now threatened throughout much of their range in the lowlands of north-west Europe, e.g. *Hammarbya paludosa*. The New Forest is now the stronghold of a number of these species. Habitat loss in the New Forest has been relatively low over the same period - Tubbs (1985) estimates a decline of 25% since 1800. However, the data show that the Forest has become subject to increasing local isolation (Townsend, 1904; Perring and Walters, 1962; Webb and Haskins, 1980; Tubbs, 1985), both in terms of habitat and species populations. The Forest is becoming more and more a closed system, both ecologically and in management terms (especially since the gridding and fencing of the Forest to contain stock).

The amount of valley mire habitat remaining in England outside the Forest

is difficult to determine precisely. Tables 7.1 and 7.2 list all the major sites known in 1986 and most of the smaller areas. Valley mire and wet heath were combined for ease of comparison, and the total area of heathland and related habitats is also given. In all cases, a maximum figure for mire and wet heath has been taken. The data are derived mainly from unpublished information from the NCC, where possible habitat maps have been used and areas calculated using a graph paper overlay method. The tables exclude at least another 16 - 20 sites containing small, relict areas of mire (no more than 1ha, usually much less), which are scattered throughout southern England. Table 7.1 includes some mires which also have northern or continental affinities; notably the North Norfolk mires (Ratcliffe, 1977a; Daniels, 1978). It also includes the western and rather base-enriched site at Aylesbeare Common (Ivimey-Cook, *et al*, 1975, Ratcliffe, 1977a). Some of the plant communities in certain lowland Welsh sites show limited similarity to the New Forest mires, particularly seepage areas in the Prescelly Hills and at Llyn Coethlyn, but they are not comparable (Ratcliffe and Hattey, 1982; Slater, 1984). A number of heathland sites have been included in which there is only limited mire development (e.g. Hazeley Heath and Ashdown Forest).

The New Forest supports about 64% of the mire and wet heath which now survives, and this is likely to be an underestimate. Outside the Forest, there are only 12 sites which contain a total area of mire and wet heath exceeding 40ha. The other main centres for valley mires are the Surrey (11%) and Dorset (17%) heaths. In Surrey, this area is distributed across three areas, of which two are subject to military training (Ash and Pirbright Ranges). The Dorset complex (Table 7.2) illustrates the problem of extreme fragmentation which has taken place in the heathlands of that region. In addition, at least 28% of the mire area lies within plantation or self-sown coniferous woodland. The other areas account for the remaining 8% of the total and many of these mires have been fragmented by agricultural, industrial or residential development or by afforestation. Almost all these sites have been notified by the NCC as sites of Special Scientific Interest, and most have some form of nature reserve status. However, there are problems in achieving effective management in areas where traditional practices have ceased, and in some cases there are threats from agricultural run-off or from lowered regional groundwater tables due to abstraction.

TABLE 7.1 Surviving areas of valley mire and wet heath in S.England (see text). Brackets denote sites where mire is weakly developed)

	TOTAL AREA OF OPEN HABITATS (ha)	APPROX. AREA OF MIRE & WET HEATH (ha)
Roydon Common, Norfolk	180	40
Dersingham Bog, Norfolk	160	65
Hothfield Bog, Kent	55	5
Ambersham & Iping Commons, Sussex	265	10
(Ashdown Forest, Sussex)	510	75
Thursley, Hankley & Frensham Commons, Surrey	1100	150
Woolmer Forest, Hants	270	21
Conford Moor, Hants	18	12
Ash Ranges, Surrey	800	110
Pirbright Ranges, Surrey	1000	220
Chobham Common, Surrey	680	8
Bagshot Heaths, Surrey/Berks	160	75
Snelsmore, Berks	105	14
Owlsmore, Berks	85	30
Longmoor Bog, Berks	14	3
Wellington College Bog, Berks	6	3
Hawley Common, Hants		10
Shortheath Common, Hants	58	4
Castle Bottom, Hants	37	12
Hazeley Heath, Hants	177	8
(Silchester Common, Hants)	125	
Emer Bog, Hants	38	6
THE NEW FOREST	15900	2894
Ebblake Bog Hants/Dorset	12	12
Dorset Heaths (24 sites, see Table 7.2)	5984	814
Black Down Hills, Somerset		100?
Aylesbeare Common, Dorset	200	20
TOTAL		4721

TABLE 7.2 Valley mires surviving in Dorset (mean area of mire per site is 33ha)

	TOTAL AREA (ha)	APPROX. AREA OF WET HEATH AND MIRE (ha)
Holt Heath	400	80
Rempstone Heaths	175	11
Upton Heath	200	13
Winfrith Heath	250	3
Hyde Heath	295	150
Hurn Common	530	(6)
Lions Hill	43	(7)
Sandford Heath	25	1
Stoborough & Creech Heaths	340	20
Povington & Grange Heaths	1200	75
Slop Bog & Uddens Heath	44	5
Blue Pool & Norden Heaths	92	1
Bourne Valley	62	7
Brenscombe Heath	35	5
Gore Heath	88	1
Horton Common	20	3
Norden	12	1
Parley Common	120	5
Thrashers Heath	13	1
Cranbourne Common	100	2
Morden Bog	180	130
Studland/Godlingston Heaths	530	80
Hartland/Arne Heaths	1200	180
Throop Heath	30	27
TOTAL		814

The national importance of the New Forest to nature conservation was recognised in Government Command 7122 (see Chapter One), which made special reference to the valley mires. The Nature Conservation Review identified the New Forest as being "the most important single area in Britain for valley mires and the *locus classicus* for this mire type" (Ratcliffe, 1977a, p. 252). It also recognised the mires as having an internationally important status. Recognition of the international importance of the New Forest mires has grown with the development of international wetland conservation (see Carp, 1980 for a historical review). This new awareness is reflected particularly in the 'Convention on Wetlands of International Importance, especially as Waterfowl Habitat', which was originally adopted at Ramsar, Iran in 1971 (hence 'Ramsar Convention'), and was ratified by the United Kingdom in 1976). Signatories to the Ramsar Convention undertake to list and protect wetlands of international importance, in addition to a general commitment to wetland conservation. Subsequent to the Ramsar Convention, a special committee was set up to establish criteria for the selection of wetlands of international importance, at the International Conference on Conservation of Wetlands and Waterfowl held at Heilinghafen in 1974. The 'Heilinghafen Criteria' were reviewed in 1977 and were finally adopted by all ratifying parties at the Cagliari meeting of Parties to the Convention in 1980. The criteria most relevant to the New Forest valley mires are given below:

1. Criteria pertaining to a wetland's importance to populations and species. A wetland should be considered internationally important if it:
   (c) supports an appreciable number of an endangered species of plant or animal,
   or (d) is of special value for maintaining genetic and ecological diversity because of the quality and peculiarities of its fauna or flora,
   or (e) plays a major role in its region as the habitat of plants and of aquatic and other animals of scientific or economic importance.
2. Criteria concerned with the selection of representative or unique wetlands
   (a) is a representative example of a wetland community characteristic of its biogeographical region,
   or (b) exemplifies a critical stage or extreme in biological or hydromorphological processes.

There is now a movement away from the high degree of emphasis on wetlands of importance to birds (see IUCN, 1984). The New Forest valley mires have

been recognised as being of international importance under 2(a) by the Council of Europe (Goodwillie, 1980), and by the International Union for Conservation of Nature and Natural Resources and United Nations Environment Programme. The Nature Conservancy Council proposes to request the Secretary of State for the Environment to designate the New Forest mires and their catchments under the Ramsar Convention.

The main features of the New Forest which are of nature conservation importance are (i) its size and continuity of semi-natural habitats, which are largely maintained by a traditional pastoral economy, (ii) the diversity and range of habitats represented, and (iii) the large area of each habitat type, many of which are now rare in a national or international context (e.g. Ratcliffe, 1977a; Tubbs, 1986). A fourth feature may also be mentioned and that is the availability within a single region of a suite of sites for scientific investigation. This allows a number of replicates (sites), which is not possible to the same extent elsewhere, especially in the case of the valley mires. The importance of the Forest thus lies in the fact that it is a large and inter-connected series of semi-natural habitats, which together form a single ecological unit. The importance of the habitat mosaic, therefore, provides the context within which an ecological evaluation of the valley mires, either collectively or individually, may be made.

A variety of criteria for the evaluation of nature conservation importance have been proposed and much discussed (see Ratcliffe, 1971; Margules and Usher, 1981; Goldsmith, 1983). Many of these criteria express attributes of ecosystems which cannot be artificially re-created (the concept of "non-re-creatability", NCC, 1986). However, as Ratcliffe (1977a; p.17) recognises, it is difficult to apply these criteria within an area such as the New Forest, since this is to artificially compartmentalise the habitat mosaic and conservation unit. The criteria most commonly used which have a scientific basis are diversity (both species and habitat), rarity, naturalness and area (Margules and Usher, 1981). Goode (1972) assessed the characteristics of valley mires which were of significance to a national nature reserve series. He concluded that the variation in the degree and type of intermixture between "bog" and "fen" elements (including strongly calcareous types) was an important feature which should

be represented in such a series. Ratcliffe and Hattey (1982) evaluated Welsh lowland peatlands on the basis of plant communities using a vegetation, rather than site, based classification. Sites were selected which best represented particular vegetation noda defined by the classification, which included a wide range of wetland communities. The authors noted that this approach places a heavier reliance on vegetational data compared to site classification methods, and that the procedure may be overly rigid for nature conservation purposes. A similar approach to site assessment has been discussed by Nilsson (1986). In the case of the New Forest mires, it has been shown that the plant communities identified depend upon the classification method used - some communities are more or less well-defined (as much by physiognomy as by floristics) whereas others are more difficult to split consistently from the vegetation continuum. Moreover, as has been discussed, one of the important features of the New Forest mires is the variation in vegetation, with many "intermediate" communities. The New Forest mires are, therefore, not best suited to an assessment approach based on certain vegetation noda.

An additional criterion of relevance to the evaluation of mires (and also lakes) is the presence of peat and other deposits. Sites which are of importance to palaeoecology in the New Forest include those which (i) have long or continuous stratigraphic records, particularly where these continue to present, (ii) sites with deposits older than about 3-4000BP, since these are scarce - Lateglacial sites are especially important in a national context, and (iii) sites which provide high temporal resolution for certain periods. The significance of sites, however, is not limited to reconstructing vegetation history, since palaeoecology has now moved beyond a simple descriptive phase in many quarters. The significance of a site will therefore depend upon the research questions which are posed. The following sections will examine the characteristics of the New Forest mires in relation to the main ecological criteria commonly used in evaluation - diversity, area and rarity. These considerations will be limited mainly to the vegetation but, where possible, the valley mire fauna will be reviewed. The vegetation data have been compiled from a wide variety of sources including personal observations, the results of the England Field Unit survey, collation of a large number of records by local naturalists (lodged with the NCC) and NCC file notes, and a number of published

sources including Townsend (1904), Rayner (1929) and Paton (1961). Together these sources provide inventory data for 21 sites and distributional data for a number of species which, although not complete, represent a data-base which is as comprehensive as most used for ecological evaluation. (Site specific details are not discussed here, but the data are lodged at the NCC office at Lyndhurst).

7.2.2 Physical determinants of plant diversity in the valley mires

The common observation that the number of species tends to increase with increasing area has been a major stimulus to research throughout the history of ecology. It suggests that area-related factors are important in determining the species richness of a site, or habitat, and that comparisons of species richness between sites must be made relative to area. In recent decades, attention has centred on causal explanations of this phenomenon, the precise mathematical relationship between species number and area and its interpretation, and the consequences for nature conservation.

Two differing relationships have been proposed which reflect the fact that the species-area curve tends to flatten out with increasing area. The first is a power function (Arrenhius, 1921; Preston, 1962), where

$$S = kA^2 \qquad 7.1$$

in which S is the number of species, A is the area, and k and 2 are constants. The second is of exponential form (Gleason, 1922; Williams, 1943), where

$$S = d + b \log A \qquad 7.2$$

in which d and b are positive constants. Neither model has theoretical primacy and the "best model" is simply that which statistically fits the data best (Connor and McCoy, 1979).

The relationship between the number of plant species and site area was investigated for those valley mires in the New Forest where relatively complete inventory data is available (see above). The correlation between species richness and area was calculated for both models and also a third, in which S is simply proportional to A without transformation. In all cases the data show a very poor relationship between species richness and

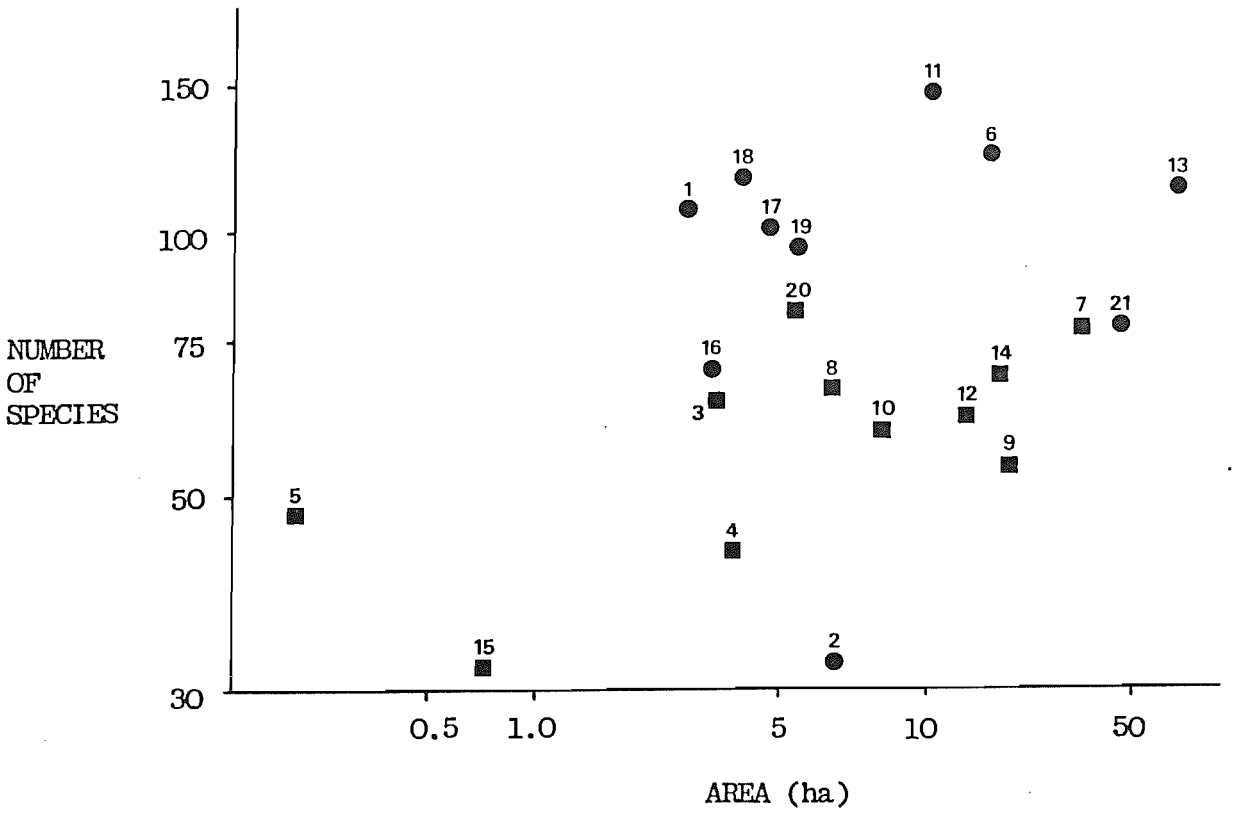


FIGURE 7.1 Species - area relationship for New Forest mires (axes in natural logarithms) ●= sites with carr.

For $S = c\ A^z$, a straight line relationship is expected between S (number of species) and A (area) when plotted on logarithmic axes, where c and z are constants. In this case, c = 57 and z = 118 ($r = 0.388$, $0.1 > p > 0.5$).

SITES:

1	Church Moor	11	Holmsley Bog
2	Barrow Moor	12	Hincheslea Bog
3	Warwickslade Bog	13	Denny/Shatterford Bog
4	The Noads Bog	14	Crockford Bottom
5	Gritnam Bog	15	Bramble Hill Bog
6	Wilverley Bog/Avon Water E.	16	Cadnam Bog
7	Cranes Moor/Vales Moor	17	Row Hill Bog
8	Rakes Brakes Bottom	18	Whitemoor
9	Fawley Bog	19	Fort Bog
10	Linwood Bog/Digden Bottom	20	Crab Tree Bog
		21	Matley Bog

area in the New Forest mires. The closeness of fit (measured by the correlation coefficient, r) was for each model, in decreasing order:

(i) $S = kA^z$, $r = 0.388$ (using the transformation $\log S = \log k + z \log A$)
(ii) $S = d + b \log_e A$, $r = 0.363$
(iii) $S = d + bA$, $r = 0.270$

The power function is fractionally superior in fitting the data, but the success (*sic*) of the two logarithmic transformation models may be due merely to the fact that logarithms tend to damp down variations in data. Figure 7.1 shows $\log_e S$ plotted against $\log_e A$ for the valley mires; this is an approximation of the power function (Eq. 7.1), in which species and area should show a straight line relationship, and from which the constants log k and $_z$ may be calculated using linear regression. [Note that measurement error in area will result in systematic underestimation of the slope parameter, z, by least-squares regression, its use here solely for comparative purposes. For a discussion of this see Connor and McCoy (1979), also Vincent (1981) and Vincent and Haworth (1982) for statistical considerations only.] From Figure 7.1 it can be seen that two small sites, Gritnam Bog and Bramble Hill Bog, are far removed from the average species number and average area. Species - area models are sensitive to the undue influence of such points (Boecklen and Gotelli, 1984) and, when these two sites are removed, the weak correlation between $\log_e S$ and $\log_e A$ becomes virtually non-existent ($r = 0.210$, $z = 0.085$).

Even the best of the three species-area models considered here still leaves 85% of the variation in species richness between valley mires unexplained ($R^2 = 0.151$). This clearly suggests that the determinants of species diversity in the mires are too complex to be modelled by area alone and that other factors, such as habitat variation, are more significant (cf Boecklen and Gotelli, 1984).

There is a strong relationship in the valley mires between the number of species and the presence or absence of carr woodland (shown by different symbols in Figure 7.1). Mires with carr had a mean of 97 species and this is significantly higher than those mires without carr development, where the mean is 60 species ($U = 15.5$, $p<0.01$). This also suggests that habitat variability is an important determinant of the number of species present. From the preceding chapter, it can be concluded that

variations in water flow, acidity and dissolved nutrient concentrations are likely to be the main environmental factors controlling the number of species present at a site, since these are the main external gradients affecting mire vegetation composition.

In the case of acidity, the number of species is positively correlated with the range in site pH (Figure 7.2). Overall, there is a trend for New Forest mires to show greater similarity in the minimum pH values recorded from each site, than in the maximum values. Sites with a wide range in acidity are controlled mainly by the outcrop distribution of base-rich facies of the Barton Clay (e.g. Denny Bog, Dibden Bottom) and particularly the Headon Beds (Holmsley, Stony Moors, etc.). For the mires in Figure 7.2, the range in minimum site values was 1.8 pH units, compared to a range of 3.3 pH units for site maxima. There was no significant correlation between the number of species and the range in corrected conductivity at a site ($r = 0.173$). Total conductivity (corrected for pH) was found to be a relatively poor environmental parameter in relation to vegetation composition. This is because the nutrient supply rate is more important than instantaneous concentration, and also elements vary between sites in their contribution to total conductivity (especially calcium, potassium and sodium; see section 6.5). On the other hand, pH is more significant as an environmental factor in determining the chemical environment, rather than as a nutrient flux.

The range in site acidity is significantly correlated with mire area (Figure 7.3). This is in contrast to the relationship between mire area and carr development, which show no significant difference to those which lack carr woodland (Table 7.3).

TABLE 7.3 Carr distribution and mire area

Mean area of mires with carr = 17ha, range = 2.7 - 68ha, n = 10
Mean area of mires without carr = 11ha, range = 0.2 - 35ha, n = 11

($U = 4.9$, p = not significant)

The carr tree species (*Alnus*, *Salix*, *Betula*, etc.) are an intrinsic part

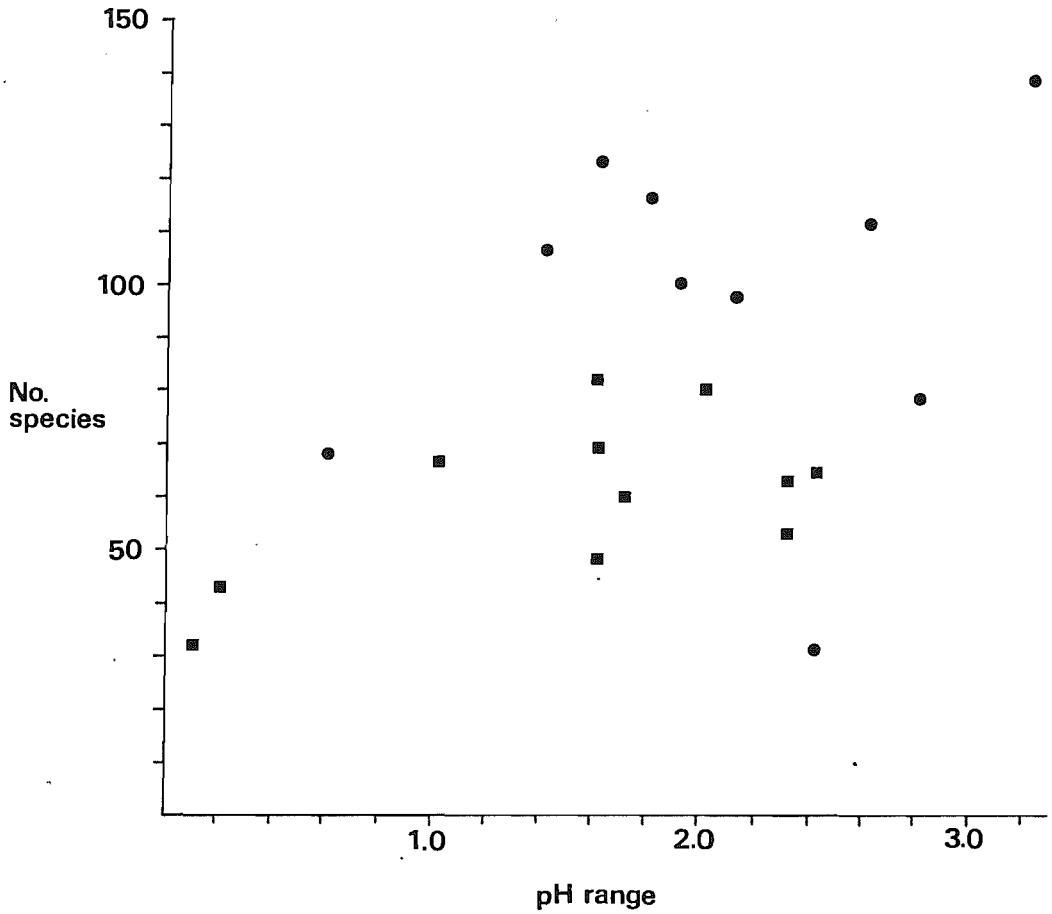


FIGURE 7.2 : Relationship between the number of plant species and acidity range of valley mires ($r = 0.440$, $p < 0.05$).

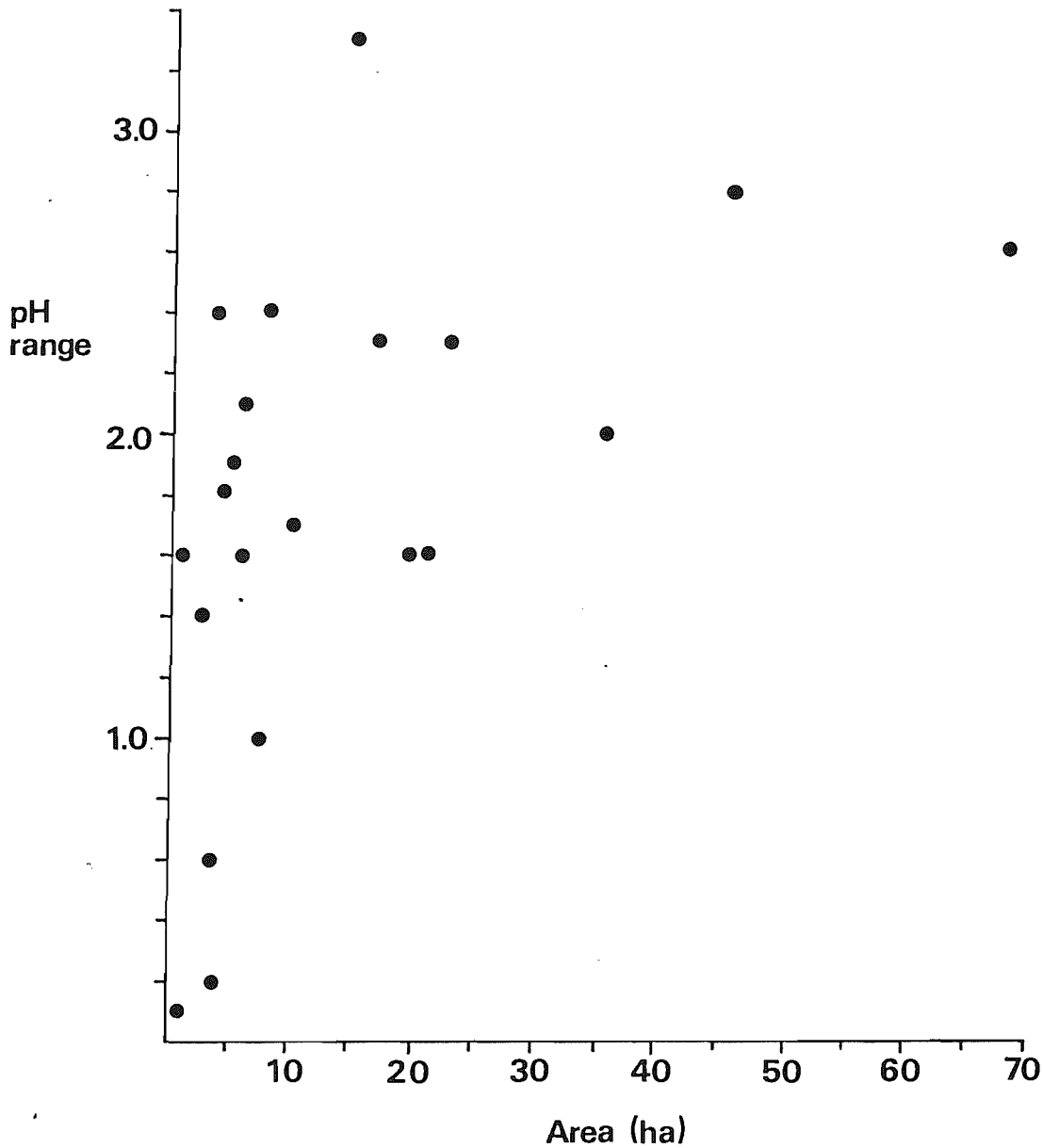


FIGURE 7.3 : Relationship between range in acidity and mire area ($r = 0.435$, $p<0.05$).

of the mire vegetation, but they also act as an important structural feature due to shade. Detrended correspondence analysis shows that the gradient from *Sphagnum* through *Molinia* to carr tree-dominated communities is the principal source of beta diversity in the valley mires. Beta diversity is a measure of the variety of communities present at a site, and reflects habitat heterogeneity (see section 6.2.4). Valley mires with carr woodland have a much higher beta diversity than those without (Table 7.4)

Table 7.4 Carr distribution and beta diversity (see section 6.2.4 for calculation beta diversity index)

Mires with carr : mean beta diversity = 5.2 Mires without carr : mean beta diversity = 2.6
($U = 7$, $p<0.001$)

The presence of the carr tree species enhances species turnover, and hence total species richness, because of the groundflora communities associated with them. This creates a threshold effect, whereby species richness is greatly inflated by the presence of carr (disproportionately more than the simple inclusion of the tree species), because of the additional gradient-shade- it generates. This is an important factor which confounds a simple relationship between species richness and area.

Not surprisingly, the beta diversity index shows a very similar pattern, in relation to mire area, as simple species richness. However, there is a much closer relationship with acidity range (Figure 7.4), and the regression suggests that the site variation in acidity may account for up to 40% of the variation in community composition. There are a number of features of interest - for instance, the regression line virtually splits the mires into carr sites above, and non-carr sites below the line.

Barrow Moor is the only carr site below the line - this site is almost completely shaded so that there is a relatively short environmental gradient in relation to light. The beta diversity index for Barrow Moor, however, shows a less anomalous relationship with the acidity range at this site than simply the total number of species (see Figure 7.2). There

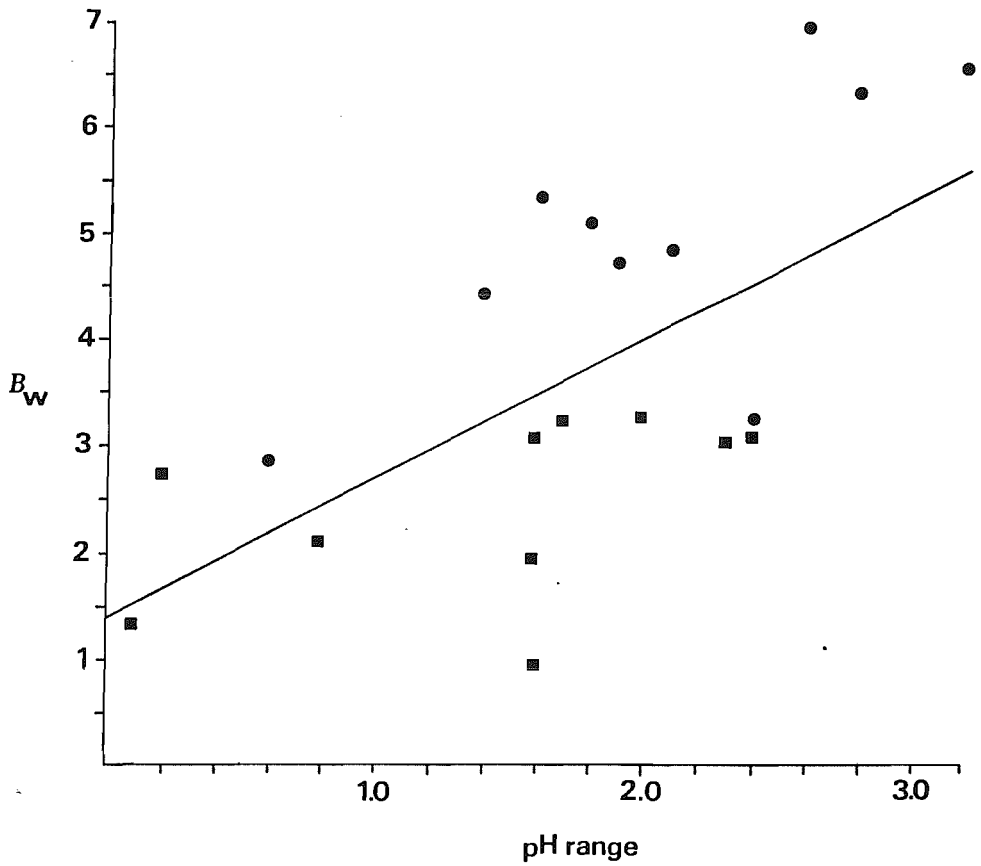


FIGURE 7.4 : The relationship between the beta diversity index, B_W, and site acidity range. See section 6.2.4 for calculation of the index. Circle = mires with carr, square = mires without carr ($r = 0.631$, $p<0.01$).

is a relatively wide range of communities present at Barrow Moor but they are intrinsically species-poor (mean no. of species per $4m^2$ sample = 7.5), most being variants of the shaded acidic mire community type (see section 6.5). The beta diversity index corrects for variation in intrinsically species-poor communities.

Three theories have been put forward to account for the patterns found in species-area relationships. First, that the common relationship between species richness and area is a phenomenon relating to the statistical distribution of the relative abundance of species, and assuming that population size depends on area (Preston, 1962). From this, Simberloff (1978) has suggested that larger islands 'sample' a larger proportion of the total species complement of a region. Second, the equilibrium theory of island biogeography (MacArthur and Wilson, 1967), which is based on a model of random extinctions in which smaller populations have a greater probability of going extinct, and on the assumption that population size is dependent on area. The number of species at equilibrium (where the rate of species extinction is balanced by immigration) is therefore higher on larger islands or habitat isolates. Third, that larger areas contain more habitats, each habitat having a set of associated species, so that there are more species in total (Williams, 1964). These theories are not mutually exclusive. In their review, Connor and McCoy (1979) conclude that each process may be important in determining species richness in different assemblages, but it is practically difficult to assess their proportional contribution in any particular study that has been carried out. Each hypothesis can be tested only by direct experimentation, and most studies have been characterised by a lack of rigour and poor explanatory structure (see critiques by Simberloff, 1978; Connor and McCoy, 1979; Gilbert, 1980; Boecklen and Gotelli, 1984).

Many studies have revealed a species-area relationship in plant assemblages but they have differed as to the degree to which area *per se* is emphasised over habitat diversity effects on species richness (e.g. Johnson and Raven, 1970; Johnson and Simberloff, 1974; McCoy and Connor, 1976; Dony, 1977; Peterken and Game, 1984). Soil type is often used as an index of habitat diversity, yet this ignores problems in the unit of measurement and small scale spatial variability in semi-natural soils, which is common even at the soil series level. Importantly, several studies have noted that groups

of small sites contain somewhat more species in total than a single large site of the same area (e.g. Higgs and Usher, 1980; Game and Peterken, 1984; Simberloff and Gotelli, 1984).

This investigation provides strong evidence that habitat diversity is the main factor influencing species richness in the New Forest mires, and that area effects in themselves are comparatively minor. First of all, it has been possible to demonstrate a relationship between species richness and variation in some of the main physical factors which are known to influence plant species distributions in the valley mires. It has also been shown that community turnover increases with increased habitat diversity. Area is a poor predictor of species richness in valley mires. This is because a simple area relationship is confounded by the occurrence of carr communities, which are determined by factors of geology and groundwater hydrology which are not themselves correlated with area. However, the competing hypothesis of the area *per se* effect (i.e. equilibrium theory) can only be disproved by demonstration of a lack of relationship between extinction probabilities and area (Connor and McCoy, 1979). This may be difficult to achieve over sufficiently long timescales, especially for mainland habitat "isolates". Nevertheless, macrofossil analysis shows that there has been low species turnover in the core assemblages over the last 2500 years. This implies low extinction and/or high immigration rates. The persistence of the present species assemblage at Church Moor for the last 5000 years indicates that the effective extinction rate has been very low during this time. This suggests that even the area of Church Moor (which is relatively small) is sufficient to permit the survival of species at the site for much of the postglacial. Thus, the influence of area on extinction rates in the valley mires may be too small to exert a significant effect on species richness.

The species-area relations of islands and habitat isolates have been discussed extensively in the evaluation, design and management of nature reserves since the late 1960's (Hooper, 1971, van der Maarel, 1971). The debate grew, particularly, from the suggestion derived from the equilibrium theory that single large reserves should be favoured over groups of smaller ones of the same total size (Diamond, 1975; Wilson and Willis, 1975).

This was widely accepted (e.g. IUCN, 1980) and gave an apparent theoretical basis for selecting size as a criterion for site evaluation. This is not, however, a necessary prediction of the equilibrium theory (Higgs, 1981; Simberloff and Abele, 1982). Moreover, there is a growing consensus that the evidence does not support this prediction, and that there has been a failure to demonstrate the general applicability of equilibrium theory (see above).

The absence of a strong species-area relationship and the small value of the slope parameter (z) in the power function suggest that there may be a low degree of isolation between plant populations in different sites (see Connor and McCoy, 1979). This also emphasises the importance of the habitat mosaic.

7.2.3 The valley mire fauna

7.2.3.1 Invertebrate communities

Very little is known about the invertebrate communities of the valley mires - inventory data is scarce and still less information is available on the functional relationships of such communities. Studies in southern England have been restricted to certain groups, notable the Odonata (e.g. Moore, 1964), or to related heathland habitats following the pioneering work of Richards (1926). There is a general scarcity of data on the invertebrate fauna of peatlands in Britain, although there is a growing body of research from northern and upland areas (especially Moor House National Nature Reserve). Several of these studies have found climate and altitude to be important factors controlling community composition (e.g. Mason and Standen, 1983; Coulson and Butterfield, 1985, 1986), and this may limit comparability with the fauna of southern valley mires. From general principles, one would predict the mire invertebrate fauna of the New Forest, and related areas in southern England, to be relatively rich compared to northern Britain. The New Forest is known to be an important outpost for otherwise more northerly species (e.g. Collin, 1961), as well as including a variety of species restricted to southern England (e.g. Ratcliffe, 1977a).

A survey of invertebrates associated with the open plant communities of

five valley mires (Cranes Moor, Crockford Bottom, Denny Bog, Hincheslea Bog and Holmsley Bog) was carried out by the NCC England Field Unit between May and October 1983 (Sheppard, 1987). This represents the most comprehensive survey of valley mire anthropods ever conducted. To date, 587 species have been recorded, and many more specimens await identification (these include a number of families with uncertain taxonomy, especially Diptera). About a quarter of the species were described as part of the valley mire fundamental fauna, comprising a characteristic fauna (species occurring in at least 4 of the 5 sites) and a group of species with specialist requirements linked to valley mire habitats. Another quarter of the species total were generalist wetland species which are not restricted to valley mires. The fundamental fauna was composed mainly of small predatory flies and spiders. Herbivores were limited and were associated with grasses and sedges. Pollen and nectar-feeding species were scarce. Analysis by Sheppard (1987) also extended to cross-site comparisons and site descriptions.

Two additional aspects are considered here. First, the unusual trophic structure of the valley mires and, secondly, within-site differences in invertebrate assemblages. I am grateful to Dr.D.Sheppard for raw sample data from Cranes Moor, for this purpose, identified to order or family level. Invertebrates were sampled from three plant communities at this site: (i) *Molinia*-dominated mire, (ii) *Sphagnum* lawn and hummocks (Newbould's shielded area), and (iii) pools and wet *Sphagnum* lawn. Sampling included pitfall traps (communities (i) and (ii) only), bulk sampling of vegetation, and swish and sweep net methods (see Sheppard, 1987). The proportion of individuals recorded in each of the main invertebrate taxa is shown in Table 7.5 for the three vegetation types, over the whole of the sampling period. The pitfall traps were excluded for purposes of comparison and other reasons concerning sample bias. This did not affect the main trends in the data.

The structure of the three invertebrate assemblages has a number of features in common. Numerically, spiders form about a third of the total sample in all three cases. The abundance of spiders appears to be a general feature in the composition of the above-ground invertebrate communities of peatlands (Mason and Standen, 1983), particularly linyphiids (money spiders

TABLE 7.5 Relative abundance of the major invertebrate taxa sampled from three different vegetation types at Cranes Moor: A = *Molinia* dominated community, B = *Sphagnum* lawn, C = wet *Sphagnum* lawn and hollows. Figures in brackets are number of individuals caught. (Data derived from NCC England Field Unit Survey).

	PLANT COMMUNITY		
	A	B	C
SPIDERS	35% (476)	36% (462)	30% (516)
DIPTERA: TOTAL	31% (422)	24% (311)	45% (834)
: Chironomidae	19% (252)	15% (213)	39% (711)
: Tipulidae	7% (96)	3% (37)	2% (30)
: Chamaemyiidae	4% (40)	1% (3)	1% (6)
HYMENOPTERA: TOTAL	8% (113)	15% (192)	11% (194)
: Ants	4% (49)	14% (174)	9% (169)
HETEROPTERA	6% (78)	4% (53)	1% (27)
HOMOPTERA	5% (67)	6% (76)	5% (84)
COLEOPTERA	11% (154)	12% (157)	7% (126)
ALL TAXA: TOTAL Nos.	1349	1292	1848

TABLE 7.6 Rare vascular plant species associated with valley mire and wet heath habitats in the New Forest. The number of sites in which each species has been recorded is given in the left-hand column. Figures in brackets refer to sites for which there are no recent records. Southern England is defined here as vice-counties 1 - 34.

5(2)	*Carex curta*	Rare in S.England
3	*C. lasiocarpa*	Rare outside Scotland
4(1)	*C. limosa*	Rare outside Scotland
10(1)	*Drosera anglica*	Rare outside Scotland
2(4)	*Eriophorum gracile*	Red Data Book
9	*Gentiana pneumonanthe*	Nationally rare
25(2)	*Hammarbya paludosa*	Nationally rare, IUCN European Red Data Book
12(1)	*Lycopodiella inundatum*	Nationally rare
1	*Pinguicula vulgaris*	Rare in S. England
18	*Rhynchospora fusca*	Nationally rare
7	*Thelypteris*	Nationally rare
1	*Utricularia intermedia*	Nationally rare
1	*U. neglecta*	Nationally rare
1(1)	*U. vulgaris*	Nationally rare

and allies) and lycosids (wolf spiders). Overall the New Forest survey showed that together lycosids (32%) and linyphiids (23%) formed over half the spider fauna (from Sheppard, 1987). Spiders were found to be the main predators in a study at Moor House (Cherret, 1964), and they formed 23% of the total sample at the Silver Flowe (Nelson and Theaker, 1982). Linyphiids were the most abundant group in both cases (note that pitfall traps also tend to overestimate numbers of lycosids), and this suggests a large proportion of the prey are derived from the below-ground component of the invertebrate community. Nelson and Theaker (1982) found that Collembola (spring-tails) were very abundant at the Silver Flowe and they suggest that they are an important source of prey for linyphiids. The Collembola play a significant role in plant decomposition, especially in deep, acidic and organic soils (Swift *et al*, 1979). The sampling methods at Cranes Moor were not designed to catch Collembola. Lycosids may be more abundant in wetter or *Sphagnum*-dominated habitats (e.g. Norgaard, 1951), and are proportionately more important in the spider fauna at lower altitudes (Coulson and Butterfield, 1986). The Diptera formed the other main component of the invertebrate assemblages, comprising mainly chironomids (midges) with tipulids (crane-flies) generally scarce (Table 7.5). This is similar to the results of Nelson and Theaker (1982) for the Silver Flowe, but contrasts with Moor House where tipulids predominate, especially with increasing altitude (Coulson and Butterfield, 1985). The chironomids are mainly non-feeding as adults, and the aquatic larvae are predominantly fungivores (Swift *et al*, 1979). Not surprisingly chironomids were most frequent in the wettest plant community sampled at Cranes Moor. Most (56%) of the Coleoptera caught were members of the Helodidae, whose aquatic larvae feed on decomposing vegetation. Smaller numbers were recorded of, principally, Hymenoptera (mainly ants), Heteroptera (predatory species), Homoptera (all sap feeders) and Lepidoptera (mainly juvenile Coleophoridae on *Juncus*). Again, this is a similar pattern to that described by Nelson and Theaker (1982).

The physical structure of the vegetation is known to be an important determinant of invertebrate community composition (e.g. Morris, 1975). Invertebrate density has been found to increase with greater complexity in vegetation architecture, especially in predatory groups such as spiders (e.g. Duffey *et al*, 1975). A weaker relationship has been found for some

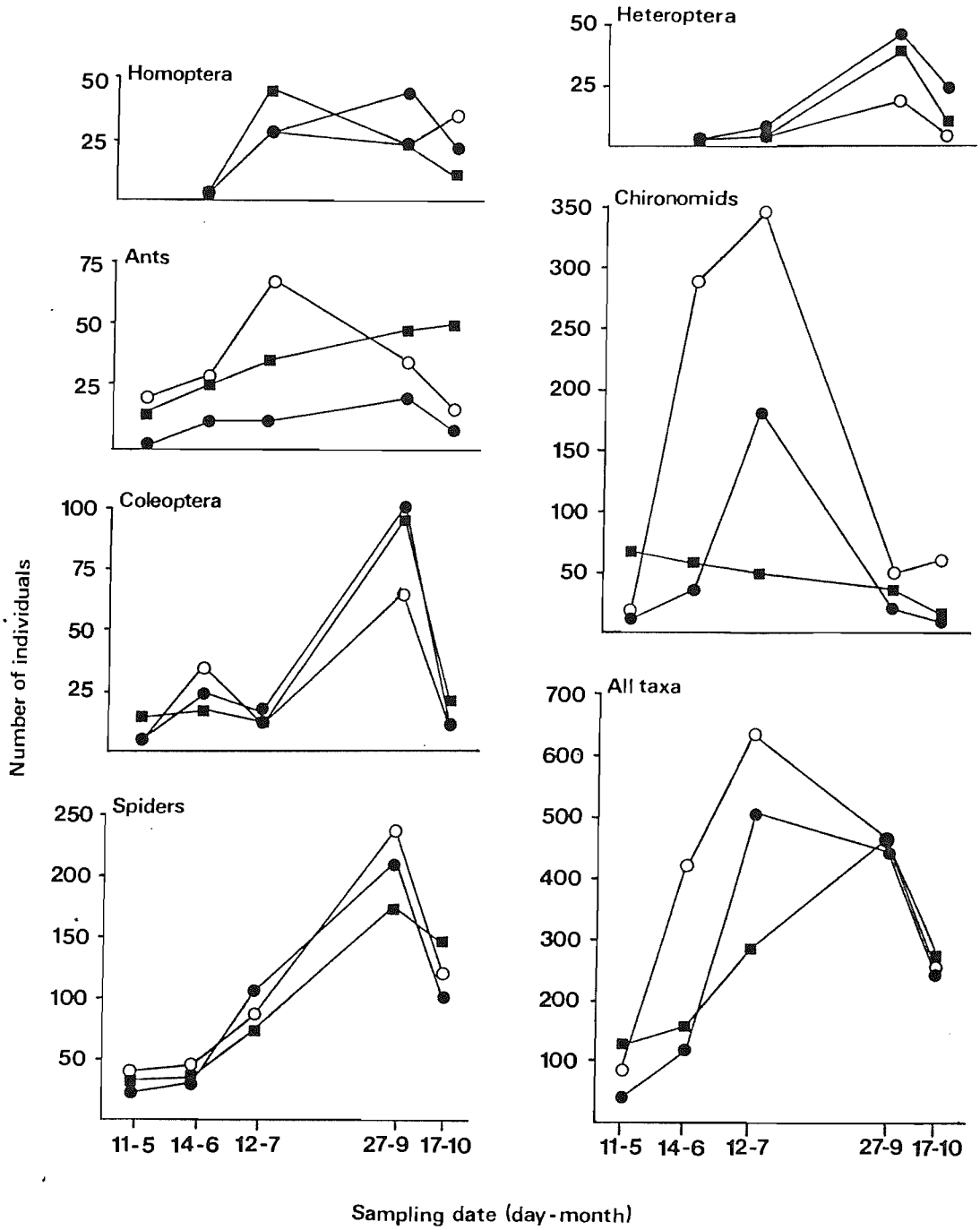


FIGURE 7.5 : Seasonal changes in the abundance of the main invertebrate taxa sampled from three different vegetation types at Cranes Moor. Solid circle = *Molinia* community, open circle = wet lawn and hollows, square = *Sphagnum* lawn. (Derived from England Field Unit survey data).

herbivorous taxa, however (Brown and Hyman, 1986). Coulson and Butterfield (1986) have found the influence of vegetation architecture to be less pronounced in peatlands than in dry land habitats. They suggest that other factors, particularly a high and exposed water table, are important in determining species associations of peatland spiders. Humidity may be an important aspect of a high water table in the case of spiders. Interestingly, Nelson (1971) reports a richer invertebrate fauna associated with mire hollows compared to hummocks. It may also be noted that all of mire-associated Diptera have semi-aquatic larvae (Sheppard, 1987). The relatively high taxonomic rank of the data analysed here for Cranes Moor prevents detailed comparison, but these observations may explain the trends in diversity that are apparent in the data (especially at family level). The *Molinia*-dominated community was the structurally most complex vegetation sampled and this appears to support the most diverse invertebrate community. The pools and wet *Sphagnum* lawn community is, however, noticeably richer than the drier *Sphagnum* lawn and supports the largest number of spiders of all three vegetation types.

The three vegetation types at Cranes Moor show some pronounced differences in invertebrate community composition, despite a similar overall structure. For example, between 27% and 38% of families in the Coleoptera, Diptera and Hymenoptera were only found in one vegetation type. In the case of the Diptera, only 30% of families were distributed across all three vegetation types. There are also differences in the pattern of abundance in each plant community type (Figure 7.5), of which the most marked is the absence of an early summer peak in chironomids in the dry *Sphagnum* lawn community. There is a typical late-summer peak in spiders in all three of vegetation types, and the Heteroptera show a similar trend. The abundance pattern in Coleoptera closely follows the small spring peak and larger late summer peak in helodid numbers. These trends towards late summer maxima counteract the early summer peak in Diptera, so that invertebrates are relatively abundant in all three vegetation types between about mid-July and mid-September. This contrasts markedly with the pronounced May - June peak in invertebrate abundance at Moor House, where invertebrates are much scarcer by as early as July on the high altitude blanket mire (Coulson and Butterfield, 1985).

The results show the invertebrate assemblages at Cranes Moor to have a distinctive trophic structure, the main characteristics of which are few above-ground herbivores and nectar feeders, but a large proportion of predators, especially spiders. Comparison with other studies suggests that these are common features of peatlands (Nelson and Theaker, 1982; Mason and Standen, 1983; Coulson and Butterfield, 1985), and also of heathlands (Webb, 1986). Insect-pollinated plants are relatively scarce in the valley mires, and Mason and Standen (1983) have suggested that low palatability and available nutrient content of most mire plants may limit the numbers and diversity of herbivores. Most of the insects sampled at Cranes Moor have aquatic larval stages. Of these, many are predatory during this stage and there are also herbivores (such as the tipulids). However, there are also fungivores (e.g. the chironomids) and saprovores (e.g. the helodids), and this suggests that decomposition processes may be the key to understanding the trophic structure of these invertebrate communities. Typically, soils with peat or mor humus layers lack earth worms and have low counts of soil bacteria (Swift *et al*, 1979). Instead, there is abundant fungal mycelium and high populations of the soil mesofauna, including enchytraeid worms, Collembola and Acari, which feed on the fungi, Protozoa, etc., as well as on the decaying vegetation itself.

The mesofauna populations (and fungi) are favoured by the low decomposition rates in the absence of comminution by earthworms and rapid bacterial breakdown (Swift *et al*, 1979). The fungal mycelium and decomposing vegetation may be an important component of the primary food source for the valley mire fauna, rather than green plants alone. Thus, paradoxically, the factors which favour organic accumulation in mires also enhance the role that plant decomposition plays in the trophic structure of the invertebrate communities, both above and below ground. This type of structure shows similarities to more aquatic systems in which detritus is important to the functioning of the invertebrate community (Griffiths, 1973). Consideration of these factors may help to explain some of the differences in the invertebrate assemblages sampled from different types of mire vegetation, since the soil mesofauna such as the Collembola is known to be affected by different plant species (MacFayden, 1952; Mason and Standen, 1983).

7.2.3.2 Odonata

The only group of wetland invertebrates for which it is possible to consider whole site assemblages is the Odonata. This has only become possible through the systematic recording of the New Forest Odonata Study Group. There are sufficient data to compare the species richness of the plant and Odonata assemblages of 11 valley mires in the Forest (Figure 7.6), with a wide geographic spread and range of habitat types. There is no apparent relationship between the diversity of these two components of the valley mire ecosystem, and the species richness of the vegetation is a poor predictor of the number of Odonata species present (R^2 = 15%). There is also no relationship between mire area and the species richness of the Odonata assemblage for these sites (r = 0.146). These findings are not necessarily unexpected, but these relationships are seldom tested with field data. The Odonata are only restricted to wetland habitats during the juvenile stages of development. In the New Forest, they disperse after emergence and hunt much of their prey in the surrounding areas of heathland and woodland, until reaching sexual maturity (Parr and Parr, 1979; Welstead and Welstead, 1984). The main factors which determine the breeding communities of valley mire Odonata are physical features of the habitat: (i) variation in hydrology from still, open water bodies, through diffuse water tracks to discrete channel flow; (ii) acidity and (iii) the presence of emergent vegetation and other structures for oviposition, etc. (Parr, 1969; Parr and Parr, 1979; Merritt, 1983; Welstead and Welstead, 1984).

The importance of the New Forest for Odonata is widely recognised, in terms of the number and rarity of species present. A particular characteristic of the New Forest is that many Odonata species are widespread and abundant despite being scarce or rare nationally. However, the significance of this has, perhaps, not been so widely acknowledged (e.g. Chelmick, 1980). Populations of *Coenagrion mercuriale* (a Red Data Book species) are widely scattered from the south-east to the north-west of the Forest, but the nationally-scarce *Orthetrum coerulescens* and *Ceriagrion tenellum* are probably the best examples. In the latter case, *C. tenellum* is a scarce or "notable" species (Ball, 1986), more or less restricted to the heaths of Surrey - Sussex, Hampshire - Dorset, and in the West Country and West Wales. In the New Forest *C. tenellum* is found in over 60 1-km squares and is common

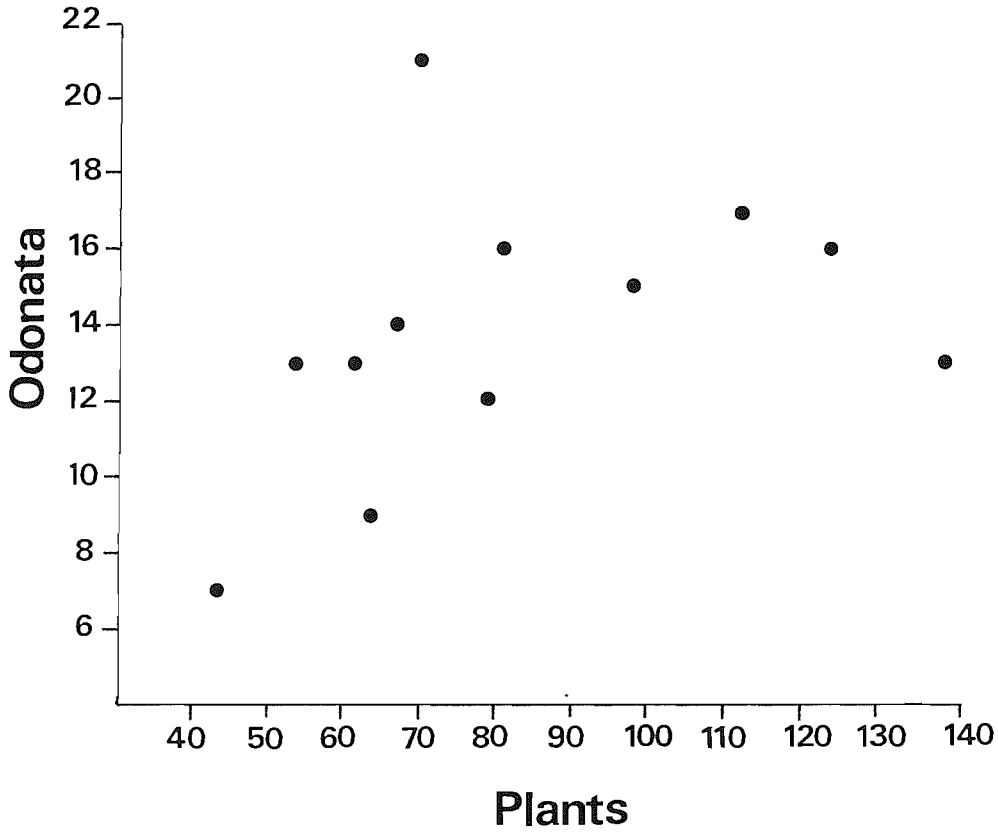


FIGURE 7.6 : The relationship between the number of Odonata and plant species (r = 0.387, not significant).

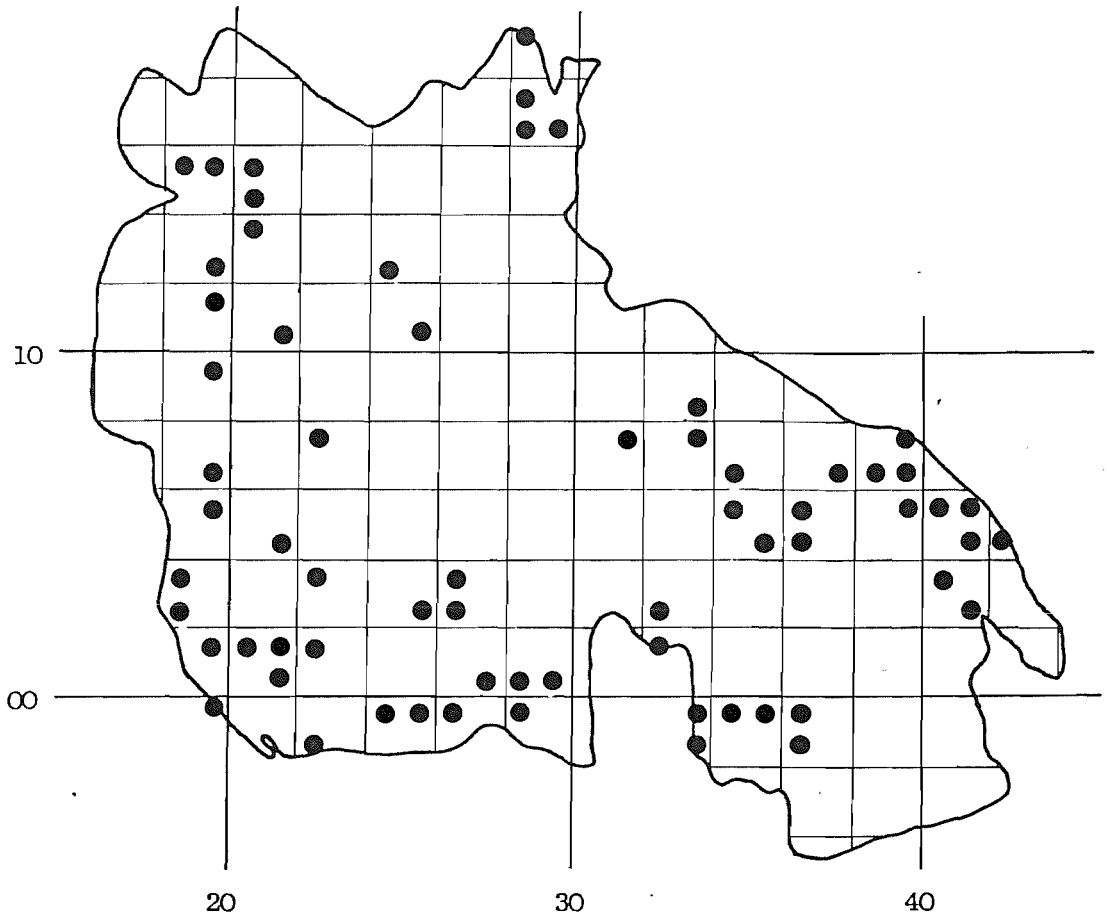


FIGURE 7.7 The distribution of *Ceriagrion tenellum* in the New Forest. Records from (i) 1km squares 1978 - 1982 submitted to Biological Records Centre and compiled by Welstead and Welstead, 1983, and (ii) additional records 1983 - 1986.

throughout most of the open Forest (Figure 7.7). During the breeding season there is little mobility between breeding colonies (Parr and Parr, 1979) and the result is a network of loosely-connected populations across the Forest. These are just the spatial characteristics of nature conservation areas which many ecologists now recognise to be important in the maintenance of long term viability of species, especially in the case of animal populations (Fahrig and Merriam, 1985; Soulé and Simberloff, 1986). Such a system of semi-connected populations maintains genetic diversity, decreases the rate of extinction, maintains higher population growth rates and increases the rate of re-colonisation.

7.2.3.3 Vertebrates

There is a relatively limited number of vertebrates associated with the New Forest mires, and none of these species utilize this habitat alone. The amphibians are found mainly in other water bodies within the Forest, but it is not known to what extent valley mire habitats are incorporated in the home range of these, and reptile species. The mires support breeding populations of wetland birds, including lapwing, snipe, redshank, curlew, mallard and teal (see Tubbs, 1986 for population estimates). The breeding waders return to the Forest around the beginning of March onwards, and this is well before the recorded late spring increase in the abundance of mire invertebrates (see Figure 7.5). Tubbs (1986) notes that there are movements between the Forest and the coast, and suggests that the birds are able to increase their food intake in this way during spring. Sampling for invertebrates in the surface peat layers at feeding sites shows that prey, such as tipulid larvae, are scarce even in June and July (cf Coulson and Butterfield, 1985). It is probable that most of the prey comprises above-ground invertebrates, such as spiders and Diptera - this would be consistent with observations on the food of waders breeding on mires elsewhere in Europe (see Cramp, 1982). Waders are not confined to feeding in the mires - curlews, for example, can be regularly observed foraging in undisturbed areas of heathland adjacent to nesting sites. The invertebrates of the valley mires are also exploited by the hobby (and formerly the red-backed shrike). Hobbies regularly hunt over the valley mires, although this is usually restricted to days with suitable weather, and the main prey are reported to be the larger Odonata such as *Libellula* spp., *Sympetrum* spp. and *Orthetrum coerulescens* (Parr, 1985). Insect hunting is frequent in

the vicinity of the nest, but the valley mires probably play the most important role during the immediate post-fledging period when the young hobbies are first learning to hunt for themselves (Parr, 1985).

7.2.3.4 Conclusions

The structure of the invertebrate communities of the mires - with a preponderence of above-ground predators - appears to be heavily shaped by the importance of the decomposer pathway in secondary production. However, it may also reflect the importance of interactions with surrounding habitats. For example, in all but the largest valley mires, the seasonal peak in heathland pollinators must result in the incursion of these insects into the mires. In this context, it is significant that 54% of the species recorded by Sheppard (1987) were not directly dependent on mire habitats. Conversely, mire species may penetrate adjacent habitats (e.g. Webb *et al*, 1984). Unpublished records by J. Crocker (1964) show that the younger stages of the raft spider *Dolomedes fimbriatus* disperse onto the surrounding heathland. The heteropteran *Pachybranchius fracticollis* is known to undergo seasonal migration between the valley mire and surrounding catchment (Sheppard, 1987). The Odonata, especially the Anisoptera, are another case in point. This suggests that the vegetation boundaries which we recognise do not reflect functional divisions of great significance between invertebrate communities. Moreover, it is the structure of the vegetation, rather than its species composition, which is most relevant to the invertebrate assemblages as a whole. The unsolved problem is whether it is possible to discern, at all, discrete, functioning communities much above the level of the individual *Calluna* bush or *Molinia* tussock (Speight and Blackith, 1983).

The evidence considered here suggests that plant inventory data have poor predictive power in relation to the invertebrate assemblages of the valley mires. However, adequate invertebrate survey is, almost literally, an impossible task. Apart from one or two of the larger and more conspicuous groups of insects, we know very little about the distribution of invertebrates across all the mires in the New Forest. It is probable that many invertebrates which are rare nationally, due to habitat loss, etc., are widely distributed in the Forest. The systematic sampling of the England Field Unit was restricted to limited areas, excluding carr, at five sites.

Yet this was a major survey programme which has considerably advanced knowledge of the valley mire fauna. This survey found that over 10% of all species sampled were nationally rare or of notable status - Sheppard (1987) concluded that each of the sites investigated held an important complement of the British fauna. The bulk of the rarities were directly dependent on the valley mires. These observations argue powerfully against a management emphasis on particular sites within the Forest as a whole, from an ecological standpoint.

Together, these conclusions suggest that the main requirements for the conservation of the mire fauna should be the maintenance of high water levels, the maintenance of diversity in habitat architecture (including vegetation poor in plant species, such as *Molinia*-dominated communities), and the maintenance of spatial heterogeneity in habitats across the Forest. In the absence of an immense survey effort, this can only be achieved by a management policy which protects the existing mosaic of mire vegetation in the New Forest in its entirety.

7.2.4 The occurrence of rare plant species

The presence of rare species is one of the most widely-used criteria in the assessment of nature conservation importance (Margules and Usher, 1981). This is probably because rarity is easily quantified, relatively speaking, and also because such species are more highly valued (although see Goldsmith 1983, and Mabey, 1980). The New Forest mires are of particular significance for the number of rare species present. Sufficient data exist for some general patterns to be identified for rare vascular plants associated with the valley mires in the Forest (see Table 7.6). This list includes (i) species given by Perring and Farrell, (1983); (ii) species occurring in less than 100 10-km squares of the National Grid (following Moore, 1979) using the distribution maps of Perring and Walters (1962); Perring (1968) and Jermy *et al*, (1978); and (iii) species which are rare in southern or lowland Britain. Species which are associated with wet heath are included, but other species occurring in swampy grasslands or flushed lawns (e.g. *Pilularia globulifera*) are excluded since these are not consistently associated with valley mire ecotones. Records for each species were organised into sites, where a site is defined as a relatively discrete area of valley mire (see Chapter 1).

Table 7.6 gives the number of sites from which each species has been recorded. It can be seen that most species occur in a small number of sites (median = 4 sites per species). The distribution of rare species within mires in the Forest is shown in Figure 7.8, from which a number of important conclusions can be drawn. First, a large proportion of the valley mires in the New Forest contain nationally, and in some cases internationally, important populations of rare vascular plants. The total number of sites holding species defined by the particular criteria given above is 54. If the list is extended to include other scarce species, then the total is much larger. For example, additional sites for *Osmunda regalis* (a scarce fern now recovering from nineteenth century collecting) and *Eriophorum vaginatum* (rare in lowland parts of southern England, but common elsewhere) increases the total to 71 sites. These figures are likely to be underestimates due to under-recording (for example, in the north-west of the Forest). Second, on average, each site which contains a rare species is important to that particular species' total population in the Forest, because most species occur in few sites. Third, it is not practicable to determine the complete status of each species in the Forest, and the data here suggest that at least one half to three-quarters of the mires in the Forest hold notable plant species (ignoring bryophytes - see below). Thus, if it is a nature conservation objective to maintain the existing natural species complement of the valley mires, then management policy must be aimed at protecting all the mires, in order to avoid reductions in nationally important plant populations. Fourth, rare species are not restricted to larger sites or to particular types of mire. It is not possible, therefore, to predict the occurrence of rare species from physical characteristics alone. In the case of *Hammarbya paludosa* 41% of recorded sites are less than 5ha, many of which are valley-side seepages. Another example is that of *Spiranthes aestivalis* (now extinct in Britain), a former station of which was Gritnam Bog (0.2ha).

The number of rare vascular plant species per site is an effective discriminant for ranking the valley mires solely on this basis (see Figure 7.8). For example, sites with four or more rare vascular plant species are Wilverley Bog/Avon Water East, Cranes Moor/Vales Moor, Holmsley Bog, Hincheslea Bog, Denny Bog/Shatterford, Fort Bog and possibly Fawley Bog.

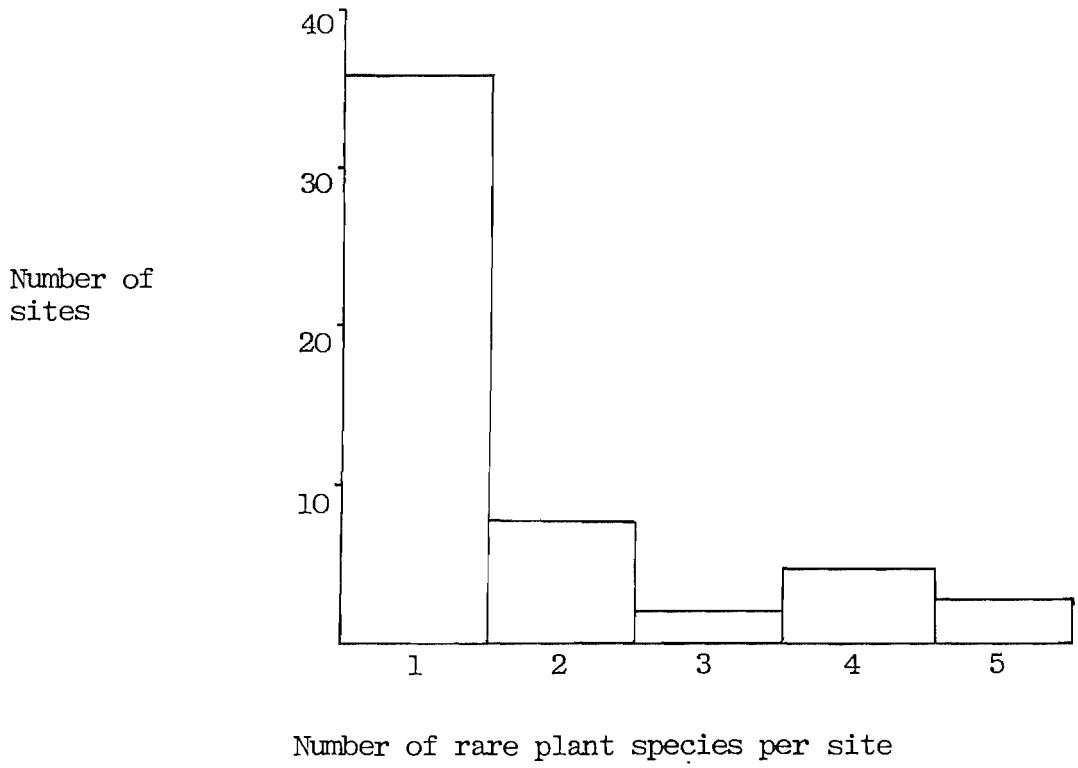


FIGURE 7.8 Frequency distribution of the number of rare vascular plant species in New Forest mires

TABLE 7.7 Bryophyte species occurring in the New Forest mires which are rare nationally or in S.England (based on Corley and Hill, 1981). Base-rich species = BR.

BR	*Preissia quadrata*
	Ricardia multifida
	Lophozia ventricosa (var Silvicola)
	Pallavicinia lyelli
	Cephalozia media
	Cephalozia macrostachya
	Calypogeia sphagnicola
BR	*Sphagnum teres*
BR	*Sphagnum contortum*
	Sphagnum molle
	Splachnum ampullaceum
BR	*Campylium elodes*
	Drepanocladus lycopodioides
	Drepanocladus vernicosus
BR	*Calliergon giganteum*

These sites contain 12 out of the 14 species in Table 7.6, but only 3 species occur in more than two sites within this group.

The New Forest mires hold an equally wide range of nationally rare or local bryophyte species (Table 7.7). Some of these are widespread throughout the Forest, such as *Cephalozia machrostachya* and *Splachnum ampullaceum* (a coprophilous species found mainly in the mires and wet heath), while others are very restricted in distribution - especially those associated with base-rich habitats such as *Philonotis calcarea*. There has not been the same level of recording for bryophytes as for vascular plants, and it is not possible to carry out an analysis similar to that above. It is probable that a number of species have a much wider distribution than records suggest.

7.2.5 Conclusions

The status of valley mires in southern England is now very limited indeed, and the New Forest supports about two-thirds of the national total of this wetland type. Outside the Forest, no more than 1300ha (28% of the total) exists in conjunction with semi-natural habitats and is unaffected by afforestation and other developments. This area is distributed across more than 34 sites. The New Forest encompasses a range of valley mire habitats which are not represented together at any other site. The Forest is possibly the only remaining centre where there is long-term viability for many of the rarer valley mire species, and it is certainly the only centre which retains an assemblage of such species. These considerations stress the collective importance of the New Forest mires. This must also be viewed within the context of the habitat mosaic in the Forest, of which the mires and wet heath are an integral part. It is important that management policy takes these factors into account when proposals which are damaging to nature conservation of particular mires are considered (such as artificial drainage). This is not to say that the Forest, as a whole, is greater than the sum of its parts. Rather, it is a functional emphasis on the importance of the mires within a single ecosystem.

Consideration of the criteria used in the ecological assessment of individual sites also suggests that it is difficult to partition the

collective importance of the New Forest valley mires to nature conservation. Firstly, no simple species - area relationships were found for vascular plants or Odonata in the valley mires. From the available data, there is no justification in favouring large areas of mire over small. Indeed, the many small areas of valley mire are important to the overall spatial diversity of habitats within the Forest, and to the maintenance of invertebrate populations such as *Ceriagrion tenellum*.

Secondly, there is little evidence that plant-based evaluation of valley mires is a good predictor of the importance of sites for invertebrates. This has been shown for Odonata (in terms of species richness), and the rest of the invertebrate fauna is probably heavily dependent on vegetation architecture and hydrology, rather than the species composition of the vegetation. Moreover, the importance of sites differs according to which components of the invertebrate fauna are used (Sheppard, 1987). Given the difficulties of invertebrate survey, this means that only partial evaluation of the mires as a biological resource is practicable with regard to management intervention.

Thirdly, a large proportion of the valley mires contain rare plant populations, although typically each species is restricted to just a few sites. This pattern presumably reflects the differing ecological requirements of these species (Table 7.6). It was not possible to extend this analysis beyond vascular plants, but inclusion of bryophytes and the more 'popular' rare invertebrates (e.g. *Stethophyma grossum*, *Formica transkaucasica*, *Dolomedes fimbriatus*) would greatly increase this number. One concludes that perhaps almost all the mires in the Forest may be significant for organisms which are rare in either a regional, national or international context. Reduction in the amount of mire habitat is likely to lead to further species losses from the Forest, which are unlikely to be replaced by immigration due to modern isolation. A policy of restraint is therefore required, if the maintenance of the present species complement of the mires is to be a management objective.

The differing claims on a single resource, the New Forest mires, means that management is inevitably the outcome of a political process. The support for the biological conservation of the valley mires has greatly increased during the post-war period. However, there are still pressures

on the valley mires, most notably under the requirements of the New Forest Act 1949, but also for infrastructure and other developments (see Tubbs, 1986). The political climate is currently more in favour of a presumption against further losses in the Forest mires than in the past. This is more consistent with the maintenance of the nature conservation significance of the New Forest mires as part of a single ecosystem, which also provides the biological basis for their management.

7.3 Management impacts on the New Forest mires

7.3.1 Introduction

The principal management practices which currently affect the valley mires are associated with the grazing of commonable stock on the open Forest. This includes the direct impact of large herbivores, as well as drainage and burning carried out by the Forestry Commission under The New Forest Act, 1949. In earlier periods, especially before the beginning of this century, the valley mires played a more prominent role in the local economy and were subject to a variety of other forms of exploitation, some of which were also linked to common rights. These included peat and turf cutting, coppicing of alder carrs, and the digging of marl. The latter occurred locally in outcrops of Headon Beds, creating pits supporting a variety of calcareous wetland communities. Marl pits can be seen in the Bull Hill - Lower Crockford Bottom area, and are also well-developed at Marlborough Deeps (although now heavily covered by scrub). Other former practices included the cutting of rushes for bedding (Shore, 1893), the use of withybeds and the raking of *Sphagnum* to make moss poultices. Recollections of commoners from the Great War suggest that *Sphagnum recurvum* lawns under carr woodland may have been used for the latter. There have also been various military impacts due to manoeuvres and camps (e.g. sewage disposal).

The emphasis in this section is on those management practices which continue today, but the available information on peat cutting and coppicing is also reviewed. An understanding of these impacts is important not only to the New Forest but also to similar sites elsewhere. This is because the Forest is the only area of lowland heath and mire in which traditional forms of management linked to a commoning economy survive.

7.3.2 The effect of grazing on plant diversity

7.3.2.1 Methods of investigation

The most appropriate method for the investigation of grazing effects is an experimental enclosure since it allows all other site factors to be held constant. It is also desirable that the experiment should run over an ecological timescale, i.e. there should be sufficient time for recruitment and extinction to take place. This precluded the establishment of enclosures during the course of this study since the probable outcome was already known - enclosures set up in the valley mires over two or three years merely result in more vigorous vegetative growth with little qualitative change (P.J.Edwards, pers. comm., 1983). An alternative approach was taken in which mire vegetation was sampled on either side of existing livestock fences, which were often of known age. This method required an initial search phase to locate suitable sites, followed by sampling. Species abundance was recorded visually as percentage cover in a 2 x 2m quadrat using a frame sub-divided into $100cm^2$ squares. Biomass determinations were carried out for species in some samples but were not conducted throughout because of the time required in sorting. Quadrats were located randomly beyond a 1m wide strip either side of the fence, in order to avoid any possible edge effects. Grazing was assessed by the presence of animals, grazed shoots, evidence of trampling and footmarks and the presence of dung at the site or nearby.

Considerable difficulty was encountered in finding suitable sites. A preliminary desk-top survey was carried out to locate mires which appeared to be dissected by either forestry inclosure or road-side fences. All potential sites were examined in the field. The following factors precluded most from being used as experimental plots:

(i) the presence of ponies - or clear evidence of pony grazing - on the inside of the fence, i.e. within the forestry inclosures;

(ii) the creation of drainage ditches within forestry inclosures;

(iii) the successful establishment of planted conifers on or near the fenced area of mire.

It became clear from this survey that, during 1982 - 1983, there were very few areas of mire and other habitats in the New Forest from which ponies

were effectively excluded, including the Forestry Commission inclosures (see Tubbs, 1986). Several small relict areas were found within enclosures. Typically, these communities consisted of large *Molinia caerulea* tussocks under a sparse shrub layer of "leggy" *Myrica gale*. *Juncus acutiflorus* was often present, together with mature or degenerate *Erica tetralix* and *Calluna vulgaris; Sphagnum recurvum* was the only frequent bryophyte although *S.papillosum* was also recorded. Three sites were found:

(i) a small fenced area, some 15 x 15m, in the mire margin at Ferny Crofts (SU 375056), date of fence unknown but before 1967.

(ii) an enclosed seepage zone, 20 x 25m, at the edge of Markway Inclosure, probably dating from 1959 (SU 247030)

(iii) where Markway Inclosure crosses Duckhole Bog (SU 252024), this fence dated from inclosure in 1959. The effects of reduced grazing were first noted by Mussett (1964), soon after fencing of this inclosure.

These areas amounted to about 0.5ha in total. Rabbits were absent from all sites and deer browsing was thought to be very low. However, pony grazing had only been totally eliminated at site (ii), and the evidence suggested that the other sites may have been subject to occasional grazing but at much lower intensities than outside these enclosures. The strict comparison within these experimental plots is therefore, one of degree - heavy intensity grazing versus light or absent. Due to the small area available, one pair of observations was taken at the Ferny Crofts and Markway Inclosure sites, while three pairs were conducted at Duckhole Bog. Sampling was carried out towards the end of the growth season, during August 1983.

7.3.2.2 The response of species to grazing

The species richness of the grazed plants (mean = 19.0 species/4m^2 plot) was significantly higher than the controls (mean = 11.2; U = 2, p = 0.016, Mann and Whitney, 1947). Overall, there was an average 70% increase in species density with greater grazing pressure. It can be seen from Figure 7.9, that the main contribution to the increase in species richness is the greater diversity of the bryophyte and Cyperaceae groups. Species richness shows interesting relationships to the changes in species abundance, as is seen at Duckhole Bog (Figure 7.9). The main offtake species were *Molinia*, *Juncus acutiflorus* and the Ericaceae. Putman *et al*, (1983)

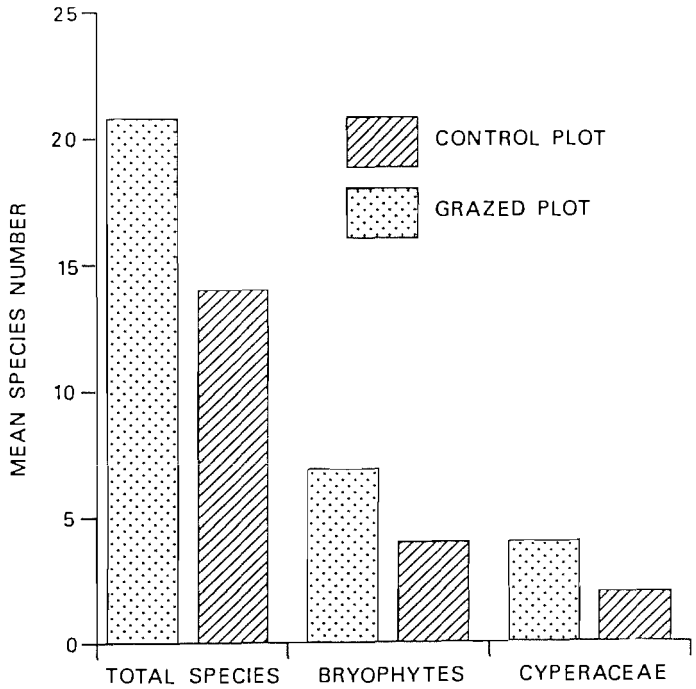


FIGURE 7.9 : Changes in species richness with grazing intensity at Duckhole Bog.

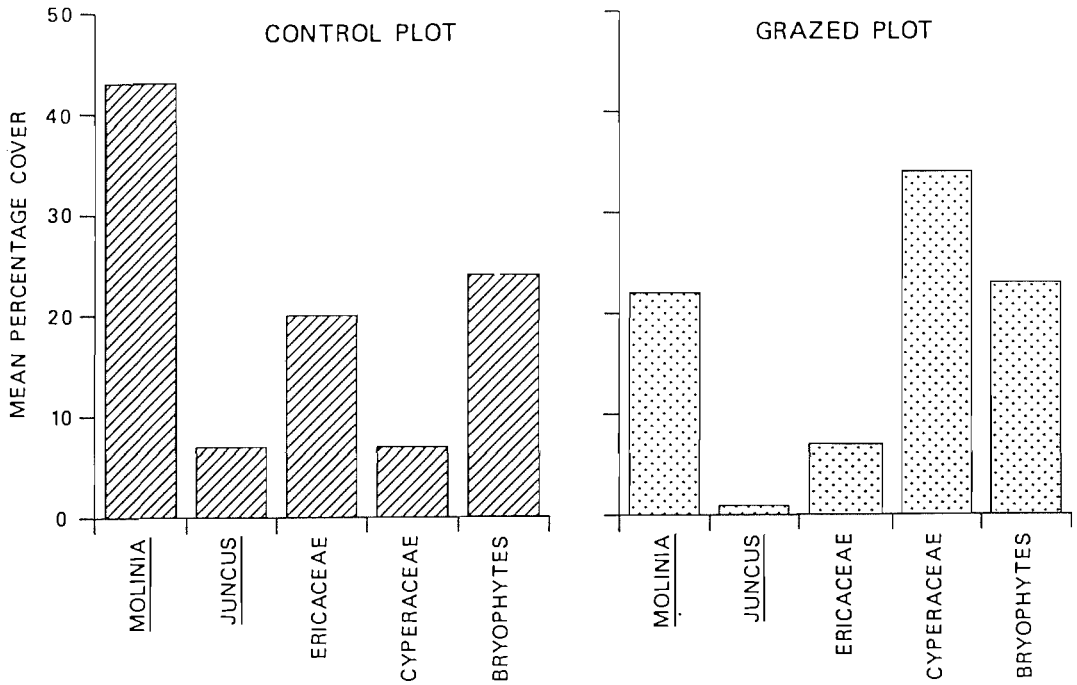


FIGURE 7.10 : Species abundance changes with grazing intensity at Duckhole Bog.

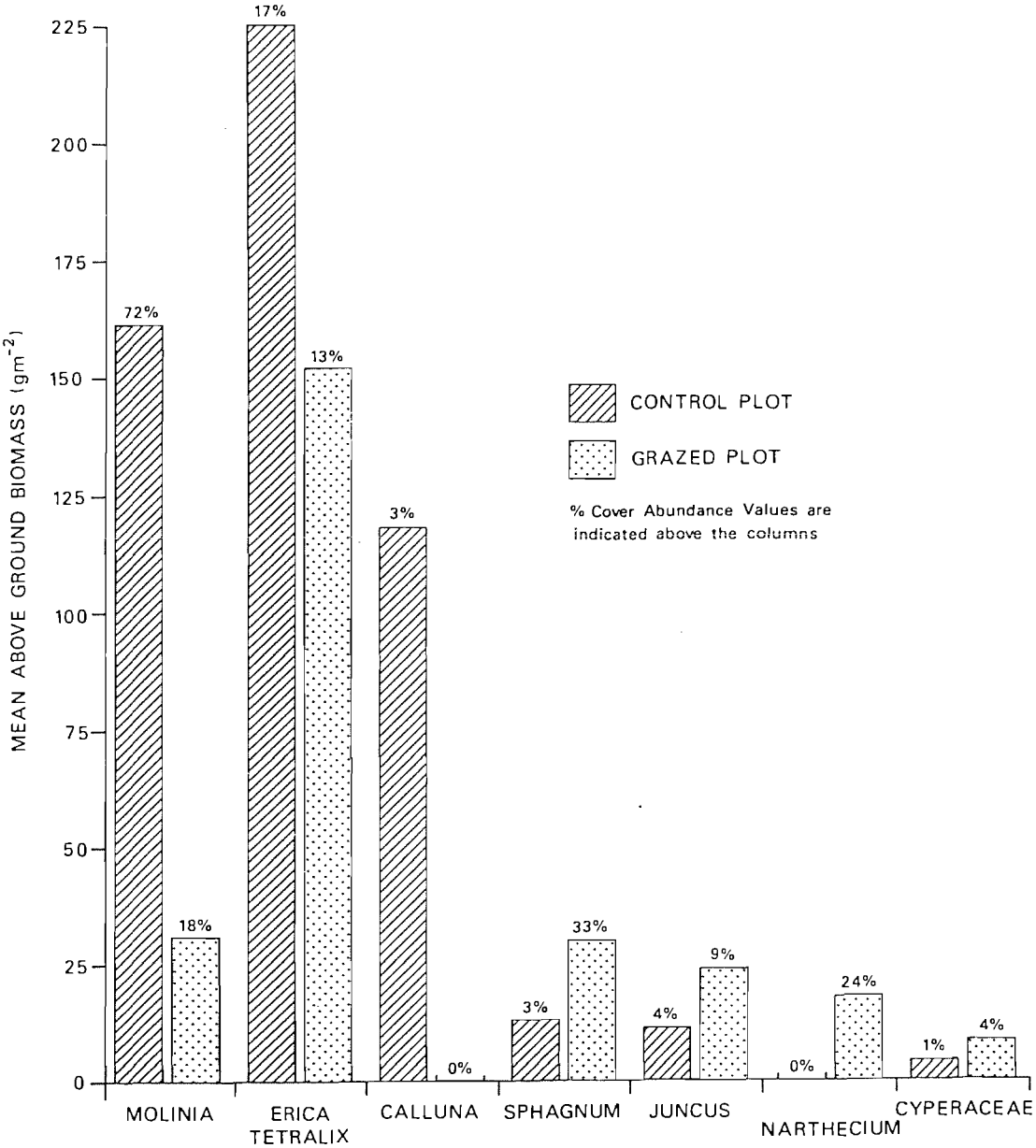


FIGURE 7.11 : Changes in biomass and cover abundance with grazing intensity at Ferny Crofts.

found that *Molinia* and *Juncus* were important components in the diet of ponies and cattle, but they reported that utilisation of the Ericaceae was much lower and more variable, although they did not include any of the highly grazed heathland areas. However, this study has shown that the abundance of both *Erica tetralix* and *Calluna* was reduced at all sites with grazing, perhaps reflecting greater utilisation of Ericaceae at heathland contact zones and where isolated plants occur within more heavily grazed communities (Putman *et al*, 1982). The increase in species richness and abundance of the Cyperaceae was closely correlated to the reduction in dominance of these forage species at Duckhole Bog (Figure 7.10), whereas the greater bryophyte diversity was not accompanied by a concomitant increase in abundance. This suggests that different processes are affecting co-existence within these components of the community. The response of the Cyperaceae is to a reduction in direct competition from the main forage species, particularly *Molinia* and *Juncus* which have a similar life-form. The bryophytes, on the other hand, may be affected by indirect changes, particularly habitat structure. In the ungrazed plots the bryophytes were restricted to shade-tolerant species which are able to co-exist with community dominants, often as virtual epiphytes on *Molinia* tussocks. The more open structure of the grazed plots allowed a complex of *Sphagna* with abundant liverworts to develop.

Changes in above-ground biomass show a similar pattern, although there are some contrasts with species cover abundance. For instance, at Ferny Crofts (Figure 7.11) *Erica tetralix* had the highest biomass even though it had a considerably lower cover abundance value than *Molinia*, the dominant, in the ungrazed plot. The Ericaceae, as shrubs, store significant quantities of material in their stems and branches over several years, and the photosynthetic:woody tissue ratio was lowest where plants were competing with *Molinia* tussocks for light.

Despite the errors inherent in visual estimates of cover abundance, this is the most meaningful community-level variable for dominance, whereas biomass measurements were found to be most useful in relation to herbivore foraging behaviour. The maximum standing biomass of *Molinia* was 378 gm^{-2} (on the basis of 100% cover) in the ungrazed plot at Markway Inclosure, where it achieved almost total cover. This compares with a maximum annual production of 496 gm^{-2} recorded for *Molinia* by Putman *et al* (1982). In

their study from 1978 - 1979, an average of 87% of total annual production was removed from the mire communities. The reduction in *Molinia* biomass in the grazed plots of this study was estimated to be approximately 80 - 90% of the standing biomass in the less grazed plots, and the mean reduction in cover was 73%. A significant difference in growth strategy was observed between grazed and less grazed plants of *Molinia*. Under high grazing intensities, individual plants produced 2 to 3 times the number of flower spikes per unit area compared to the controls. In terms of sexual versus vegetative allocation, there was an increase from 0.24 - 0.3 spikes/g vegetative matter in less grazed plots to 0.9 - 1.5 spikes/g in the heavily grazed plots. This aspect of the biology of *Molinia caerulea* has not been described before.

7.3.2.3 The effect of grazing on diversity : species abundance patterns

At all the sites investigated, *Molinia* was the most abundant species in the ungrazed plots but achieved dominance in only one of the grazed plots (at Duckhole Bog). The degree of community dominance by a given species is usefully measured by the indix of d, where

$$d = \frac{N\max}{N\ \text{total}} \qquad \text{(Berger and Parker, 1970).}$$

N max is the abundance of the dominant and N total the total abundance of all members of the community. This measure is conceptually simple and is effective as any other one-parameter index of species - abundance patterns (May, 1975). Figure 7.12 shows a marked inverse relationship ($p<0.0005$) between species richness and community dominance by *Molinia*. The enhanced species density of the grazed experimental plots over the controls can be related to a pronounced reduction in the dominance of *Molinia* due to grazing ($p<0.004$, $U = 0$). This emphasises the importance of strong interactions between a few species in determining the structure of these mire communities (cf Paine, 1980).

The two components of diversity, species richness and equitability, can be expressed graphically by plotting cumulative abundance against species rank (Figure 7.13). Dominance is the opposite of equitability and has an inverse relationship with diversity. The resulting curve is a diversity profile for the community and shows how relative abundance is distributed

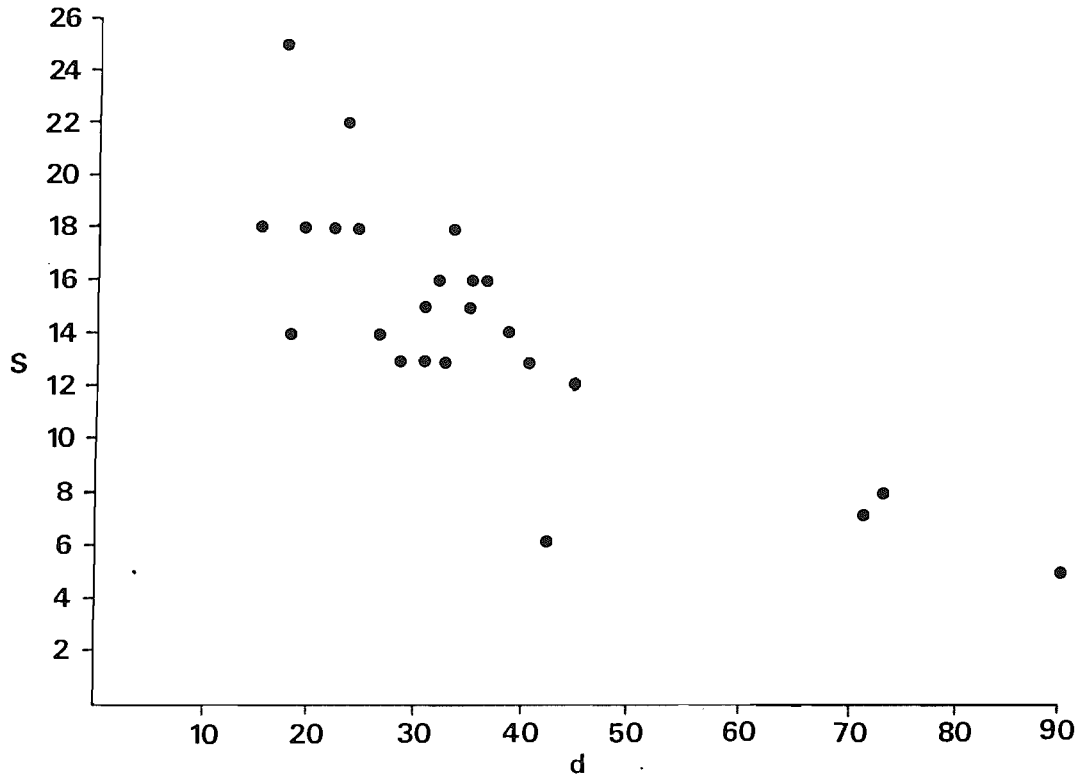


FIGURE 7.12 : The relationship between species richness (S) and community dominance (d) by *Molinia* (see text).

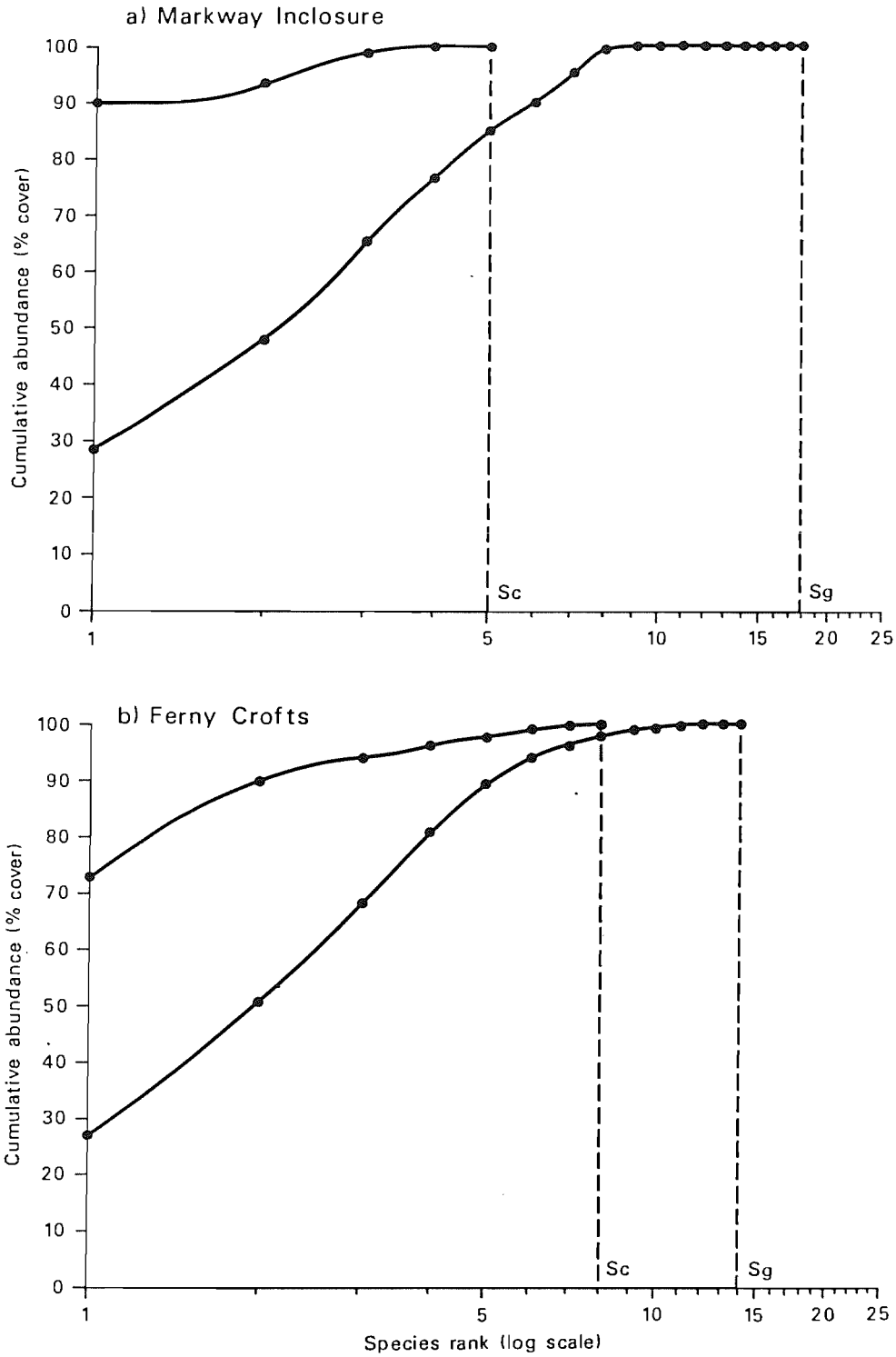
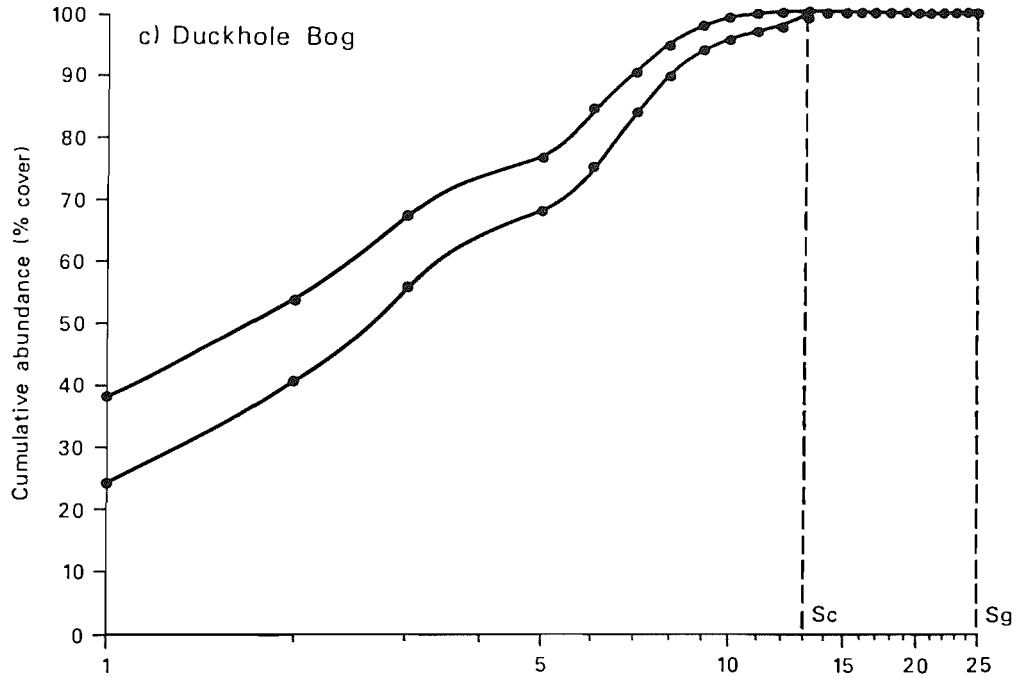


FIGURE 7.13 : k-dominance curves for grazed and control vegetation plots (see text).



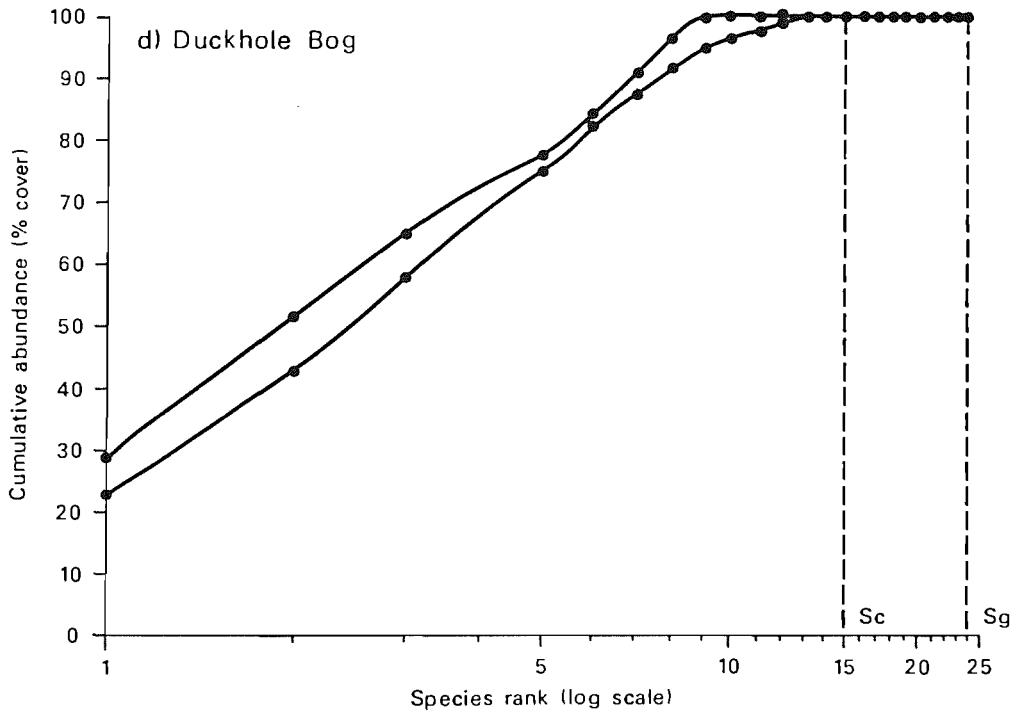


FIGURE 7.13 (continued)

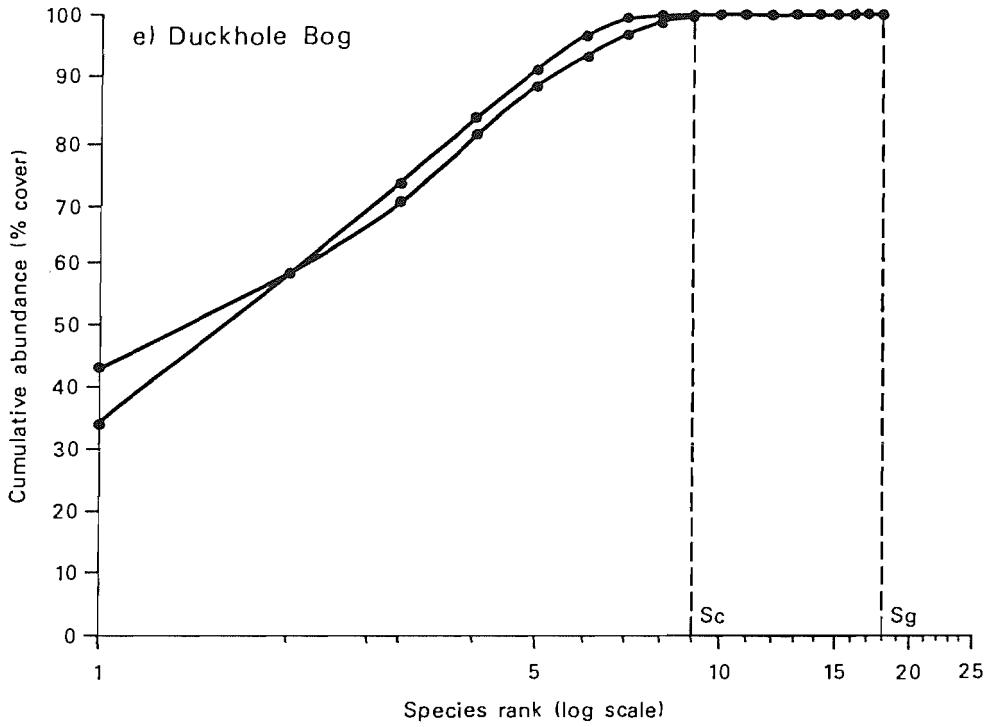


FIGURE 7.13 (continued)

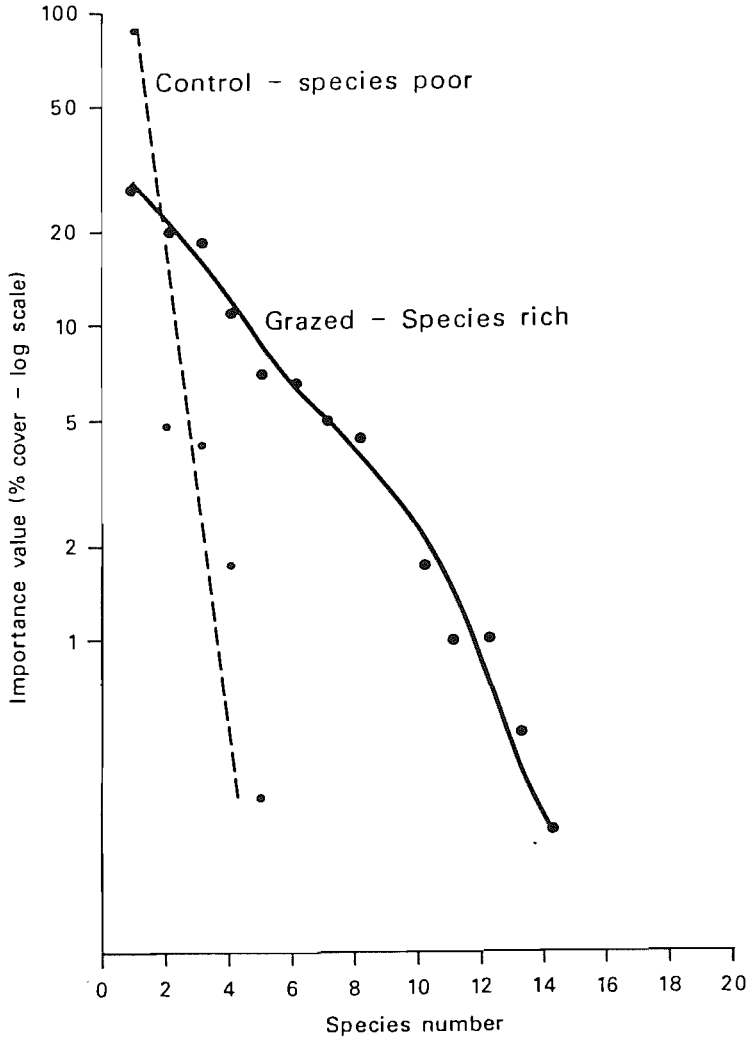


FIGURE 7.14 : Dominance - diversity curves for grazed and control communities at Markway Inclosure.

among the total number of species. This has been termed the k-dominance curve (Lambshead *et al*, 1983; Platt *et al*, 1984), and one community is more diverse than the other if the cumulative abundance of the first is less than or equal to the second over all species ranks. In other words, the lower the curve, the higher the intrinsic diversity. This comparative method is superior to single measures of diversity, such as the Simpson and Shannon - Wiener indices, in cases where the k-dominance curves for the communities intersect (Lambshead *et al*, 1983). The comparison of diversity profiles shows that the grazed plots have a markedly higher diversity than the controls in almost all cases. One grazed sample at Duckhole Bog was anomalous in this respect (Figure 7.13e), since the diversity profile intersected two of the control plots at the site. The intrinsic diversity of this community is, therefore, not directly comparable to the other samples (Lambshead *et al*, 1983). The dominant in this sample was *Rhynchospora alba* and was associated with relatively high species richness.

A general feature is the tendency for the grazed and ungrazed dominance curves to converge. This shows that the higher diversity of the grazed communities is mainly due to a reduction in the dominance of a very few abundant species, often just *Molinia*. Again, this emphasises the importance of a small number of species, principally *Molinia*, in determining the community structure of the open mire vegetation. The contrast in community structure with grazing is seen most clearly in the samples from the small enclosure at Markway. These communities have been represented by dominance-diversity curves in Figure 7.14, which illustrate two different types of species abundance pattern (see Whittaker, 1965). The species-poor, ungrazed plot is dominated by highly productive *Molinia* tussocks. Co-existence of the other species in this community is due largely to a life-form which is complementary to that of the dominant (Grubb, 1977); for example, shade-tolerant, almost epiphytic bryophytes, or shrubs such as *Myrica* which are able to establish themselves between the tussocks. A more complex pattern exists for the grazed plot, which has a roughly sigmoidal curve. Three components of the community may be identified for this type of curve: a small group of co-dominants, a larger number of moderately important species, and a class of rarer ecological specialists (Whittaker, 1965).

From the contrasting species abundance patterns, it is clear that the organisation of these communities is determined principally by the strong interactions between *Molinia* and the rest of the community. These results are comparable to the organisation of sessile animal community food webs, particularly as shown by the extensive studies by Paine (e.g. 1966, 1980, 1984) of intertidal habitats. Paine has observed a high variability in the interaction strengths of species within webs, with important consequences for species deletion stability - that is, the probability that no species will become extinct following the removal of a species from the system, such as the exclusion of the starfish *Pisaster ochraceus* from benthic marine communities (Paine, 1966).

In terms of species deletion stability, the grazed communities sampled here are highly unstable. Removal of the principle herbivore, the commoners' pony, results in a large proportion of the species present in the community being lost. From other sites examined during the initial search phase and from general observations, it is clear that these findings are applicable to most of the open mire communities in the Forest where *Molinia* is not limited by other environmental factors. The *Molinia*-dominated community is the most stable configuration. A significant proportion of the New Forest valley mires is unstable in respect of its species composition, and the current diversity of this vegetation is maintained by grazing.

7.3.2.4 A discussion of the reasons for increased species richness due to grazing

Despite the importance attached to diversity, in terms of nature conservation values, the mechanisms controlling the co-existence of plant species are poorly understood. Three hypotheses may be advanced to explain the increased diversity due to grazing. The first states that species have an imperceptible effect on each other because their populations are prevented from reaching the carrying capacity of some potentially limiting resource by grazing. This is easily rejected, since the mire vegetation is usually closed so that space, if not light, is a limiting resource. Hence co-existence must be explained within the context of the competitive exclusion principle, and increased diversity must arise from either a larger number of available niche axes, or greater partitioning of niche axes by the species in the community.

The principal mechanism by which grazing may increase habitat space is the creation of a more heterogeneous environment, in which replacement can occur on the death of an individual plant - the regeneration niche of Grubb (1977). Such 'gap phase dynamics' are thought to be important in the maintenance of diversity. Many studies attribute the principal cause of coexistence to disturbance of the community (e.g. Levin and Paine, 1974; Connell, 1978; Hastings, 1980; Hubbell, 1979; Paine and Levin, 1981). Disturbance may create a mosaic of patches in which competitively inferior species are able to establish and escape from dominants, at least temporarily; with their persistence in the community maintained by repeated disturbance events. These communities are said to be at competitive non-equilibrium in that they are prevented by disturbance from reaching a constant composition due to competitive interactions. Grubb's (1977) thesis is, in a sense, more elegant in that it does not necessarily require an external driving force, such as disturbance for diversity to be maintained. He observes that many communities persist longer than the life-span of the constituent species and when an individual dies it may be replaced by an individual of the same or a different species. Grubb argues that the opportunities for differentiation between species in their regeneration requirements provide a far greater source of niche partitioning than between adult plants.

Grazing in valley mire *Molinia* communities will increase the number of regeneration niches in two ways. Firstly, trampling creates a wide variety of transient microsites for germination and vegetative invasion. The impact of such physical disturbance on community composition and species richness will depend on intensity and frequency, and the nature of the substrate. The second mechanism arises from the fact that grazing reduces the standing crop and leaf litter of *Molinia* this is a simple yet important change. Reduced canopy shade creates more favourable conditions for regeneration while less litter removes a physical barrier to dispersal, germination and growth of the immature plant. In a sense, the various microsites are present all the time, it is just that their exploitation by other species is prevented by the presence of *Molinia*.

The ecology of plant life-form is a useful concept for the interpretation

of the results from this grazing study. A smaller plant, such as a bryophyte, experiences greater spatial heterogeneity compared to a larger plant which experiences the environment at a coarser spatial scale because of its more extensive root network and shoot system. The increase in species richness of the grazed plots was due mainly to larger numbers of bryophytes and Cyperaceae. Slack (1982) and Johnson (1977a) have also found that the number of bryophyte and small herb species rises at a disproportionately faster rate between communities of low and high species richness. Removal of *Molinia* effectively increases the environmental heterogeneity of the habitat relative to the small plants colonizing the grazed site. The plant assemblages which develop on grazed *Molinia* tussocks in valley mire and lawn communities are good examples of this phenomenon. These grazing-tolerant species will be more sensitive to small-scale environmental variation.

Niche theory has been much concerned to explain co-existence within communities in terms of niche partitioning (e.g. MacArthur and Levins, 1967; MacArthur, 1972; Whittaker, 1975). It was shown that, for a community at competitive equilibrium, if species do not possess some minimum degree of niche divergence then the inferior competitors will be excluded (see Pickett, 1980). Hence, co-existence between similar species is only possible if niche overlap is reduced by a narrowing in the niche breadth of the species in the community.

Habitat partitioning within the *Sphagna* has long been recognised by mire ecologists, such as well-defined zonations along habitat gradients (e.g. height above the water table - Ratcliffe and Walker, 1958) and inter-specific differentiation in relation to combined factors (e.g. conductivity and pH - Newbould and Gorham, 1956). Co-existence in the *Sphagna* may be maintained by additional separation along other microhabitat axes, especially shade and height above the water table. This has been demonstrated by a variety of field and laboratory studies (Ratcliffe and Walker, 1958; Clymo and Hayward, 1983; Andrus *et al*, 1983; Hayward and Clymo, 1982; Wagner and Titus, 1984). Using a similar approach to above, Vitt and Slack (1984) have investigated niche breadth and overlap in *Sphagna* simultaneously along four major microhabitat axes (pH, corrected conductivity, water table and shade). They found that, although average

overlap was high, all species were segregated with low overlap along at least one of the four gradients. Furthermore, their results suggest that gross conductivity encompasses several independent microhabitat axes. Sodium and potassium concentrations, in particular, behave independently of the total conductivity which is due mainly to calcium and magnesium (see 6.5.2). At a larger spatial scale, multivariate analysis of niche diversification in raised mires has shown that microclimatic variables provide further axes along which niche partitioning has occurred (Johnson, 1977a, b).

The maintenance of diversity by niche partitioning has received attention from a number of mire ecologists in recent years, notably Slack (1982; Vitt and Slack, 1984) and Watson (1980, 1981). However, the usefulness of this approach has been questioned in explaining co-existence between plants (see review by Grubb, 1977) and in other sessile organisms (Levin and Paine, 1974; also Loucks, 1970). The rejection of niche partitioning in maintaining co-existence in plant communities stems largely from the lack of evidence supporting this hypothesis (Pickett, 1980). There are several difficulties, moreover, which have not been considered fully by recent studies of mire community diversity.

Firstly, there are problems with the falsifiability of the hypothesis that co-existence is maintained by niche partitioning as a result of competition. This arises from the fact that there is a greater probability of co-existence with a larger number of niche axes. Hence, high niche overlap can only disprove the hypothesis if all the niche axes are known, which they cannot be. Secondly, the theoretical underpinnings of this approach to plant communities are based on mathematical models developed for animal populations. Minor problems may be overcome, such as the measurement of abundance - for example, individual stem counts may be applicable to acrocarpous mosses (Watson, 1981), although not pleurocarps. The major obstacle is that the Lotka-Volterra competition equations, on which the MacArthur-May type niche model is based, are singularly inappropriate to plant populations. Perhaps most severe is the assumption of uniform mixing. Relaxation of this restriction leads to generalised competition models which are characterised by second-order partial differential equations that are not susceptible to analysis

(Schaffer and Leigh, 1976). Moreover, the relevant parameters of plant populations and the nature of plant competition are incompatible with the Lotka-Volterra model (Schaffer and Leigh, 1976; Werner, 1976; Newman, 1982).

However, the main result of the rejection of the Lotka-Volterra competition equations is to dislocate measures of niche overlap and partitioning from any theoretical basis concerning the separation necessary for stable co-existence. This is because measures of niche overlap (e.g. Pianka 1975), are directly equivalent to the competition coefficient of the Lotka-Volterra equations from which they are derived. Thus, although these indices can be used as an empirical measure of niche separation between plants, it is not possible to state the minimum level of overlap necessary for stable co-existence. These difficulties have led to the development of new models of plant competition and co-existence (e.g. Newman, 1982; Schmida and Wilson, 1985). The relative simplicity of *Sphagnum*-dominated communities suggests that this would be a profitable area of further research in mire ecology.

Why should *Molinia* be so successful and exert such an influence on community organisation in the open mire? An answer may be found within Grime's (1977, 1979) framework of three primary evolutionary strategies (see Chapter One): (i) competitors which exploit conditions of low stress and low disturbance; (ii) stress-tolerators (high stress - low disturbance) and (iii) ruderals (low stress - high disturbance). Grime (1979, p. 66) describes *Molinia caerulea* as a stress-tolerant competitor, i.e. it is successful in low intensities of disturbance and is intermediate between those plant species which are able to acquire resources at a high rate in productive, crowded vegetation, and those which are able to endure limited productivity due to external constraints. Typically, stress-tolerant competitors are robust perennials with a capacity for lateral spread by rhizomes or expanding tussocks (Grime, 1979). There are two components to a plant's ability to achieve dominance. Firstly, mechanisms whereby it achieves a larger size than competitors and, secondly, deleterious effects exerted on other plants. Tussock morphology enables herbaceous plants to gain height and spread laterally in order to capture the major share of light and other resources. The presence of a high

density of herbaceous litter throughout the year plays a major role in the competitive exclusion process (Al - Mufti *et al*, 1977). The deciduous habit of *Molinia* leads to the production of abundant litter, which lowers the number of microsites available for regeneration and may exclude species which have a complementary shoot phenology to *Molinia* (e.g. early vernal or evergreen species).

The ordination results (Chapter 6.5) show that the competitive ability of *Molinia* is a major structuring force in the valley mires. Other evidence also supports the notion that the tussock growth strategy is of fundamental importance to community organisation in herbaceous peatland vegetation (Clapham, 1940; Keatinge, 1975; see also Wheeler, 1984). Within the New Forest mires, there are three prominent groups of plants which are both important sources of community variation and are closely correlated to the principal external environmental gradients in the valley mires. These are the carr tree species, *Molinia* and the *Sphagna*. The relationship between plant growth strategies and mire community structure may be examined by correlating the dominance of these groups with the ordination results (Figure 7.15). The principal gradient in the valley mires reflects decreasing environmental stress within the peat soils from the *Sphagnum* lawn, with high acidity, low ionic concentrations and low aeration, to the carr woodland (axis one of the ordination : see Figure 6.11 and Table 6.8). This represents a continuum along which the environment will favour stress-selected species at one end and species with greater competitive ability at the other. It is well known that *Molinia* is restricted from anoxic environments (see Chapter 6.4). Such conditions create the highest environmental stress within the mires and anoxia rapidly increases with depth in the upper peat horizons. Vascular plants require specialised adaptations in root morphology and physiology (Chapter 6.4) if they are to compete with the often dominant, surface-growing *Sphagna*. Conversely, at the other end of the continuum plants are favoured which can rapidly exploit above and below-ground resources and are able to maximise dry matter production. Here, the tree species are competitively superior (Figure 7.15), particularly *Alnus glutinosa* and *Salix cinerea*. Interestingly the work of McVean (1956a) suggests that *Alnus* exhibits a more stress-tolerant strategy compared to tree species

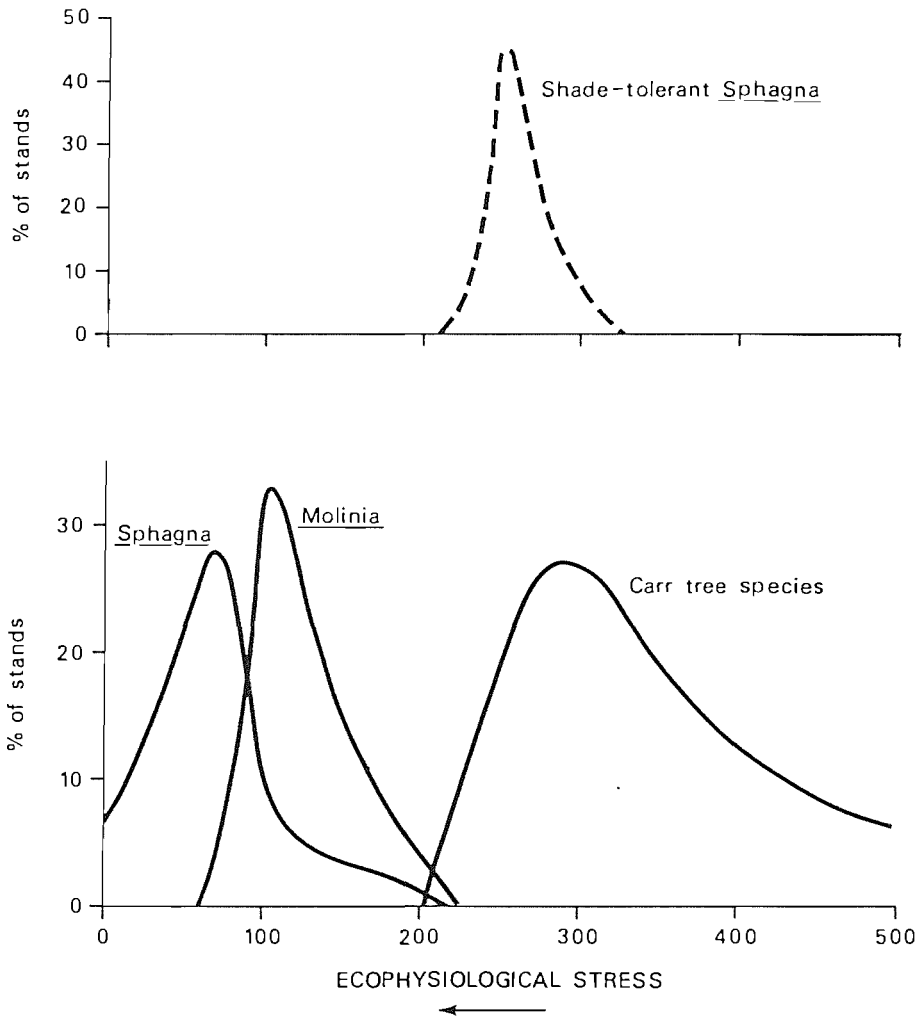


FIGURE 7.15 : Relationship between community structure and plant growth form in valley mires (see text).

in the surrounding dry woodland. The *Alnus* seedling is better adapted than other species to establishment in very wet or waterlogged soils, and is also more resistant to complete inundation at all stages of development - despite exhibiting a higher subsequent growth rate on drier soils (McVean, 1956a).

The dense canopy shade resulting from the carr woodland is another major ecological gradient in mire community structure (Chapter 6.5). This creates an additional dimension to environmental stress. Both Grime (1979) and Tilman (1980) predict that relatively high levels of stress will result in a reduction in species richness because the survival of species becomes limited by the environment. This prediction is supported by the observation that low species richness within the carr groundflora communities is significantly correlated with an increase in acidity (Chapter 6.5). This is shown by the distribution of shade-tolerant *Sphagna* dominance at the high-acidity end of the gradient within the zone of carr canopy shade (Figure 7.15).

7.3.25 The role of grazing in the management of valley mires

A number of studies have shown grazing to be a positive management tool in peatlands and related herbaceous communities (see Table 7.8). Grazing experiments have often been initiated by a decline in species following the cessation of traditional management practices, especially on marginal land. Generally, the species richness of plant communities is increased by grazing and the magnitude of change is similar to that in the grazed communities of the New Forest mires. However, the changes associated with grazing do not always enhance the interest of a site. For example exclusion of sheep grazing may be beneficial to nature conservation in the moorland and blanket bog habitats of upland Britain (Rawes, 1983). The outcome of a change in grazing regime depends on the type of herbivore and the intensity of grazing (Welch, 1974). Normally, grazing is intended to control dominance and, clearly, community composition will vary according to whether the herbivore selects or avoids the major dominants (Harper, 1969).

It is also important to identify the nature conservation objective for a site, since not all interests are necessarily favoured by grazing. For

TABLE 7.8 Studies into the effects of grazing on mire communities

Source	Habitat	Herbivore	a) Grazing	b) Exclusion of grazing	Floristic response (Species richness)
Welch and Rawes, 1964	High altitude moor	Sheep	Bryophytes, Lichens, Herbs *Nardus stricta*, *J. squarrosus*	*Deschampsia flexuosa*	-
Persson, 1984	Wet fen meadow	Cattle	Herbs and especially bryophytes	*Molinia caerulea*, *Nardus stricta*, *Filipendula ulmaria*, *Galium boreale*	Up to 50% reduction with exclusion
Rawes, 1983	High altitude blanket bog	Sheep (grouse not excluded)	Principally *Eriophorum vaginatum*, *Sphagnum*, leafy liverworts, lichens	*Deschampsia flexuosa*, *Narthecium ossifragum*, *Empetrum nigrum*, *Calluna vulgaris*	No clear change but wildlife value enhanced with exclusion
Williams *et al*, 1974	Woodwalton Fen	Cattle		*Calamagrostis epigejos* *Agropyron repens*	Major increase with grazing
Wheeler 1983	Lowland valley fen	Sheep and cattle	Fen meadow species, esp. *Carex acutiformis* *Juncus sub-nodulosus*	*Epilobium hirsutum*	53% reduction with exclusion

example, exclusion of large herbivore grazing on mires may create a more favourable habitat for certain terrestrial invertebrates (Nelson, 1971), in which there is a greater abundance of flowers, seeds, stems, etc. in addition to an increased number of microhabitats. Large herbivore grazing might be expected to particularly affect phytophagous insects such as the Orthoptera (Dempster, 1963). This has been shown by the exclusion of rabbits from Weeting Heath in the Brecklands, which led to higher densities of *Chorthippus brunneus* (Grayson and Hassell, 1985). It was suggested from this study that the Orthopteran population dynamics were related to changes in the food quality of grasses and microclimate. Grazing is thought to be responsible for the exclusion of the dragonfly *Sympetrum sanguineum* from the open Forest, due to the limited availability of tall emergent vegetation around open water bodies (Welstead and Welstead, 1986). This emphasises the importance to invertebrate conservation of maintaining variation in habitat architecture in valley mires.

Grime (1973) has proposed a 'hump-backed' model for the behaviour of plant species richness in response to the intensity of environmental stress and management practices, such as grazing or mowing (Figure 7.16). At low intensities of environmental stress or grazing, competitive species are able to sustain high rates of dry matter production, so that species richness is depressed due to competitive exclusion. At the other extreme of intensity, species richness is also low because of the scarcity of species tolerant to the severe conditions limiting productivity. Intermediate conditions result in the decline in the vigour of the competitive species (the potential dominants) because productivity is limited so that more stress-tolerant, but less competitive, species are able to survive. This model and a similar proposal by Tilman (1980) have been corroborated by a number of studies (see Grime, 1979; Wheeler and Giller, 1982; del Moral, 1983; Hixon and Brostoff, 1983). In order to increase floristic richness, therefore, grazing should be directed at communities of relatively low environmental stress so that net productivity is reduced. The model predicts that grazing should enhance species richness within *Molinia*-dominated communities, where environmental stress is relatively low, but may depress species-richness where the intensity of stress due to the environment is higher

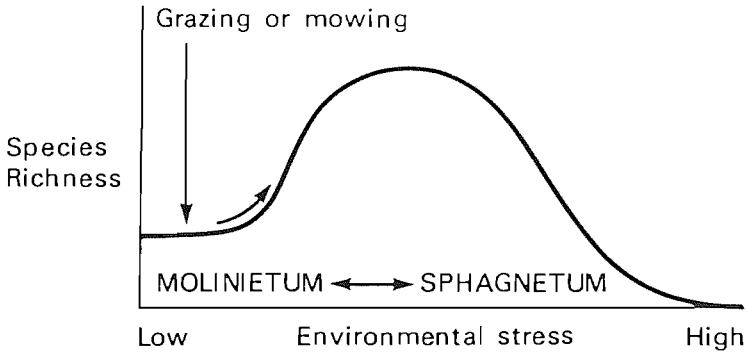


FIGURE 7.16 : A model for species richness in open valley mire communities, based on Grime (1973).

as in the *Sphagnetum* (low pH, nutrient flux, aeration, etc.). The introduction of grazing to parts of a mire which have relatively low stress environments will allow the establishment of more diverse communities which, under these conditions, would normally be excluded by *Molinia*.

Within the mire habitats, the limited literature suggests that grazing is most effective in enhancing plant diversity when applied to fen communities, where the environmental stress is relatively low compared to ombrotrophic sites. Valley mires of the New Forest type are intermediate between these two other types, and environmental conditions (and hence stress) can vary greatly within a single site. Wheeler and Giller (1982) found that species richness exhibited a strong inverse relationship with above ground biomass and litter production in herbaceous fen vegetation in Norfolk Broadland. Apart from *Phragmites* reedbeds, they found that high species densities were only maintained by summer mowing. Species-rich communities only occurred when the above-ground biomass was less than 1500 g m^{-2}, double the upper threshold suggested by Al-Mufti *et al*, (1977) and Grime (1979). In the New Forest, this study and that of Putman *et al*, (1982) show that low species richness in *Molinia*-dominated communities occurs with an above-ground biomass in excess of the range 450 - 550 g m^{-2}.

Although there is little comparative evidence, grazing may be a more superior management option compared to mowing. This is because grazing is more species-specific and maintains a micro-pattern of vegetative type and structure within an area due to differential grazing pressure (Bakker *et al*, 1983; 1984). Trampling is an important associated effect, especially at high stock densities, and it might be expected to increase diversity by creating additional regeneration gaps. However, mire communities are not composed predominantly of ruderal plants (see Wheeler and Giller, 1982) and include many species with high capabilities for vegetative propogation. Trampling and raised nutrient levels by cattle are thought to have caused the loss of valley mire communities from Gibbon's Brook in Kent (Rose, 1953). In N. Sweden, simulation of trampling in a fen meadow previously grazed by cattle, suggests that grazing offtake was more important in maintaining populations of now rare plant species rather

than the creation of regeneration gaps due to trampling (Elveland, 1984). Trampling can also disturb peat profiles. In practice, grazing and mowing are seldom viable management alternatives at the same site, however.

In the New Forest, grazing of the valley mires is principally by commonable stock and to a lesser extent by deer. Ponies utilise the valley mire and wet heath habitats to a much greater extent than cattle (Putman *et al*, 1983; Pratt *et al*, 1986). Even so, there is great spatial variability in the proportion of the standing crop which is actually consumed (Putman *et al*, 1983). There is growing awareness that the future conservation of most open communities in the New Forest depends on grazing by large herbivores, and hence on the continuation of the commoning system (see review by Tubbs, 1986). The consensus is that the numbers of ponies and cattle depastured on the Forest needs to be around recent levels (Report of Working Group on Strategy, 1986), which were described in Chapter 1. The evidence of this investigation into the grazing of mires may be coupled with that of Edwards (1985). He concluded that the areas of streamside lawn supporting numerous grassy mounds are derived from *Molinia* tussocks through heavy grazing. Tubbs (1986) also takes this view and estimates that 40% of the total lawn habitat is covered by hummock grassland which may have originated in this way. The implication of these observations is that a significant element of the mire and grassland vegetation would revert to species-poor, *Molinia*-dominated communities, on relaxation of grazing pressure, where environmental conditions permit tussock formation and a standing biomass of more than about 500 g m^{-2} (water movement, nutrient flux etc.).

This has implications for the conservation of valley mires both in the New Forest and elsewhere. It suggests that the present mire vegetation is a reflection of the ebb and flow in grazing pressure, in much the same way as other plant communities in the Forest have been affected by the number of large herbivores. It also suggests that, at sites no longer grazed, there has been a loss of nature conservation interest in those mire communities which are not limited by low intrinsic productivity. This phenomenon has been observed in East Anglia, where Williams *et al*, (1974) found that rabbits were unable to control the spread of coarse grass species in the absence of cattle at Woodwalton Fen, because they

were too selective and consumed too little quantity of material. The cessation of commoning is thus the main management problem for lowland valley mires as it is for the lowland heaths, as can be seen at sites such as Ambersham Common, Sussex, for example. The main factor in the case of the mires is the removal of high effective densities of large herbivores.

7.3.3 Burning

The management of heathlands by burning is well-established in the New Forest. Controlled burning has taken place since the 1870's, but unofficial, 'wild' fires continued to be relatively frequent up until comparatively recent times. Webb (1986) has suggested that, contrary to belief, fire may not have been used to manage lowland heaths much before the 19th century, in common with the upland heather moors. In support of this, Webb quotes Gilbert White's description of the punishment for heather burning on Woolmer Forest in the late 17th century. However, the fact that heather burning was an officially punishable offence does not mean that heathland fires did not occur. Indeed, in the same passage White (1789, Letter VII) gives the impression that large fires ("vast" and "for hundreds of acres") were not infrequent ("usually with a north or north-east wind"). Fires of this size would not need to occur very often for them to have a major effect on the heathland. The object of grazing, as stated by White, was to improve the forage quality for those with grazing rights - he also describes the damage caused to timber by fires which could not be controlled, and this may be why they were deterred by officialdom. An important point is that wild fires were much more difficult to control before the advent of mechanical methods (see Pasmore, 1977), and this was part of the reason for their discouragement in the New Forest. The 1698 Act for the Increase and Preservation of Timber in The New Forest gave the Verderers various powers to fine offences which included the burning of heather (Tubbs, 1986). It is probable that the penalties for heather burning in Woolmer Forest during this time also reflect a shift in the use of royal forests towards timber growing by the crown which occurred from the late 15th century onwards (see Chapter One).

In the present, heathland fires in the New Forest rarely extend onto the expanse of valley bottom mires, although it is not unusual for areas of valley-side, seepage mire to be included in controlled burns. In the past, however, valley mires were probably more frequently burnt by 'wild fires', especially if carried out in dry conditions during the summer. The effect of fire on valley mire communities is mainly dependent on the depth of the saturated zone below the surface. The time of year is therefore an important factor. Under wet conditions, the *Sphagnum* carpet may escape being burnt, with the fire confined to *Molinia* and *Erica tetralix* tussocks and associated species such as *Leucobryum glaucum*. *Myrica gale*, like ericaceous shrubs, will regenerate readily after fire. However, once burnt the *Sphagna* (and also *Cladonia impexa*) take a long time to regenerate, and charred remains may predominate even 3 - 5 years after the burn. In a study on the effects of fire at Glasson Moss, a raised bog in Cumbria, Lindsay and Goode list intrusive species, following fire which include *Campylopus* spp., *Polytrichum commune*, *Molinia* and *Trichophorum cespitosum*; sensitive species included *Rhynchospora alba*, *Drosera* spp., *Narthecium*, *Sphagna* and several *Cladonia* species (Lindsay, 1977). In the New Forest, a similar pattern of response is observed although there are some differences. The effect of fire on *Trichophorum* is more neutral and *Narthecium* is occasionally favoured, possibly due to nutrient release (see Rose, 1953). *Molinia* is particularly favoured by fire which may result in a tussocky, species-poor community, as has been observed by a number of workers (e.g. Rose, 1953; Tubbs, 1986; Rodwell, in prep.). Despite this, there have been burning proposals to control *Molinia* in the Forest, such as at Ridley Bottom.

Fires during extreme drought conditions have a much more severe effect, particularly when the fire is able to penetrate into the peat deposits. In 1976, fires occurred in mire and wet heath vegetation at Denny Bog, Yew Tree Heath and Whitemoor, near Hincheslea. These sites were monitored, using $1m^2$ quadrats along transects, for the next two years by the NCC (unpublished data). There was, initially, limited seedling colonisation in the autumn of 1976 but there was little further regeneration in 1977 and 1978. At Denny Bog, 20% of quadrats continued to have no vegetation cover throughout this period. Ten years later, in 1986, all of these sites are characterised by a closed, almost 100% cover of *Polytrichum commune*.

Other species occur mainly as isolated, individual plants, the most frequent being *Juncus squarrosus*, *Calluna*, *Erica tetralix*, *Molinia*, *Agrostis tenuis* and *Pinus sylvestris*. *Campylopus introflexus* is restricted to occasional bare peat areas, where it is dominant, and *Polytrichum piliferum* occurs in locally drier areas. The post-fire vegetation was - and continues to be - heavily modified by grazing pressure. At Denny, grazing was observed to slow down the rate of colonisation by vascular plants. The fire at this site had burnt within the peat for about seven days and vegetation regeneration has taken place on a bare mineral substrate which is lower than the surrounding surface of the mire and wet heath (and is hence wetter). It is a feature of such peat fires that they continue to smoulder, for example Hothfield Bog, Kent burnt for six weeks in 1949 (Rose, 1953) and fires continued for over two months in 1976 at Glasson Moss, Cumbria (Lindsay, 1977).

7.3.4 Artificial drainage

7.3.4.1 History of drainage in the New Forest

Most of the evidence for the early history of drainage comes from documentary sources, an account of which has been given by Pasmore (1977), particularly in relation to the activities of the Verderers. More recent drainage has masked field evidence of earlier operations. Three phases of artificial drainage have occurred in the New Forest; the mid-nineteenth century, the 1920 - 1930's and the recent post-war era. No documentary records are known from before the mid 19th century. The stimulus for the first major drainage work in the Forest was the compensation made available under the Southampton and Dorchester Railway Act 1845, which provided £12,000 for "drainage or otherwise improving the Forest". Most of the Railway Fund was used for a programme of tile drainage and open ditching between 1847 and 1852, with about 500 acres thought to have been tile-drained (Pasmore, 1977). Following the Deer Removal Act 1851, maintenance of open drains continued until 1895 when the financial burden on the Verderers effectively stopped any further work until 1923. Unfortunately, records of work carried out were lost when the Office of Woods passed its powers to the Forestry Commission.

After the First World War, The New Forest Drainage Scheme was established, which was supported financially by the Office of Woods and the Verderers.

TABLE 7.9 List of valley mires in the New Forest in which drainage operations have been carried out by the Forestry Commission pursuant to Section II of the New Forest Act 1949, during the period 1965 - 1986

Of the 19 sites, 8 valley mires have sustained significant damage (indicated by an asterisk)

1	Alder Hill	1967 - 1968
2	Avon Water	1965 - 1966
3	Bagshot Moor*	1970 - 1971, 1982
4	Bank	1971 - 1972
5	Cowleys Heath	1976 - 1977
6	Crab Tree Bog*	1969 - 1970
7	Crockford Bottom	1984 - 1985
8	Denny Bog*	1967 - 1968, 1970 - 1971, 1980 - 1981
9	Dibden Bottom*	1971 - 1972, 1980 - 1981, 1984 - 1985
10	Fawley Bog	1969
11	Fernycroft Bog	1972 - 1973
12	Greenmoor*	1972 - 1973, 1984 - 1985
13	Hincheslea Bog	1973 - 1974
14	Latchmoor Bottom*	1984 - 1985
15	Matley Bog*	1965 - 1966, 1976 - 1977
16	Ogdens	1972 - 1973
17	Withybed Bottom*	1982
18	Yew Tree Heath	1972
19	Duckhole Bog	1986

In two years, during 1923 and 1924, drainage was carried out in 22 sites, mainly wet grasslands but including some mires and 18½ miles of open drain was installed. This was followed by another 27 projects in 1930, mostly adding to the drains constructed in 1923 - 24 (Pasmore, 1977). Many of these drains have been identified in the field by Tubbs (1986). At least 5 schemes are thought to have involved maintenance of drains constructed out of the Railway Fund. There were also at least 9 major new projects which drained extensive areas of mire, especially within the Avon Water catchment (Tubbs, 1986).

The drainage during these two early periods set a precedent which established a requirement for drainage maintenance and new schemes by the Forestry Commission in subsequent years after the Second World War. This was formalised under section II of The New Forest Act 1949 (see Chapter One). However, contemporary operations differ significantly from the original drainage work. Deeper machine-dug drains (open ditches) are created compared to the initial labour-intensive systems dug by hand. Indeed, one of the objectives of The New Forest Drainage Scheme was to help relieve the unemployment of that time (Pasmore, 1977). During the period 1965 - 1986, a total of 99 separate drainage projects have been carried out by the Forestry Commission, excluding a larger number of minor works. An even greater number of proposals were dropped in this period, many times larger than the number actually carried out, following consultations with the Nature Conservancy Council and other bodies. Table 7.9 lists the valley mire sites which have been affected by drainage operations, excluding minor works (e.g. culverts), together with the dates when they were carried out.

7.3.4.2 The ecological effects of artificial drainage

The object of artificial drainage is to increase the discharge capacity of the mire, thereby reducing storage and lowering the water-table. The critical assumption is that the rate of water movement through the peat and into the drain is not prohibitively low. This is determined by the hydraulic conductivity, K, of the peat in both the acrotelm and catotelm, and this is known to vary widely in both layers (see earlier, especially Table 5.6). In the case of blanket peat the hydraulic conductivity may

be very low, such that even on moderate slopes the rate of water movement may be only a few metres a year. Under such conditions, Stewart and Lance (1983) found that drains only relieve surface-saturation within 1 - 2m of the drain. A greater range in the thickness of the acrotelm is encountered in valley mires. Observations show the acrotelm to be up to 45 - 60cm deep (see Chapter Five) in the New Forest, compared to about 5 - 10cm in many blanket peats (see Stewart and Lance, 1983). The effectiveness of drainage in the valley mires, therefore, depends particularly on the thickness and hydraulic conductivity of the acrotelm.

Drainage allows air to enter deeper layers of peat which were previously waterlogged. The physical properties of peat deposits continue to change after drainage has occurred. Research has shown that this is due, firstly, to increased compaction. Secondly, partial dehydration of peat particles reduces the amount of immobilised water within the peat, leading to greater porosity (Ivanov, 1981). The two processes are compensatory and the net change in active porosity produced by drainage varies between mires. The change may be virtually insignificant or it may be reduced from its original value by as much as two orders of magnitude; the reduction in hydraulic conductivity normally falls into the range of 10 to 100 times the initial value (Ivanov, 1981). Soviet scientists have demonstrated a temporal pattern in the value of K following drainage. Hydraulic conductivity reaches a minimum in about 10 years or so, subsequently rising although still remaining below the original figure (see Ivanov, 1981 for a review). The values involved have been derived from a limited range of conditions, but this pattern suggests that, initially, the dominant process modifying hydraulic conductivity is compaction, but subsequently physiochemical changes in peat composition have the major effect.

The processes are strongly influenced by land-use after drainage (Ivanov, 1981). In the New Forest, high stock densities of ponies and cattle may greatly increase the effects of trampling on hydraulic conductivity and other hydrological variables, especially in wet heath and lawn-mire transition zones.

The results of drainage depend on first, the hydrological changes which occur and, second, the response of the vegetation to these changes. A major problem is that the complicated changes produced in time by drainage of mires and their subsequent use have not been sufficiently studied, so that it is not yet possible to evaluate them for prediction (Ivanov, 1981). The factors known to affect the results of drainage include the initial humification and botanical composition of the peat, the initial saturation and water supply of the mire, the type of drainage used and the level of drainage attained, the time elapsed since drainage, and subsequent land-use. The soils of the lawns have developed in poorly-sorted, stony infill material with a clay or loamy matrix. They often have slowly permeable horizons and are mainly groundwater gley soils due to their position in the landscape. In a study by the Soil Survey, it was considered that the soil water regimes of such soils were not greatly improved by ditch drainage, and that the effects of drainage can be difficult to separate from other factors (Robson and Thomasson, 1977). They concluded that the net improvement of drainage was marginal. In some circumstances, drainage may also limit the productivity of grasslands in the summer, since the low hydraulic conductivity of the soils prevents easy upward movement of water to replenish losses from evapotranspiration.

The factors affecting the distribution of mire, lawn and other plant communities in the valley bottoms (and hence their response to drainage) include: (i) microtopography, (ii) soil parent material, (iii) nutrient quality of flood waters, (iv) frequency of immersion, (v) soil water regime, (vi) intensity of grazing, (vii) dunging behaviour, (viii) trampling and compaction by stock, and (ix) burning. It may be important to note that most of the fertile streamside lawns are limited to areas of relative freely-draining, silty alluvium on well-defined floodplains. Their extent is probably limited by edaphic and physiographic factors, which cannot be influenced by artificial drainage.

In addition to the average depth of the water table, other hydrological variables are important to the ecology of valley mire communities (see Chapter Six). The rate of throughflow and degree of water table fluctuation are particularly significant since they affect the nutrient flux

and aeration of mire waters. Drainage is known to increase the amplitude of fluctuation in the water table level (Ivanov, 1981). Studies from upland blanket peat catchments in Britain have shown drainage to generate higher peak flows and to reduce the runoff response time (Conway and Millar, 1960; Robinson, 1985).

The ecological response of the vegetation to the hydrological changes caused by artificial drainage is complex. The evidence from valley mires suggests that community structure is modified by both direct physiological effects and a change in competitive interactions. For example, a lowered water table reduces the period during which the rooting systems of larger plants are within the zone of low oxygen concentrations. This severely limited the growth of *Menyanthes trifoliata* at Denny Bog following drainage (Goodall, 1972), a species adapted to anoxic conditions (Armstrong and Boatman, 1967). Greater aeration reduces environmental stress (*sensu* Grime, 1979) and allows the invasion or increase in abundance of more competitive species, such as *Molinia*, whose growth form may significantly alter the structure of the vegetation, eliminating species intolerant of shading (see section 7.3.1). The increase in *Molinia* dominance following drainage has been noted at a number of mires (Rose, 1953; Ratcliffe and Hattey, 1982). A lowered water table at Wicken Fen was followed with invasion by *Calamogrostis* and reduced species richness (Rowell, 1986). Increased water table fluctuation and movement are known to favour the abundance of *Molinia* (Rutter, 1955). Dessication is an important factor affecting the competitive interactions within *Sphagnum*-dominated communities (e.g. Rydin, 1985). Both the frequency and duration of dessication are known to be important (Green, 1968; Clymo, 1973; Proctor, 1982). Ecophysiological studies have shown the water content of *Sphagnum* to be severely affected by repeated wetting and drying (Hayward and Clymo, 1982).

The diffuse flow-net, comprising interconnected runnels and hollows, is a distinctive micro-habitat within both valley-bottom mires and valley-side seepages in the New Forest. It supports a number of rare and specialist plants, including *Utricularia* spp., *Hammarbya paludosa* and *Carex limosa*, as well as being important to aquatic invertebrates, such as the coenagrionid damselflies (Welstead and Welstead, 1984). These

communities are particularly susceptible to conversion to an artificial, arterial drainage system. Seepage step mires are especially sensitive to artificial drainage since they are naturally subject to a more fluctuating soil water regime (Clarke and Allen, 1986), and to erosion (Tuckfield, 1980).

Mechanical damage to the mire surface may also occur from machinery and the tipping of excavated spoil. This may result in the invasion of dry land species, such as gorse and birch, along the banks of the drain, as has occurred at Holmsley Bog.

Changes in plant community composition and habitat structure are accompanied by losses and gains in the mire fauna. The invertebrate communities of valley mires are still poorly understood and most evidence for the changes induced by artificial drainage comes from the Odonata. In the New Forest, the damage to Odonata populations caused by the construction and maintenance of drains is due to several factors:

(i) The creation of hydrological conditions unfavourable to most New Forest Odonata, which are adapted to slowly-flowing flushes.

(ii) Changes in channel morphology, such as steep sides to the drainage ditch, which hinder the emergence of nymphs.

(iii) Re-excavation of drains and other maintenance operations remove nymphs along with the muddy substrate and detritus.

(iv) Tipping of spoil along the banks isolates the channel from the natural mire vegetation.

(v) Growth of scrub along spoil shades out the channel.

Drainage not only results in a reduction in species richness, but also a change in species complement. A variety of mire species (including several national rarities) may be lost, while there may be the addition of more widespread species, which are favoured by the faster flowing conditions, such as *Corduleoaster boltonii*. Field observations have shown that populations of *Coenagrion mercuriale* are directly reduced by drainage operations (A and N Welstead pers. comm., 1983).

Parr and Parr (1979) found that the population density of the small red damselfly *Ceriagrion tenellum* on Ober Heath was greatest where the stream

was wide and well vegetated. Lower numbers were recorded in more heavily shaded sections and this species was virtually absent from the deeply-incised, gravel bed sections of the stream. These habitat requirements and the relatively low mobility of individuals at water resulted in three well-defined sub-colonies along a 1km stretch of the stream, with little movement of individuals between populations. Parr and Parr (1979) state that New Forest populations of *C. tenellum*, in small mires, runnels and pools, are especially susceptible to drainage schemes. They attribute this species' limited distribution in Britain to the extreme selectivity of the flying population to boggy streams, and the presence of *Hypericum elodes* may be a key factor in the selection of oviposition sites.

More direct change results from the geomorphological consequences of drainage operations. In a survey of 24km of drainage channel, Tuckfield (1980) found that 24% by length showed erosion, 40% deposition and 36% no apparent change since the work was executed. Following the construction of drainage ditches, usually of rectangular cross-section, there is a tendency for the side walls to collapse, increasing the width-depth ratio and creating a shallow, V-shaped section similar to reaches of more natural streams. Vegetation colonisation of the collapsed material stabilises the channel and inhibits further erosion (Tuckfield, 1980). Mire systems in valley heads are most susceptible to erosion, especially in areas where the interfluves are covered by Plateau Gravel or head deposits. Tuckfield found that where a natural stream channel is artificially deepened, head-ward erosion above the section frequently occurs at rates of up to 1m/year. An example of this took place at Silver Stream, where a ditch draining wet heath and mire has caused a knickpoint to migrate upstream into Holmhill Bog, leading to the direct loss of willow thicket and flushed open mire communities (see Chapter Three). Tuckfield's study showed that changes of surprising magnitude could be induced by relatively small drainage operations.

The physical factors considered above, and other features of the environment make it difficult to predict changes in forage quality and productivity following drainage of wetlands in the New Forest (Putman, *et al*, 1983). No studies have been made of the effect of drainage on production, but

observations suggest that the nutrient flux is an important additional factor. Nutrient-poor mires are likely to develop a very short and sparse sward of *Carex* following effective drainage, with a lower yield as well as a loss of winter forage and early bite. Drainage of nutrient-rich sites, on the other hand, may result in a streamside lawn dominated by *Agrostis canina* and *A. tenuis*. The maintenance of fertility in these situations depends upon nutrient inputs from overbank sedimentation coupled with relatively rapid runoff after flood events. However, although these lawns are highly productive, they do not provide a significant amount of forage in winter or early spring, in contrast to the valley mires (Putman, *et al*, 1983).

7.3.4.3 The impact of drainage on the New Forest mires

The evidence required to assess the impact of drainage would, ideally, be in the form of observations before and after a drainage operation with a control section for comparison. No experiments of this kind have been carried out, although in a few instances specific observations were made before and after drainage. The long term impact of drainage in the Forest, over the last 150 years or so, is even more difficult to evaluate. The main source of evidence for the changes induced by drainage comes from the records of naturalists and the following account summarises the data collated by the Nature Conservancy Council and information from the New Forest Invertebrate Survey.

1. Botanical data: The best case-study of drainage in the Forest is that of Denny Bog during 1969 - 1970, due to the attention the drainage proposals received. Drainage in the Woodfidley Passage area of the mire resulted in the loss of the nationally rare *Utricularia intermedia*, other hollow/pool species such as *Menyanthes trifoliata*, and a large population of *Dactylorhiza incarnata* (Bowman, 1971). In another part of the mire complex a separate population of *U. intermedia* was reduced by 40% and a *Nymphaea alba* population became extinct. Elsewhere, re-excavation of a drain through Wilverley Bog in 1950 led to the death of *Sphagnum* adjacent to the drains and the destruction of mire communities, noted by Conway and Pearsall in an unpublished survey in 1950, and Rose (1953). A varied fen association was lost at Dibden Bottom, including *Oenanthe fistulosa*, *Bidens cernua*, *Epilobium palustre*, *Veronica scutellata*

and *Iris pseudacorus*

Most historical records are too imprecise to help in evaluating the effects of drainage works earlier this century. However, documentary evidence suggests that parts of Holmsley Bog have become markedly drier since then. The evidence is in the form of three detailed maps drawn by Commander Arathoon in the 1930's and passed to Dr.D.Coombe of Christ's College, Cambridge (I am grateful to A.J.Byfield for drawing these to my attention). The maps show the distribution of *Carex limosa* along the eastern margin of the mire adjacent to Holmsley Inclosure. Arathoon's maps show *Carex limosa* widely distributed across the valleyside, which was dissected by a network of drainage ditches, including a wet seepage zone described as "raised and very boggy". This area is now occupied by wet heath communities with conditions unsuitable for *C. limosa*, a species dependent on very high water levels. This evidence suggests a contraction in the distribution of *C. limosa* at Holmsley Bog due to drainage, a population still persisting elsewhere in the mire. Rose (1953) noted an increase in *Molinia* since 1938, which is possibly linked to drainage at Holmsley. A number of botanists, including J.E.Lousley, were of the opinion that drainage was a contributory cause to the national extinction of *Spiranthes aestivalis* in the Forest (Bowman, *in litt*, 1970).

2. Invertebrate data

(i) Odonata: Two species have declined marked this century. *Gomphus vulgatissimus* is now considered extinct in the New Forest, with the last record in 1977, although it was once found in some abundance along the Ober Water and Avon Water (see Frazer, 1950). This nationally rare dragonfly required shingle banks and shoals for ovipositing and basking, and emergent vegetation along stream banks. The other species *Platycnemis pennipes*, is favoured by similar conditions and has also declined during the post-war period. Drainage and river maintenance operations are thought to be important factors in the decline of these species (Peachey, 1984).

Recent records show that drainage operations continue to have deleterious effects on New Forest Odonata populations. *Coeragrion mercuriale* was lost from Green Moor following clearance of two short stretches of open drain and marginal vegetation during 1984 - 1985, while a population of *Ischnura pumilio* was not relocated after excavation of a ditch at Withybed Bottom.

A small breeding pond was drained at Latchmore Bottom by a short ditch in 1984. Nine out of eleven breeding species recorded at this site before drainage were lost, including *Ischnura pumilio* and *Ceriagrion tenellum*. Only *Cordulegaster boltonii* and *Sympetrum striolatum* were present in the following year.

(ii) Wetland Lepidoptera: This is one of the best documented invertebrate groups. Past records are based mainly on the Victoria County History of Hampshire published in 1900, Fassnidge (1923-24, 1929, 1931) and Goater (1974), while more recent records have been collated by the New Forest Invertebrate Survey. The change in status of 13 species is summarised in Table 7.10 (derived from Sterling, unpublished). Apart from ubiquitous species, this list includes most of the wetland microlepidoptera which were common earlier this century and are now very rare, while six species have not been relocated since the 1970's or earlier and may be extinct. A notable exception is the plume-moth *Buckleria paludum*, whose larvae feed on *Drosera* in wet heaths, for which records show no marked decline since the days of Fassnidge in the 1920's. The reasons for the change in status of the species in Table 7.10 are not known, and it is likely that different population factors are important in different species. However, the overall pattern is one of decline this century.

(iii) Coleoptera: A well-established colony of the carabid *Pterostichus aterrimus* was lost from Denny Bog following the drainage carried out in 1970. This species disappeared from the fens of Huntingdon, Cambridgeshire and Norfolk earlier this century, but still survives in Ireland (Appleton, pers. comm., 1986). Its disappearance from the New Forest probably marks the extinction of this species in Britain.

(iv) Hymenoptera: The rare bog ant *Formica transkaukasica* was also lost from Denny Bog after the drainage operations; it has also disappeared from four other New Forest mires since 1951 - 1956 (Redhill Bog, Crab Tree Bog, Harvest Slade Bottom and Wooton stream). This species has specialised habitat requirements in wet *Sphagnum* vegetation and is restricted to the New Forest and adjacent parts of Dorset.

There are a number of other records for miscellaneous groups which show species losses following drainage, including the large marsh grasshopper

TABLE 7.10 Changes in status of lepidoptera associated with the New Forest mires (derived from Sterling, unpublished).

ORTHOTAELIA SPARGANELLA	Records indicate a steep decline between early 1930's and mid 1950's. Now very scarce
DASYSTOMA SALICELLA	Common in the late 1930's but despite specific searches in previous sites only a single larva has been located in recent times (1982)
STATHMOPODA PEDELLA	Recorded in the 19th century. No post-war records for the New Forest
MOMPHA LOCUPLETELLA	Recorded in the 19th century. No post-war records for the New Forest
SPARGANOTHIS PILLFORIANA	Becoming much less widely distributed than previously (1920's - 1960's) and less abundant where it does occur
CRAMBUS ULIGINOSELLUS	Has declined from a generally abundant species in the 1920's to a very localised one
SCHOENOBIUM FORFICELLA	Common in 1920's and a number of records between 1954 and 1969. Now only recorded from one site
EUDONIA PALLIDA	Formerly common, this species is only recorded up to the 1960's and there are no recent records
CATALLYSTA LEMNATA	Recorded as abundant during the 1920's, this species has not been relocated in the post-war period
STENOPTILIA GRAPHODACTYLA	Restricted to *Gentiana pneumonanthe* and recorded from three sites earlier this century, this species is now presumed to be extinct in the New Forest
PARAPOYNX STAGNATA) P.STRATIOTATA) PHALONIDIA MANNIANA)	All species which have never been common in the New Forest but have not been recorded since the 1960's or earlier

Stethophyma grossum from Yew Tree Heath and the medicinal leech *Hirudo medicinalis* and the fairy shrimp *Chirocephalus diaphanus* from Denny Bog.

In summary, there is specific, recent evidence which shows population decreases and local extinctions of plant species and a wide range of invertebrates following drainage of valley mires. There are also historical data for a wide range of different organisms which indicate a long-term decline in the biological richness of the New Forest wetlands. The reasons for this historical decline cannot be easily demonstrated, but the observations on the effects of drainage suggest that this has been a major contributory factor. A number of species extinctions have occurred in the post-war period which indicate that this decline has not been halted.

7.3.4.4 Discussion

Drainage destroys the natural dynamic equilibrium of peat deposits - the main physical characteristics of a drained mire are not stable, in contrast to the intact mire where they are virtually constant (Ivanov, 1981). Changes in vegetation following drainage are a response to greater water table movement as well as a reduction in the degree of waterlogging. In the New Forest, the changes typically comprise a loss of pool and hollow communities and the more specialised mire species, and an increase in the dominance of *Molinia* with a concomitant reduction in species richness (see section 7.3.2). Under certain conditions, especially in areas of shallow peat, the mire communities may be completely lost along a "drawdown zone" close to the edge of the drain (presumably due to the higher hydraulic conductivity of the mineral sediments). The vegetation is then replaced by *Agrostis*-dominated or sparse *Carex*-dominated communities in which *Myrica gale* may persist as a scattered shrub layer.

The most comprehensive evidence for the impact of drainage in New Forest mires comes from the draining of Denny Bog during 1969 - 1970. Pressure for drainage at this site developed rapidly between meetings of the consultative committee for drainage in April 1968 and January 1969, although calls for drainage had been made since the early 1950's. This

stemmed from a desire by the Commoners to regain an area formerly regarded as lawn and by the Forestry Commission to improve land in an adjacent small-holding. The only feasible alignment of the drain was along the southern margin of the mire. Extensive biological survey took place during the period leading up to drainage of the mire. The evidence reviewed above shows that there was a rapid loss of plant species adapted to highly waterlogged conditions, some of which are scarce or rare nationally. Drainage also resulted in the local - and in one case, national - extinction of a wide range of invertebrates. At a structural level, drainage has modified the pattern of water flow within the mire - water movement is now laterally across the mire expanse into the open drain, rather than along the main axis of the mire.

These and other recent observations suggest that drainage is the principal cause for the apparent decline in a wide range of wetland organisms that has been recorded this century. The effects of recent drainage operations also suggest that the impact of nineteenth and early twentieth century drainage must have been substantial. The threat to nature conservation had been recognised by 1930, when The Entomological Society of Hampshire and South of England made strong objections to the damage sustained by the plant and insect communities of Holmsley Bog. An economic cost-benefit analysis of drainage operations in the New Forest has never been carried out, nor has such an appraisal been made in ecological terms compare with the similar situation described by Stewart and Lance, 1983 for upland blanket peat). Yet, in the New Forest the environmental cost, in terms of nature conservation, is high - especially since the Forest is the main centre for lowland valley mires in Britain and, indeed, western Europe (see 7.2). There is, thus, an onus on the clear justification of the benefits of proposed drainage. The protective mechanisms in the Forest may have reduced the damage to mires from drainage, but current legislation (or, at least, its interpretation) has failed to stop it, including irreversible losses such as the national extinction of *Pterostichus aterrimus* at Denny Bog. Moreover, the Odonata are a good illustration of the point that significant ecological damage can occur from relatively minor works, which are often outside the consultation process (e.g. Withybed Bottom and Latchmore Bottom).

7.3.5 Peat Cutting

The cutting of peat for fuel from the valley mires has occurred widely throughout the Forest (Barber, 1975, 1981a; Tubbs, 1986), as in other parts of southern England (e.g. Seagrief and Godwin, 1960; Cawse 1975; Moore and Wilmott, 1976). At least 31 sites are thought to have been affected by peat cutting in the New Forest. Peat cutting is detectable by the presence of vegetation 'stripes' (especially on air photos) or rectilinear pits. Often, though, the field evidence is not very apparent and peat stratigraphy is a more reliable indicator of cutting. A change from consolidated to fluid peat coincident with a hiatus in the pollen record provides the best evidence of former peat cutting. In addition to peat cutting, turves were removed from the mire margins and wet heath zone, both practises falling under the commoners' right of turbary (see Chapter One). Peat cutting has had a profound effect on the structure of the valley mires, but these are relict features which are disappearing as infill succession proceeds. Ombrotrophic peat is thought to have been removed from *Sphagnum* Bog at Cranes Moor, and possibly from other sites (see Chapter 5.3). Such peat deposits would have been more easily exploited than groundwater-fed sites and may have provided better quality fuel.

Turbary has probably been carried out in the New Forest for many hundreds of years. However, documentary evidence dates mainly from the mid - 17th century onwards and rarely distinguishes between the cutting of peat from the mires and turves from the heath (see Tubbs, 1986). Turbary was also practised on the commons of NE Hampshire and in the Test and Itchen valleys (Shore, 1893). Earlier documentary evidence from elsewhere in Hampshire is cited by Shore, who states (p.189) that, in 1248, 2600 'peats' cost 3s. 4d. from Bramshete Moor, Crondall near Farnham. Shore does not distinguish between peat and heathland turf, but his paper deals specifically with peat deposits which are referred to as having been 'dug' rather than cut and peat 'pits' are also described. In the New Forest, Shore describes peat digging in the past tense, at a time when turf cutting was still widely practised. The decline in turf cutting in the New Forest did not occur until the start of this century, due to the increased availability of alternative fuel from the improved transport

network. Pasmore (1977) illustrates this point with the diary entries of J.Taylor, an agister, which show a switch from burning turf from the Forest to imported coal during the period 1907 to 1923. Peat cutting appears to have died out much earlier than this, and may have ceased in the county as a whole by the mid - 19th century (Shore, 1893). This is consistent with the pollen evidence from the New Forest, which makes use of the 19th century rise in *Pinus* pollen, following its reintroduction. At *Sphagnum* Bog, Cranes Moor, there is a relatively rapid rise in *Pinus* pollen (Barber and Clarke, 1987) in the peat above the cut surface of the mire; which suggests an early to mid - 19th century date for the resumption of peat growth, although there may have been a delay before renewed accumulation began (see Chapter 5.3). Peat cutting may have ceased earlier in Little Bog and Flush Bog, both wetter sites within the Cranes Moor complex (cf Seagrief, 1955). At Burley Common Moor, there is some 60cm of peat accumulation before a rise in *Pinus* pollen (Miller, 1979). This suggests a much earlier date for the end of peat cutting in the mire, despite frequent turf cutting in this area up to the end of the 19th century (see Pasmore, 1977). The observations of early naturalists suggest that the effects of peat cutting were more apparent in the last and early part of this century. Writing in 1911, Rankin (p.264) describes "deep pits filled with water" (possibly from the Burley or Beaulieu Road areas). At most sites infill succession has progressed beyond this stage now, and open pits are only found at *Sphagnum* Bog on Cranes Moor; perhaps because of the low productivity of the site (see Chapter 5.3).

Today, the plant communities of former peat cuttings are variable and the degree of water movement is an important factor affecting community structure. It is important to recognise that peat cutting does not 'reverse' succession, since valley-mire succession is not comparable to a basin-filling process. Cuttings within zones of low water movement favour *Sphagnum*-dominated communities, while in areas of higher water movement a less species-rich *Molinia* tussock dominated community is common. Locally, *Phragmites* has invaded peat cuttings, such as within the Avon Water complex of mires which has a relatively high nutrient status. The most frequent species of the *Sphagnum*-dominated cutting community are *S.auriculatum* var *auriculatum*, *S.cuspidatum* and *Eriophorum*

angustifolium. These two species of *Sphagna* may be the sole dominants in wetter cuttings, for example at Fawley Bog. A diverse assemblage of *Sphagna* has developed in cuttings where there is a more consolidated vegetation mat (e.g. Lugden Bottom, Bisterne Common and Denny Bog), in which *S.papillosum*, *S.magellanicum* and *S.palustre* are also frequent. These communities usually contrast strongly with the drier vegetation of the 'baulks' between cuttings, which is typically composed of a *Molinia-Erica tetralix* community with hummock-forming species of *Sphagna*, such as *S.capillifolium* and *S.papillosum*. The *Molinia*-dominated community also includes *S.auriculatum* var *auriculatum* and *Eriophorum angustifolium* as frequent associates growing in the runnels within the semi-floating mat of tussocks, with *Potamogeton polygonifolius* (also common in the *Sphagnum* community), *S.papillosum* and *Carex echinata*. In aerial photographs, the higher cover abundance of *Eriophorum* and the wetter surface result in the cuttings appearing dark in contrast to the adjacent vegetation, also dominated by *Molinia*. The effect of water movement in determining the composition of the colonizing vegetation within a single site is seen well in the Denny Bog system downstream of the railway crossing. Marginal peat cuttings, adjacent to the wet heath zone, contain *Sphagnum*-dominated communities, whereas cuttings along the centre of the mire are dominated by *Molinia*.

The infill succession at Morden Bog, Dorset has been studied by Cawse (1975) who describes the following sequence:

S.cuspidatum		*S.pulchrum*		*S.pulchrum*		*S.pulchrum*
Eriophorum	→	*S.cuspidatum*	→	*S.cuspidatum*	→	*S.cuspidatum*
Potamogeton		*Eriophorum*		*S.papillosum*		*S.papillosum*
Phragmites				*Eriophorum*		*Eriophorum*
						Erica tetralix

The vegetation in this part of the mire is similar to the New Forest, with *Molinia*-dominated ridges and *Sphagnum*-dominated pools, except for the presence of *S.pulchrum* which appears to partially replace *S.auriculatum* (these two species occupying similar ecological ranges, see Daniels and Eddy, 1985). The infill assemblages described by Cawse are similar to those observed for the Forest. A *Sphagnum* - *Eriophorum* community is also described by Rankin (1911) for the semi-aquatic vegetation in peat cuttings, which included *Drosera intermedia* and *Utricularia minor*.

The literature on the ecological effects of peat cutting is extremely limited. Several general principles, however, may be drawn from White's (1930) extensive study of active traditional cutting in mires of Northern Ireland. He found that the recolonizing vegetation was dependent on the depth of cutting, the surrounding vegetation and the area cut, in decreasing order of importance. The main effect of depth on colonisation was to create selective mortality in those species unable to withstand winter waterlogging. This factor continued to be the most critical factor even after a closed canopy had formed, persisting at some sites for over 150 years. White found that the recolonising vegetation generally had close affinities to the surrounding vegetation; this may be due to the response of the vegetation to environmental variables other than water level, such as nutrient status, in addition to the immediate source of colonising propagules. It is also interesting to note that he observed the area cut to have a marked negative influence on the rate of re-colonisation, but no effect on the composition of the final community. Katz (1926) regarded the age after peat cutting to be the most important factor determining vegetation composition.

Smart *et al*, (1986) have investigated the historical ecology of peat cuttings on Thorne Waste, Yorkshire, a lowland, raised bog. These were created by the turf trade during the 16th to 18th centuries. Peat cutting died out by the 19th century, but was later resurrected, initially to provide horse and cattle litter, and it continues today. The combination of drainage and peat extraction led to the loss of original habitats. The peat cuttings have served as an artificial habitat, where a number of species have been able to persist. These are mainly poor-fen species from the lagg zone of the intact mire - the ombrotrophic species have been lost. The Welsh lowland mire survey (Ratcliffe and Hattey, 1982) found a number of plant communities present in peat cuttings at some sites which would not otherwise be present.

The effects of peat cutting on the nature conservation interest of the valley mires are mixed. The almost certain destruction of true ombrotrophic communities at Cranes Moor (see Chapter 5.3), and possibly other sites, is an immense loss to the study of the mires and past vegetation history. Peat cutting has truncated the profiles of many sites, limiting

the potential for vegetation and environmental reconstruction. Possible species extinctions and the loss of particular community types are largely unknown. It should be noted, however, that the macrofossil investigations (Chapter Five) show the vegetation of cut areas to have a close relationship with intact sites. Possibly with a few exceptions, cutting may have changed the relative proportions of dry and wet communities in the Forest rather than qualitatively altering species representation in the mire.

Within the context of the present vegetation, peat cutting is responsible for greatly increasing the structural diversity of the habitat (a point also noted by White, 1930, in Ireland). The effect of this is to enhance the range of communities present and to spatially increase the species turnover within sites. Moreover, a number of rare hollow species are closely associated with peat cuttings, such as *Carex limosa* and *Drosera anglica*. One of the two extant sites for *Eriophorum gracile* in the Forest is within an area of known peat cuttings in Fort Bog. This species is associated with wet surface conditions (e.g. Perring and Farrell, 1983) and its decline from perhaps, five other sites in the Forest and nearby Dorset (NCC, unpublished) may be linked to the cessation and subsequent infill of peat cuttings. At least two sites in the New Forest where this species has been recorded are known to have been affected by cutting (Denny Bog and Stoney Moors). Segal (1966) describes *E.gracile* as occurring in the early phases of infill succession within seepage zones of Dutch peat cuttings.

The increased structural diversity is also important to invertebrate communities, of which the best studied group is the Odonata. A large proportion of the Odonata in New Forest mires are favoured by the presence of pools, such as those created by peat cutting. The development of vegetation is known to be an important factor in creating suitable breeding sites, but there have been no studies into the effects of infill succession on Odonata breeding communities. There is limited evidence to suggest that changes should be expected as vegetation succession proceeds. Chelmick (1978) describes *Libellula depressa* as a pioneer species of pools, which declines in numbers as plant colonisation increases, and Fowell (1974) suggests that the leaves of *Sphagnum cuspidatum* are an important microhabitat for *Enallagma cyathigerum* nymphs. The development

of a bottom mud and detritus layer is also important for nymphs of *Ceriagrion tenellum* (Fowler, 1974).

In addition to the relatively deep peat deposits in the mires, there is little doubt that turf cutting had a significant impact on the mire margins and wet heath zone. Field evidence (including air photos), documentary records (see Pasmore, 1977; Tubbs, 1986) and personal accounts from commoners show that most turves were removed from the wetter heath areas, where the humus horizon is thickest. Turf cutting was widespread on the heaths of southern England until the beginning of this century (Webb, 1986). Tubbs (1986) estimates that about 35ha of turves were cut annually in the Forest during the mid-nineteenth century, possibly affecting an area of up to 100ha due to the practice of leaving two turves for every one cut in order to assist regeneration. This practice probably greatly accelerated succession after cutting (compare with the findings of White, 1930). Unlike the deeper peat cuttings, the turf cutting communities have not survived on the heathland areas. This is probably due to the relatively smaller magnitude of the disturbance, faster recovery of the vegetation, and also to the masking effect of subsequent fires. There is therefore no evidence of the modifications in plant community composition due to turf cutting. The exposed peaty or organic-rich, mineral surfaces would have favoured weakly-competitive species compared to the closed, uncut community. However, comparison with the effects of burning suggests that a ground layer rich in lichens (e.g. *Cladonia* spp.) and bryophytes (such as *Sphagna* and *Leucobryum glaucum*) would have taken a long time to develop on the cut areas. Also by analogy with burning, *Ulex minor* may have been frequent and, in wetter sites, *Drosera* species.

Turf cutting may have been important in maintaining populations of three rare wet heath species; *Gentiana pneumonanthe*, *Lycopodiella inundatum* and *Rhynchospora fusca*. Of these, the ecology of *Gentiana pneumonanthe* is best studied. This species is intolerant of competition (Simmonds, 1946) and is favoured by factors which reduce the amount of standing vegetation, including grazing (Tubbs, 1986), mowing, trampling and burning (Ogunyemi, 1977; Chapman, 1983). Fire not only creates a bare surface for colonisation, but also raises the surface soil temperature

due to the greater heat absorption of the black peat soil (Chapman and Rose, 1983). The higher temperatures favour greater seed production by *G.pneumonanthe* following colonisation. Turf cutting, therefore, should also benefit populations of *G.pneumonanthe* and may be a viable management option in heathlands no longer managed by burning and grazing. The present distribution of the two other species in the Forest suggests that they would also be favoured by turf cutting. *Lycopodiella inundatum* is most frequent on bare peat surfaces and in wet ruts along paths in wet heath. *Rhynchospora fusca* occurs in a distinctive microhabitat, around shallow seasonal pools in bare peat or in areas of surface instability and slumping (e.g. a seepage zone at Acres Down). Slater (1984) notes colonisation of old peat cuttings by *R.fusca* some years ago at Borth Bog, Wales.

7.3.6 Coppicing

The coppicing of alder, particularly for charcoal, was widely practised in the New Forest and the exploitation of alder is known to date back to the Roman era (Sumner, 1927). The structure of many carrs suggests they have been coppiced this century (the comments of Moss *et al*, 1910 also suggest this), but some stands appear to have a natural, multistemmed habit (see McVean, 1953). Possible examples of coppice compartments are found in Row Hill Bog and Whitemoor. Air photo evidence (1951, 1967) shows that these have not been coppiced since at least the Second World War. Coppicing continued in some places, however, into the 1950's, apparently on a rotational basis (Lambert and Manners, 1954), providing charcoal for military applications (Tubbs, 1986).

The ecological effects of coppicing the alder carrs are largely unknown. It is probable that the response of the groundflora and the rate of regrowth would be heavily influenced by the level of herbivore populations, as Tubbs (1986) suggests, especially at more accessible sites. The "*Phragmites* phase" recorded in cores from a number of carr sites (Chapter 5.6) suggests that, under certain conditions, coppicing allowed the development of tall fen vegetation before eventual replacement by regenerating alder. Although coppicing probably ceased due to lack of demand, early nature conservations proposals recommended that the alder

carrs be left unfelled (Lambert and Manners, 1954). This was for two reasons. Firstly, the extraction of timber caused damage to the mire surface. Matley Bog alder carr, in particular, was much disturbed by felling operations. Secondly, coppicing would have created an external disturbance to permanent transect studies by Lambert and others from Southampton University, which were being carried out at this time. Coppicing may also be damaging to epiphytic lichen assemblages in the carr woodland, including a number of rare species (Rose and James, 1974). A more open canopy may also affect the humidity of the microclimate in the carr. On the other hand, coppiced stands may have been a habitat for some invertebrates no longer recorded in the Forest (e.g. the moth *Anticollix sparsata* and the bee *Macropis europaea* both of which depend on *Lysimachia vulgaris* as a food plant).

7.4 Ecological principles for the managementof the valley mires for nature conservation and as a grazing resource.

The relationship between the vegetation and grazing by commonable stock, especially the ponies, is the most important issue facing the conservation of the New Forest valley mires for two reasons. First, grazing helps to maintain much of the present vegetation diversity and habitat structure in the mires. Second, it is the reason for pressure for drainage which is currently the single greatest threat to the mires.

As has been discussed above, grazing greatly enhances the species diversity of plant communities in which conditions favour the potential production of a large standing crop of *Molinia*. This is the most widespread vegetation type in the valley mires of the Forest. These findings also apply to at least some lawn and swampy grassland communities, which support nationally rare species such as *Galium debile*, *Pulicaria vulgaris* and *Mentha pulegium*. Vegetation offtake and trampling are probably both important effects of grazing by stock. Thus, the continuation of relatively high levels of grazing, dispersed throughout the Forest, is important to maintaining the nature conservation interest of not only the valley mires, but also grassland communities which are, themselves, rare habitats outside the Forest. The commoning system is probably the best way of achieving a dispersed pattern of grazing which, at the same time, creates a mosaic of grazing intensity and thereby habitat structure

throughout the Forest. Its perpetuation is therefore desirable from an ecological, as well as a cultural, point of view.

The rest of this section will consider the role the valley mires play in the ecology of the grazing system, and the implications that this has for the management of the mires from a nature conservation perspective. In order to do this, it is first necessary to examine the ecological constraints on the grazing system. The following discussion draws heavily on results from the RSPCA investigation into the behavioural ecology and body condition of New Forest ponies (Pollock, 1980) and the NCC study of food and feeding behaviour of stock by the Department of Biology at Southampton University (Putman *et al*,1983). It should be noted that many of these findings have been long recognised by local opinion, a point which Tubbs (1986) also makes. However, at least some of the results appear counter-intuitive and these studies have also helped to crystallise the ecological issues which face the management of the Forest. Most attention will be paid to grazing by ponies, since these are the main herbivores to exploit the mires.

The reproductive rate of New Forest ponies is very low, most mares foaling once in every two, or even three, years (Pollock, 1980). There is also an almost universal loss of body condition by late winter. In general, only stallions left on the Forest (most are removed) and some nulliparous mares are capable of maintaining their condition throughout the winter (Pollock, 1980). The ability of ponies to survive the winter successfully depends not only on the effective stock density, but also on genetic characteristics of the pony population which have been artificially modified in recent centuries (see review by Tubbs, 1986). The greatest loss of condition is associated with mares suckling foals, when increases of over 100% above maintenance may be required by the lactating mare for mineral and nutrient intake. Pollock (1980) found that the worst body condition scores coincided with late winter and also foaling time (April/May). Failure of foaling is due, especially, to abortion during the winter months and his investigation confirmed that this was due to a loss of condition (rather than the reverse). Mares experience the demands of late pregnancy at the end of the winter (March) when the least food is available.

It is clear that winter performance is the key factor in the New Forest pony population, and this is of importance to the commoning system for both economic and animal welfare considerations (see Countryside Commission, 1984). Survival of ponies outside the growing season is based on the utilization of accumulated body reserves which is supplemented by browsing (mainly gorse and holly) and limited grazing.

Over-wintering performance, therefore, is the main factor to which management effort should be directed, and it is the criterion against which the benefits of various management proposals should be measured.

Vegetation types which provide late summer grazing are important in maximising body reserves, as are those which provide forage during the winter itself. However, the plant communities which offer "early bite" are particularly important since they bring forward the start of the growing season and are a source of fresh growth (with higher nutritive value) during the immediate period before foaling.

The grazing system is further complicated by behavioural traits of the stock. In ecological terms, the most significant is the importance of a "focal area" in the home ranges of the stock (Tyler, 1972; Putman *et al*, 1983). These are centred on open, mainly grassland areas, such as streamside lawns or the reseeded grasslands. From early in the growing season, both ponies and cattle tend to congregate on these areas and they continue to concentrate on them until well after the end of the season. Although they may make frequent use of other vegetation close to the focal area, they seldom penetrate deeply into these other habitats. The result is a marked uneveness in the utilization of available resources - there may be little to eat on the areas frequented by stock while, at the same time, there is an abundance of food in other habitats. The sub-optimal use of available forage is a major challenge to efficient stock management in the Forest.

7.4.2 The role of the valley mires in the grazing system

The principal forage species in the mires is *Molinia* and in some areas a very large proportion of annual production may be consumed (see section

7.3.2). The productivity of the mires is considerably greater than the grasslands, other than the streamside lawns, and - importantly - the growing season in the mires begins earlier than all grasslands. (Putman *et al*, 1983). The season begins in February and March in the mires, with the first flush of *Molinia* by April and peak production between May and July (data in Putman *et al*, 1982). It is also significant that young *Molinia* is one of the most nutritious sources of forage. Moreover, the nutrient value of *Molinia* in the mires is much higher than that growing in other habitats, with high levels of nitrogen, potassium and phosphorus (Putman *et al*, 1983). This presumably reflects the higher nutrient flux in the mires where water movement is concentrated. Putman *et al* found the growing season to be more or less the same for all grasslands, from late April to early October. Peak production is later than in the mires, between June and July, and fairly high levels continuing until September. The streamside lawns peak slightly later, sometimes not until August - September.

Leaf-fall in *Molinia* occurs during October and about half the nutrient content is withdrawn before the leaves are shed, so that the straw is of very low nutritional value (Putman *et al*, 1983). The other important forage species in the mires, although less abundant, are *Juncus* spp. Putman *et al*, 1983). These species contrast with *Molinia* in that the leaves are evergreen, so that there is less marked seasonal variation in standing crop. A considerable amount of production occurs in *Juncus* before the growth of other plants (as early as January). Peak productivity is also early, between May and June, with growth continuing to November. *Juncus* has a relatively high nutrient value, but the mature foliage has below average digestibility compared to other forage types in the Forest (data in Putman *et al*, 1982). However, the winter nutrient value compares favourably with other sources, due to its evergreen habit. *Juncus* is highly favoured in autumn and winter.

These patterns of production are reflected closely in the exploitation of the mires by stock, principally ponies. The use of wet heath and mire is virtually exclusively for feeding, since these habitats are not important for shelter or shade. The main period of exploitation is between February and September. There is a large increase in occupancy

of mire and wet heath between January and February, a finding common to both studies of pony feeding (Pollock, 1980; Pratt *et al*, 1986). Personal observations suggest that the main forage species in this initial increase are *Juncus*, *Carex* (mainly *panicea* and *demissa*) and *Calluna*. The overwintering basal nodes of *Molinia* stems also start to 'green' during this period. Exploitation of the mires increases to a peak in May for ponies and April for cattle, during which time offtake closely follows production (Putman *et al*, 1983). There is sustained use of the mires during the summer months, but in many areas there is a super-abundance of *Molinia* standing crop due to the uneveness in grazing pressure. This resource is only seasonally available since, by winter, it is lost due to senescence. There is a secondary peak in the exploitation of the mires during August and September (Pratt *et al*, 1986), as stock compensate for drought-limitation of production in other habitats. Both pony studies noted the importance of wetlands for grazing during this period.

In conclusion, it is clear that the valley mires play an important role in the grazing system of the open Forest. The reasons for their importance can be summarised as follows:

1. Production and exploitation of some forage species in the mires, and wet heaths, takes place as early as February. The mires are also the first major source of "early bite" with the *Molinia* flush in April. Furthermore, they are the first habitat to reach peak productivity (in May). The mires are, therefore, a critical source of forage production during the period when most animals are in their worst body condition.

2. In addition to total production, the early growth of *Juncus* and *Molinia* is an important source of nutrients when the physiological demands on mares are greatest.

3. The mires are a significant source of forage in late summer and, in extreme years, may provide the only available grass production. In some years, at least, they are important in enhancing the body condition of stock before entering the winter months.

When measured against the criterion of winter performance, the grazing quality of the mires is seen to be high, since they help to extend the

length of the growing season at both ends, and also make a significant contribution during the critical late - winter period. This is the ecological context within which management practices, particularly drainage, must be assessed. Yet, to a large extent, there has been a failure to do so. In particular, the ecological benefits of draining valley mires to obtain lawn communities have to be questioned.

Although some streamside lawns are highly productive, most do not provide a significant amount of forage in the winter or early spring (Putman *et al*, 1983). The mires and wet heath are exploited earlier than the streamside lawns, and peak production on the latters occurs much later in the growing season when forage is abundant (Pollock, 1980; Putman *et al*, 1983; Pratt *et al*, 1986). Moreover, the offtake of production is almost instantaneous on the lawns and other grasslands, so that there is seldom much standing crop. The tendency for stock to concentrate on these areas means that the lawns have come to be regarded as a "double-edged weapon" in their management (Putman *et al*, 1983). Thus, the ecological benefits to grazing from draining valley mires are doubtful, even where the outcome of drainage has been regarded as successful. This is because the advantages of winter forage and early bite are lost, and production is maximised later - rather than earlier - in the year.

This analysis is further complicated by the difficulties of predicting the effects of drainage (see 7.3.4.2). The complex relationships between all the factors involved means that the outcome of drainage cannot be reliably predicted *a priori*. However, even in areas where the results of drainage are fairly well understood - such as an area of known lawn now reverting to mire - the perceived improvement to grazing from drainage maintenance is open to doubt for the reasons above. Faced with a situation in which a theoretical base is lacking, one concludes that an ecological assessment of the costs and benefits to grazing of drainage can only be made with empirical data. Such an assessment would require monitored trial areas over a number of years, with controls. This has not been carried out by the proponents of drainage nor by the Forestry Commission, and an attempt by the NCC to do so was unsuccessful due to the lack of resources.

There are other reasons given for drainage proposals, which include the relief of flooding to adjacent property, the improvement of 'passages' and other crossings of streams and mires, the elimination of danger to stock, the reduction in parasite infection, and the reduction in poaching. The validity of the latter two reasons is also questionable. Firstly, poaching is undesirable in many agricultural situations because it encourages unpalatable tussock-forming species. In the case of the mires, however, the main tussock-forming species, *Molinia*, is also the main source of forage. Compaction due to trampling is probably more significant on the grasslands, wet heath and drained mire.

The problem of parasite infection is more complicated. It is often claimed that the valley mires are a serious source of infection from strongylosis (redworm). Pollock (1980) found that all ponies examined showed evidence of infestation with internal nematodes (ascariasis and/or strongylosis). These are generally regarded by horse veterinarians as the greatest common parasitic threat to their fitness and health. However, Pollock found no association between body condition and helminth egg counts in faecal samples, although the number of samples were sometimes small. He also found that there is a large, mobile and dispersed parasite population throughout the Forest, and that strongyle egg counts peaked in early spring and late autumn which is the typical pattern for elsewhere. The suggestion that the valley mires as a major source of infection appears to stem from the generally accepted view (see Pollock, 1980) that eggs shed by adults between March and November are probably very susceptible to dessication, although they may still generally develop to a stage where infection is likely. However, it does not follow from this that the mires must be the main vehicle for infection, nor that drainage will significantly reduce the problem. First, there is no evidence that the mires support higher densities of eggs than other habitats in the Forest. Second, the parasite levels in the Forest are so high (Pollock, 1980) that the problem is best combatted by targetting the host, rather than attempting to reduce the reservoir of infection. Third, even if the mires did promote the survival of the early parasite stages during the summer, this would not apply to the late autumn peak in the egg population and may not be relevant to the early spring peak (and notwithstanding the previous point).

7.4.3 Conclusions concerning grazing and the management of the valley mires

It has been argued here that drainage may yield marginal benefits to grazing, if at all, and does little to improve over-wintering performance which is the main factor limiting stock grazing in the New Forest. Earlier it was shown that grazing is important in maintaining the present diversity of not only the valley mires, but also a number of other wet grassland habitats of high nature conservation importance. There is also evidence which shows that drainage operations are currently causing significant damage to the plant communities of the valley mires and their associated fauna. A number of species extinctions have probably occurred during the post-war period as a consequence of drainage 'maintenance' activities. Historical data indicate that a more long-term decline in the biological richness of these systems has taken place.

Management decisions concerning drainage are made in the face of a balance between, on the one hand, demonstrated damage to the nature conservation interest of the Forest and, on the other, unquantified costs and benefits to grazing which the available evidence suggests may be seldom more than a marginal improvement. It must also be recognised that drainage of valley mires, which are of recognised international importance, is being carried out within a SSSI on Crown land by a public body, the Forestry Commission. The drainage works carried out in the 19th and early 20th century have been used as a precedent to justify current 'maintenance' work, for which the Forestry Commission is responsible under the New Forest Act 1949. However, the original schemes are contrary to present environmental policies in relation to SSSI and to the duties of the Forestry Commission (Wildlife and Countryside Acts 1981 and 1985). There is no <u>ecological</u> (not nature conservation) justification for the continuation of such large-scale drainage activity in these habitats.

Ultimately, however, the aims of management for nature conservation and for commoning in the New Forest have to be, and indeed are, compatible (see Tubbs, 1982, 1986). There may be situations when drainage is actually necessary to achieve the ultimate goal of maintaining the

grazing system in the Forest, and management options should be considered on their merits. For example, it has been suggested that the re-creation of small areas of lawn to act as new 'focal points' may help to redistribute grazing pressure more evenly in the Forest. It is argued this would help to reduce stock management problems by a more efficient use of available resources (Putman *et al*, 1983). A more even distribution of grazing pressure is unlikely to damage the diversity of the mires since the foraging behaviour of stock will probably always generate a mosaic in vegetation structure. It would probably enhance the nature conservation interest. There are, however, alternative options to drainage for increasing the dispersion of grazing pressure, and this example also illustrates the point that alternative management options should be explored where there are conflicts of interest in the management of the mires. Some conflicts may be solved - or compensated for - by a greater input of resources or management effort. For example, methods of improving passages which are less damaging than drainage (bridges and/or causeways), and the release of alternative grazing areas to replace any real losses due to 'encroachment' (i.e. recovery) of mire vegetation. There may also be less damaging methods of protecting stock from dangerous areas in the mires, and more effective methods of parasite control, and these should be investigated more fully.

The valley mires already play a positive role in the grazing system. A role which still has only limited recognition. This is due to a large extent, I believe, to poorly-defined criteria for forage productivity and grazing success. In particular, there is an emphasis on habitats which maximise mid-summer production - a factor more relevant to a relatively intensive system of agriculture, rather than free-ranging stock which graze year-round in a semi-natural ecosystem. The challenge for the future is to seek a management system which integrates both the nature conservation interest and the commoning system on a sustainable basis.

CHAPTER EIGHT : CONCLUSIONS

During the course of this study, several recurrent themes have emerged which appear central to the functioning of valley mire ecosystems, and which help to unify approaches to understanding their origins, development and present status. These are, particularly, (i) the hydraulic system of valley mires and its relationship to groundwater supply, and also (ii) variations in the ecophysiological demands on plants in different parts of the valley mire environment. Both are important directions for further research, in either a palaeoecological or contemporary context. Another important, and poorly-understood, area for research is the valley mire fauna - not only in terms of nature conservation, but also in relation to the unusual structure of the invertebrate communities in mires generally.

The proximate cause of valley mire formation is the collection of groundwater and throughflow in breaks of slope, hollows and valley bottoms. Bisequal soil profiles are widespread and the generation of lateral flow is an important factor in determining the development and present distribution of mire vegetation in the New Forest. This study has placed the inception of peat within a broader framework of pedogenesis in the New Forest, the soils of which are typically acid, have impermeable or slowly permeable horizons and are seasonally waterlogged.

Explanation of the ultimate causes of valley mire formation is less tractable. It is necessary to test explanatory hypotheses against an appropriate null model of peat inception, which has logical primacy over others. Put simply, this hypothesis states that peat development is a natural process under the environmental conditions of the present interglacial, and that its timing depends upon the time taken for the system to adjust to these conditions. It has been shown that the development of mire communities and the formation of peat are not synchronous with primary deforestation in any of the sites described here. Peat formation has commenced at several sites in later prehistory without forest clearance. These data falsify the hypothesis that valley mire formation is due to a direct change in the water budget caused by anthropogenic deforestation. There is a broad temporal correlation between climatic change and a

regional acceleration in the rate of mire formation between about 3600 and 2200 BP. However, there are also empirical and theoretical lines of evidence which suggest that the influence of climate is less marked compared to ombrotrophic mires, due to the indirect coupling between effective precipitation and the growth of valley mires. The climatic control hypothesis can only be tested with independent evidence of local change in effective precipitation.

The origins of valley mires present some methodological difficulties, in terms of formal causal explanation. It is also important to recognise that the stratigraphic record may be much simpler than the real history of mire communities in the New Forest, especially since peat formation and preservation is dependent on the sedimentary environment, as well as decomposition processes.

Macrofossil analysis has shown the preferred directions of valley mire succession to be strongly "compartmentalised" in different components of the vegetation. Several communities were found to have a high probability of self-replacement, and have been markedly persistent over portions of postglacial time (and are therefore "climax" communities). These characteristics of valley mire succession may be related to the stable configuration of environmental variables during the period of mire development. These are, especially, the pattern of water flow and the nutrient dynamics of the valley mire, both of which are dependent on lithology and topography. Mire succession is also influenced by the interdependence of mire hydrology and vegetation composition.

It has been argued here that palaeoecology is able not only to help reconstruct past environments, but is also able to test hypotheses of general relevance to ecology (see also Gould, 1976). This is despite a number of difficulties which have been critically reviewed here. Palaeoecological data are also important in understanding the present day communities of mires, because of the significance of peat formation to the mire environment. One particular example stands out in this study, which is the stability (in terms of persistence) of valley mire vegetation in which *Molinia* is an important structural element. This is one of the least diverse plant communities in the valley mires. Such evidence

disproves the important ecological hypothesis that diverse communities are more stable, which has sometimes formed part of the rationale of nature conservation evaluation (e.g. Ratcliffe and Hattey, 1982).

The limits to the distribution of valley mire communities in the New Forest are determined mainly by the ecophysiological response of plant species to the degree, and fluctuation, of waterlogging (discussed in Chapter Six). It is often claimed by some involved in the management of the New Forest that, in the absence or neglect of artificial drainage, the mires are spreading and getting wetter. This hypothesis requires long-term data to test it which are not available (comparisons are sometimes made with the last century). However, this study does provide some evidence and theoretical considerations which are relevant to this management issue.

Firstly, the potential for mire development is constrained by the groundwater profile (see Figure 3.1). This is governed by topography and the hydraulic conductivity of the catchment substrates, which have both remained largely unchanged during the postglacial. It is also controlled by the effective precipitation, which has declined slightly on average over much of the last fifty years, although it has become more variable (Lamb, 1977). This suggests that there has been little potential for the lateral expansion of valley mires due to natural processes in the recent historical period. However, within this constraint on area, peat may accumulate up to the potential groundwater profile, assuming the rate of production is greater than the rate of decomposition. Once the mire surface exceeds the groundwater profile, then it is dependent solely on direct rainfall and further increase in the height of the peat column is determined by the factors discussed in Chapter Five.

The second line of evidence comes from the age-depth ratio of the catotelm - this provides a measure of the "accumulation rate" of the mire, based on the material which has been through the actively decomposing acrotelm zone and has entered the main peat mass. The results from this study indicate that the average "accumulation rate" of valley mires in the New Forest over the last 2 - 3000 years has been in the order of 10 - 20cm/1000yr. This figure is low compared to other types

of mire, and it was suggested in Chapter Five that this is due to a relatively high rate of decomposition. This also argues against recent rapid growth in the mires due to natural processes.

Analysis of community composition has confirmed the conclusions of earlier research on the relationship between mire vegetation and environmental variables (Newbould and Gorham, 1956; Newbould, 1960), and the results support the conceptual framework of Rose's (1953) zonation model (see also Atkinson, 1978). Moreover, multivariate analysis of the floristic variation in the valley mires shows that Rankin's (1911) distinction of four main vegetation groupings still remains valid. It is also suggested here that it may be useful to include physiognomic features in mire vegetation classification, rather than floristics alone. This is because of the difficulty in consistently partitioning the floristic continuum in certain components of mire vegetation (the "general bog communities" of several authors), which may be related to the very large variability in some mire environments, which can occur over very small horizontal and vertical distances. Further insight into the factors controlling valley mire community composition is likely to come from two main directions of future research: (i) the ecophysiological response of individual species (or ecotypes) to particular toxins (e.g. Fe, Al) and limiting nutrients (e.g. P); and (ii) the spatial dynamics of competitive interactions between individual plants - the relatively simple spatial organisation of *Sphagnum* communities appears to offer particular potential in this respect (see 7.3.2.4).

The results of this study also show that internal, physical features of the vegetation are important factors in the underlying gradients of floristic variation. From this, it is suggested that strong interactions between a few species are important in structuring valley mire communities. For most of the open mire vegetation, the most important species in this context is *Molinia caerulea*. Indeed, the role of *Molinia* in the valley mire communities of the New Forest emerges as another central theme to this research.

The investigation into the effects of large herbivores on the mires, using natural experiments, has shown that the diversity of many of the open

communities in the New Forest mires is maintained by grazing, where *Molinia* is not limited by environmental factors (anoxia and other factors limiting productivity). In other words, much of the mire vegetation (and also of the grasslands) is maintained in an unstable state, and succession would rapidly proceed to a species-poor, *Molinia*-dominated climax community if grazing was removed. Soulé and Simberloff (1986) suggest that a conservation strategy for nature reserves should be based upon the identification of target or keystone species, whose disappearance would significantly decrease the value or species diversity of the conservation area. Efforts should then be directed at maintaining the population of that species. In the New Forest valley mires, the target interaction is *Molinia* and grazing, and the keystone species is the commoner's pony.

Acceptance of this proposition, requires the resolution of two current management dilemmas in the New Forest, if the nature conservation interest of the valley mires is to be maintained. It also has implications for the management of related valley mires elsewhere. Firstly, although the present levels of grazing may be beneficial to the management of open Forest communities, they are incompatible with the nature conservation interest of some woodland habitats, especially in the Inclosures which in the past have had a history of low intensity grazing (see Tubbs, 1986). Secondly, the pressure to carry out drainage in the valley mires is closely linked to the commoning system. The evidence described in this study shows there to have been an apparent long-term decline in the nature conservation interest of the valley mires due to drainage. Yet, it has also been argued here that the undrained valley mires and wet heath play an important role in the year-round grazing system, when measured by over-wintering performance.

A subsidiary aim of this study has been to draw together various sources of data and lines of research. It is hoped that this has been achieved to the extent that further management experiments will be contemplated in the future conservation of the valley mires.

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APPENDIX ONE

Sites described in the text

Acres Down SU 277088

Alder Hill SU 204136

Avon Water E/Wilverley Bog SZ 244000 - 260995

Bagnum Bog SU 180020

Bagshot Moor SU 368001

Barrow Moor SU 250078

Boundway Hill SZ 262998

Bramble Hill Bog SU 257158

Buckherd Bottom SU 210084

Burley Common Moor SU 206045

Burley Moor SU 213043

Cadnam Bog SU 280150

Church Moor SU 248069

Cowleys Heath SU 414025

Crab Tree Bog SU 266028

Cranes Moor (*Sphagnum* Bog) SU 190020

Crockford Bottom SZ 349991

Cark Hat SU 232159

Denny Bog/Shatterford Bottom SU 340050

Dibden Bottom SU 393068

Digden Bottom/Linwood Bog SU 175095

Duckhole Bog SU 255026

Fawley Bog SU 410050

Ferny Crofts Bog SU 360050

Flush Bog SU 195027

Fort Bog SU 335085

Godshill Ridge SU 185149

Green Moor SZ 330990

Gritnam Bog SU 284068

Hampton Ridge SU 195133

Hatchet Pond SU 363013

Highland Water SU 270070

Hincheslea Bog SU 275004

Hive Garn Bottom SU 197150

Holmsley Bog SU 210010

Holmhill Bog SU 264022

Latchmore Brook SU 190126

Little Bog SU 195030

Little Holmsley Bog SU 214007

Lodge Heath SU 330018

Long Bottom SU 190140

Longwater Lawn SU 325085

Lugden Bottom SU 180010

Magpie Green SU 209001

Matley Bog SU 330070

Ober Water SU 260030

Ogdens SU 180110

Rakes Brakes Bottom SU 222126

Redhill Bog SU 209020

Row Hill Bog SU 321085

Silver Stream SU 270025

Stephill Bottom SU 350050

Stony Moors SZ 214997

Strodgemoor Bottom SU 180030

The Noads SU 398 062

Three Beech Bottom SZ 295998

Vales Moor SU 190040

Warwickslade Bog (Highland Water) SU 275068

White Moor SU 278079

Whitemoor SU 329085

Widden Bottom SZ 289993

Withybed Bottom SU 253103

Yew Tree Heath SU 360070

APPENDIX TWO

NEW FOREST RADIOCARBON DATES

NATURAL ENVIRONMENT RESEARCH COUNCIL

New Forest Series 1

Sphagnum Bog, Cranes Moor	60 - 70cm	: 4550 ± 70 BP	(SRR - 1914)
	148 - 158cm	: 5750 ± 60 BP	(SRR - 1915)
	238 - 248cm	: 7000 ± 80 BP	(SRR - 1916)
	362 - 372cm	: 8590 ± 90 BP	(SRR - 1917)
	435 - 445cm	: 8000 ± 110 BP	(SRR - 1918)
Flush Bog, Cranes Moor	100 - 104cm	: 8630 ± 60 BP	(SRR - 2126)
	160 - 164cm	: 9110 ± 60 BP	(SRR - 2127)
	275 - 279cm	: 9570 ± 60 BP	(SRR - 2128)
	316 - 320cm	: 10070 ± 60 BP	(SRR - 2129)
Church Moor	120 - 130cm	: 5170 ± 50 BP	(SRR - 1919)
	180 - 190cm	: 8260 ± 50 BP	(SRR - 1920)
	260 - 270cm	: 12440 ± 60 BP	(SRR - 1921)
Warwickslade Bog	96 - 97cm	: 7830 ± 100 BP	(SRR - 2250
	106 - 107cm	: 8590 ± 120 BP	(SRR - 2251)

New Forest Series 2

Hive Garn Bottom I	32 - 34cm	: 690 ± 80 BP	(SRR - 2686)
	66 - 68cm	: 2630 ± 50 BP	(SRR - 2687)
	95 - 98.5cm	: 2700 ± 70 BP	(SRR - 2688)
Hive Garn Bottom II	36 - 39cm	: 1530 ± 70 BP	(SRR - 2689)
	53 - 56cm	: 2370 ± 60 BP	(SRR - 2690)
Stephill Bottom	51 - 55cm	: 590 ± 70 BP	(SRR - 2691)
	93 - 97cm	: 3080 ± 210 BP	(SRR - 2692)

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Barrow Moor	140 - 160cm	: 1455 ± 70 BP	(UB - 2214)

All dates in radiocarbon years before present (1950).

APPENDIX THREE

Key for sub-fossil *Sphagnum* branch leaves

This key follows the treatment of the genus by M.O.Hill in Smith (1978), and initially provides a guide to section level. Keys to species, where available, are indicated.

Specimens should be stained, which may be done using a simple water-based dye such as gentian violet.

1-	Spiral fibrils in branch cortex, if available	*Sphagnum* (key A)
-	Spiral fibrils not present, or branch absent	2
2-	Margin denticulate	3
-	Margin not denticulate	5
3-	Apex scabrous and with hyaline cells broader than long; most leaves broad, cucculate	*Sphagnum* (key A)
-	Apex not scabrous with hyaline cells usually not broader than long, leaves narrower	4
4-	(Pendent) Branch leaves with abundant ringed commisural pores	*Rigida* (key B)
-	Dorsal pores ± invisible without folding due to highly protuberent hyaline cells. Green cells hardly or not exposed on dorsal surface	*(Acutifolia-S.molle)*
5-	Green cells of branch leaves triangular or trapezoid in section, widest exposure on ventral surface	*Acutifolia*
-	Green cells not, or slightly, exposed on ventral surface, or if with a moderate ventral exposure then with a greater dorsal exposure	6
6-	Dorsal pores in mid-leaf large, numerous and conspicuous, 0.012-0.040mm; ventral pores prominent. Leaf often reflexed	*Squarrosa* (key C)
-	Pores small, less than 0.012mm, or if larger then not more than 1 per cell (*S.tenellum*)	7
7-	Leaf ovate/lanceolate; Green cells triangular or trapezoid in section, broadly exposed on dorsal surface; Dorsal pores not along commisures	*Cuspidata* (key D)
-	Green cells ± barrel-shaped in section with a narrow dorsal exposure; Dorsal pores along commisures (sometimes absent); Leaf shape variable	*Subsecunda*

Key A- In Smith (1978), p.33 (see also Daniels and Eddy, 1985, pp.32-33)
Key B- In Smith (1978), pp.55-56 (see also Daniels and Eddy, 1985, p.33)
Key C- In Smith (1978), p.40 (see also Daniels and Eddy, 1985, pp.34-35)
Key D- In Klinger (1976)

Smith, A.J.E. (1978) The moss flora of Britain and Ireland. C.U.P.
Klinger, P.U. (1976) Bearbeitung der mitteleuroppaischen *Sphagna Cuspidata* im Hinblick auf moorstratigraphishe Fragestellungen. Mitteilungen der Arbeitsgemeinschaft Geobotanik in Schleswig Holstein unt Hamburg. Heft 27 Kiel
Daniels, R.E. and Eddy, A. (1985) Handbook of European Sphagna. I.T.E.

APPENDIX FOUR

Tentative key for the determination of species of the Sect. *Cuspidata*, based on branch leaf characters. Translated from Klinger (1976)

1. Pores almost only in the form of pseudopores with the border at least partially indistinct 2

1'. Pores always open, edges clearly visible 3

2. Pores ranging from very small to moderate in size, clear, partly with distinct border, roundish to spindle-shaped. Hyaline cells oblong, relatively long at base of leaf, fibrils firm, cell angles often broadly Y or H-shaped on the dorsal side of cells near the apex *S. jensenii* H.Lindb.

2'. Pores very small, indistinct even with heavy staining, hyaline cells narrow and relatively short, often absent in the extreme apex of the leaf *S. obtusum* Warnst.

3. Pores on both sides of the leaf very small, 0.008mm (only in *f.falcatum* slightly larger sometimes), relatively rare, mostly absent from the ventral side, the ± falcate leaves and the cells very drawn out, edge of leaf often denticulate *S. cuspidatum* Hoffm.
   a) Leaves up to 10mm long, slightly falcate, not inrolled at margin, often with scattered denticulations, leaf apex commonly reduced to one cell width, hyaline cells in leaf apex absent *f.plumosum* (Bryol.germ.)
   b) Leaves up to 3mm long, mostly strongly falcate, margin inrolled, not denticulate, leaf apex dentate and emarginate *f.falcatum* (Schimp)

3'. Pores at least on one side of the leaf 0.008mm, sometimes smaller in aquatic forms 4

4. Pores almost completely absent on the ventral side, on the dorsal side in single or double rows in the middle of the hyaline cells *S. majus* (Russ) C.Jensen

4'. Pores on the ventral side ± abundant 5

5. Dorsal side of the leaf with distinct rows of pseudopores along the commissures 6

5'. Dorsal side without such rows of pseudopores 8

6. Pseudopores on dorsal side in continuous rows, green cells on the ventral side not exposed, appearing linear, fibrils on dorsal side commonly ± close-set and parallel, relatively narrow. Pores on the ventral side often smaller less numerous than in the closely similar *S. pulchrum*, leaf shape more narrowly ovate with longer leaf tip than in this species *S.lindbergii* Schimp

6'. Pseudopores in continuous rows, only in the top half of the dorsal side, green cells on the ventral side exposed 7

7. Leaf apex on the dorsal side with rows of ringed pseudopores but few true pores in the middle of the leaf and the leaf base with ± wide pores in distal angles, leaves up to 2mm long, often falcate *S. balticum* (Russ) C.Jensen

7'. Dorsal side of leaf with rows of pseudopores in the apical part and only small distal pores (aquatic form), leaves mostly longer *f.ruppinense* (Warnstorf)

8. Green cells not exposed on the ventral side, appearing linear. Few pores on the dorsal side, numerous pores on the ventral side. Fibrils on the dorsal side strongly developed, sparsely distributed , hardly parallel and at distal ends widely Y or H-shaped like in *S. jensenii*. Pseudopores numerous, sometimes wider, but not in continuous rows, some, however, ringed as in *S.balticum* *S. pulchrum* (Braithw) Warnst.

8'. Green cells on the ventral side at least partly exposed 9

9. Pores on the ventral side often 0.02mm, often blending into membrane gaps 10

9'. Pores on the ventral side mostly 0.015mm 12

10. Hyaline cells in leaf base frequently longer than 0.2mm, often absent in leaf apex. Pores on the ventral side of leaves from hanging branches often very wide (membrane gaps), leaves 2.5mm or more *S. riparium* Angstrom

10'.Hyaline cells at leaf base commonly under 0.18mm, leaves 2mm long 11

11. Hyaline cells in leaf apex almost rhomboidal. Often very regular, leaves broadly lanceolate to ovate with narrowly obtuse or emarginate tip *S. tenellum* (Brid.) Brid.

11'.Hyaline cells all oblong. Leaves lanceolate with narrowly emarginate tip, often slightly falcate. Distal pores on the dorsal side of leaves from hanging branches commonly widened into membrane gaps *S. angustifolium* (Russ.) C.Jensen

12. *S. recurvum* group (only distinguishable with the aid of stem leaves):
   a) Leaves mostly narrowly lanceolate, margin strongly incurved, often slightly falcate, stem leaves almost triangular with sharp cusp, fibrils absent *S. fallax* (Klinggr.) Klinggr. emend. Isov

b) Stem leaves less sharply cuspidate to obtuse. Fibrils in the apical region as *f. fallax* (Klinggr.) combined aquatic and juvenile forms of this group

c) Leaves mostly somewhat wider as in *S. fallax*, slightly incurved or falcate, stem leaves lingulate-triangular, with short, obtuse, somewhat fringed apex *S. flexuosum* Dozy et Molk

APPENDIX FIVE

Further notes on multivariate analyses used in the study

There are several features of the raw community data matrix which may hinder interpretation or may lay a different emphasis on the data to that required by the investigation. It is widely recognised that it is necessary to edit these undesirable features before carrying out multivariate analyses (Austin and Grieg-Smith, 1968; Maarel, 1979; Gauch, 1982). At best effective editing permits the examination of different facets of complex data, and at worst inadequate editing may totally confound subsequent analyses. Editing options fall into several categories: (i) Standardisation of sample totals, (ii) Omission of rare species, (iii) Deletion of outliers, (iv) Separate analyses of disjunct data sets, (v) Transformation of species abundance (e.g. square root or logarithmic). Manipulation of these options permits a range of emphasis to be placed on data analysis. However, changing the parameters of the technique being used may have equally important effects on the resulting analysis (for example, principal components analysis - see Noy - Meir *et al*, 1974). The choice of particular algorithm and editing options is the subjective element of multivariate techniques. There can be no advantage in objectivity unless these preliminary procedures are stated explicitly, their selection justified and their effects evaluated.

Detrended correspondence analysis (DECORANA) and two-way indicator species analysis (TWINSPAN) have been widely used by ecologists, and are probably the best all-round ordination and classification package currently available in community ecology (see section 6.2). This appendix discusses the options used here with DECORANA and TWINSPAN, and their significance in relation to ecological interpretation. These techniques are closely related, in that the reciprocal averaging (RA) method of ordination forms the basis of both methods, see Hill (1979a,b), Hill and Gauch (1980), Gauch and Whittaker (1982), Gauch (1982). Species and sample totals are standardised internally in both these techniques. However, there are significant differences between them in the options available for editing and their response to undesirable features of the data.

Rarities, outliers and disjunctions

Reciprocal averaging is a compromise between an emphasis on species and an emphasis on samples; an unfortunate consequence is that species which are both rare and occur in samples with low total abundance are treated as being extremely distinctive. Thus, such species and the samples in which they occur are placed at extreme ends of the RA ordination axes. In turn, TWINSPAN pays greatest attention to species and samples at the extremes of the ordination when splitting the axis to make a dichotomy. The effect of rarities in TWINSPAN may be partially overcome by manipulating the emphasis placed on relative abundance in TWINSPAN.

Unlike DECORANA, TWINSPAN records species abundance in only a semi-quantitative way - abundance values are divided up into a scale which can be defined by the user. The abundance categories are terms "pseudo-species" and the divisions are referred to as the "pseudospecies cut-levels" (Hill, Bunce and Shaw, 1975). By varying the cut-levels, one can place differing degrees of emphasis on abundance values, such as present, low, medium and dominant. The default cut-levels in TWINSPAN (Hill, 1979b) place less emphasis on dominants than alternative cut-levels, such as those used by Alcock (1985) and the National Vegetation Classification (Rodwell, in prep.). The latter is most effective where rare species are retained since, although included, these species are not allowed a large influence in the analysis. One of the most significant effects arising from the choice of cut-levels, is the organisation of the classification hierarchy. The TWINSPAN hierarchy is important not only because it displays cluster relationships, but also because the sequence of divisions tends to determine the size, and therefore the characteristics, of the clusters. This is because TWINSPAN operates by more or less dividing RA ordination space into equal volumes - the order of the hierarchy, therefore, has important consequences for the size and the relationships of clusters which will be affected by the dichotomies occurring at higher levels. The cut-levels can be given different weighting, and this is one approach to the problem of rarities. However, this is downweighting of abundance only and not frequency, and is detrimental for species which occur frequently but are never very abundant. A good example is *Drosera rotundifolia* which occurred in 51% of samples but was seldom more abundant than 1 - 4% cover.

Rare species present a dual problem of low frequency and/or low abundance. The conventional approach in multivariate analysis is to omit those species occurring in less than a certain proportion, often 5%, of samples. In addition to pragmatic reasons, the rationale behind this procedure is that rare species carry little of the overall information in multivariate analysis and their distribution is more influenced by chance (Gauch, 1982). However, rare species are often specialists and are useful environmental indicators, which have been studied in more detail than more common species. Therefore, it is desirable to retain rare species in analysis, but to accord them less influence than more frequently occurring species. Furthermore, rare species may occur with high abundance in certain samples, so that they are significant components in some communities. For example, in the survey data collected by the England Field Unit, 14 species (out of a total of 247) occurred in less than 5% of all samples but were present with cover values of over 35% in at least one sample. Clearly, omitting species occurring below an arbitrary frequency represents a crude approach to this problem. An alternative to omitting species from the analysis, is to downweight species according to their frequency and their abundance. This option is available in DECORANA (Hill, 1979a). Species rarer than AMAX/5 are downweighted in inverse proportion to their frequency, where AMAX = the frequency of the commonest species. For species j, the abundance in particular sample (a_{ij}) is replaced by:

$$\frac{(a_{ij}) \times fi}{(AMAX/5)} \quad , \text{ where } fi = \frac{(\sum_i a_{ij})^2}{(\sum_i a^2_{ij})}$$

The term fi is analogous to the diversity measure ,N_2, of Hill (1973b) which is the reciprocal of Simpson's diversity index, i.e. it is the reciprocal of an arithmetic mean of the proportional abundances. This is more satisfactory for ecological analysis, since species which are rare with low abundance are downweighted more than those with high abundance.

In this study (section 6.5), simple editing of species occurring in less than 5% of all samples (9 out of 184) in the England Field Unit survey data, led to the omission of 177 species, and only 28% of all species were retained. Downweighting, on the other hand, led to 93% of species being retained but 90% were downweighted to some extent. The most frequent

species was *Molinia caerulea* and AMAX = 0.8. Some of the species retained were downweighted by as much as a factor of 0.036.

Reciprocal averaging, like many ordination techniques, is susceptible to outliers (aberrant samples or groups of samples). However, DCA (an improved version of RA) has been found to be more robust (Hill and Gauch, 1980), so that both problems of rare species and outliers are more severe with TWINSPAN than DECORANA. By contrast, data disjunction does not cause difficulties with TWINSPAN, at least at higher levels, because the data are re-ordinated on each division. However, the final ordering of the two-way table represents an almagamation of gradients in the data at different levels for various subsets of the data, with the result that the table may be difficult to interpret ecologically.

DCA is impaired by data disjunction, which may result in a distinctive "wedge-shape" distribution of points in ordination space (e.g. Figure 6.11), where the variation in higher axes is compressed at one end of the main gradient. This is attributable to the methods of detrending and rescaling used in DECORANA (see Hill and Gauch, 1980). A number of other recent studies have now described this type of distortion with DCA, using real and simulated data (see Minchin, 1987), and it is probably the most common fault of this technique. However, the distortion was easily rectified by simple editing of the dataset in this analysis, producing readily interpretable results. It is important to recognise the possibility of distortion in the results of DCA, the other main source of which is the enhanced distinctiveness of samples containing species whose overall abundance in the dataset is low, especially where the total number of species is small (see Dargie, 1986; Minchin, 1987).

Analysis of data recorded on the Domin scale

It is generally desirable to transform abundance values used in multivariate analysis into a scale ranging in the order of 0 - 10. This has the advantage of giving roughly even emphasis to qualitative and quantitative information. Similarly, logarithmic transformation into such a scale allows a wide range of abundances to be expressed in a manner which matches human perception of species abundance. The reasoning behind these

procedures is reviewed by Gauch (1982).

Data recorded on the Domin scale exists in the following forms: (i) absent, (ii) present on a scale of 0 - 10. In the Domin scale, 0 denotes a species present in the stand but recorded outside the quadrat. Scores are calculated in DECORANA in the form $\sum_i a_{ij}$, so that if $a_{ij} = 0$ no contribution is made to the row or column totals, i.e. it is equivalent to absence and is ignored. This is in contrast to TWINSPAN which uses qualitative pseudospecies, where 0 denotes the presence of a species but at unspecified abundance. If the objective of DCA is to interpret ecological space, it may be more appropriate to allow the 0 Domin scores to be omitted, since environmental heterogeneity will be greater with a larger sampling area. However, 0 scores can easily be included in DECORANA simply by adding a constant to all scores, but in practice this has little effect. In the analysis of the mire survey data, transformations of this kind retained the main structure of the ordination in all cases. There were negligible differences in eigenvalues and axis lengths varied by less than 1%. There were small discrepancies in the positions of samples along the higher axes and some reversals of axes were encountered. The species ordinations were generally more variable and the origins of the axes shifted by up to 10% of the total axis length, but on the whole these effects were minor.

Cut-levels or abundance scales used in TWINSPAN

Two-way indicator species deals with essentially qualitative data, but a semi-quantitative abundance scale is created by defining a number of coarse cover-abundance categories (Hill, 1979b). The abundance scale can be varied by altering the number and value of the cut-off points, or "cut-levels". This allows the investigator to adjust the emphasis to be placed on dominance, presence or absence, etc., which may vary according to whether the full species complement or the formation-type is most important, for example. Three abundance scales were employed in the analysis of the England Field Unit survey data (Table 1), and the results are discussed in section 6.5. The first scale (a in Table 1) gives dominant species a major influence in the analysis, and has been used by the National Vegeta-

tion Classification (Rodwell, in prep.) and the England Field Unit (Alcock, 1985). Scale b corresponds to the default cut-levels recommended by Hill (1979b), in which even minor species (in terms of abundance) play a significant role. The third scale, c, is intermediate between a and b. As would be expected, scale b was found to be most sensitive to rare species (low frequency) in terms of re-classification. Analysis using the cut-levels in c was most robust in this respect but exhibited poor ordering in the two-way tables. The cut-levels used in the NVC were also relatively robust in respect to rare species and proved the most satisfactory in the classification of slightly "aberrant", or atypical, samples. There are also quite considerable advantages of conformity in using these cut-levels. This is of particular importance now that TWINSPAN has become so widely adopted in plant ecology, which should lead to a major advance in the communication of inforatmion and results.

Table 1 Cut-levels used in different trials of TWINSPAN (see text)

	Cut-levels (Domin)					
a	0	1	4	6	8	10
b	0	2	3	4	5	
c	2	3	4	6	8	

Domin scale:

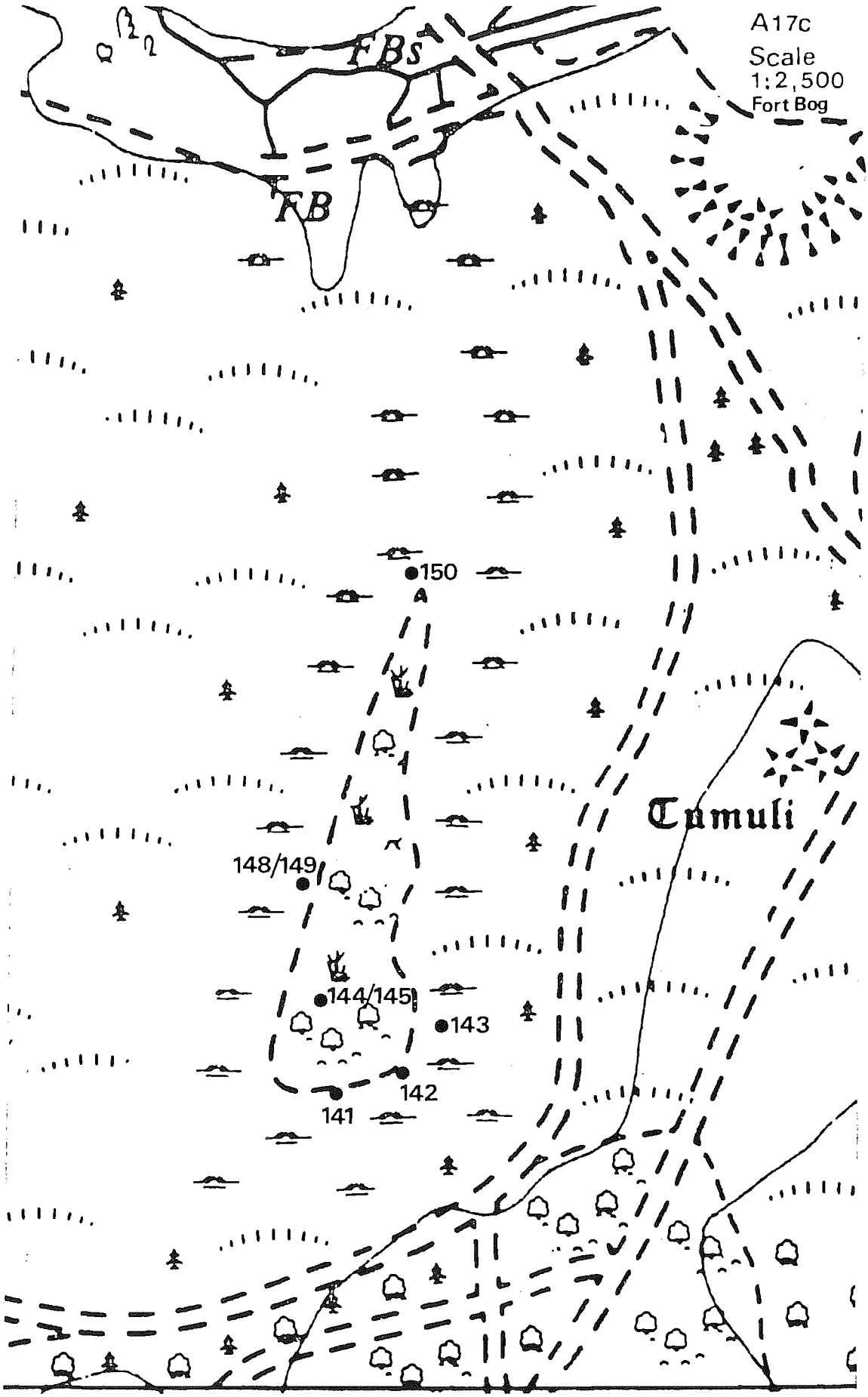
+/0	present	6	26 - 33%
1	1 - 2 individuals	7	34 - 50%
2	1%	8	51 - 75%
3	1 - 4%	9	76 - 90%
4	4 - 10%	10	91 - 100%
5	11 - 25%		

Additional reference

HILL M O (1973b). Diversity and evenness: a unifying notation and its consequences. Ecology 54: 427 - 432.

APPENDIX SIX

Field stratigraphy and surface vegetation for other sites investigated in Chapter 5


A17c
Scale
1:2,500
Fort Bog
FBs
FB
150
A
Tumuli
148/149
144/145
143
142
141

FORT BOG QUADRAT 141

Carr margin : Species-poor *Molinia-S.recurvum-Juncus acutiflorus-Eriophorum angustifolium*

Molinia caerulea 7 *Eriophorum angustifolium* 5 *Juncus acutiflorus* 5 *Phragmites australis* 3 *Erica tetralix* 3 *Drosera rotundifolia* 2 *Betula pubescens* 1 *Calluna vulgaris* 1 *Carex rostrata* 1 *Juncus bulbosus* 1 *Myrica gale* 1 *Narthecium ossifragum* 1 *Pinus sylvestris* 1 *Rhynchospora alba* 1 *Sphagnum recurvum* 8 *S.palustre* 2 *S.subnitens* 2 *S.capillofolium* 1 *Aulocomnium palustre* 1 *Cephalozia macrostachya* 1 *Cladopodiella fluitans* 2 *Odontoschisma sphagni* 2 *Mylia anomala* 1

Sphagnum cover 70%

Depth (cm)	Troels-Smith Components	Description
0-50	Tb^2 Th^1 Dh^1 Dl^+	Unconsolidated *Sphagnum* and monocot rootlet peat with *Betula* wood
50 - 80	Th^3 Sh^1	Unconsolidated monocot rootlet peat with Phragmites and a little Eriophonum
80 - 100	Th^3 Sh^1	Similar to 50 - 80 but more consolidated
100 - 115	Ag^3 Th^1 Ga^+	Stiff stony clay

FORT BOG QUADRAT 142

Phragmites - Molinia - Erica tetralix peripheral zone to carr

Anagallis tenella 2 *Dactylorhiza incarnata* 1 *Drosera rotundifolia* 3 *Erica tetralix* 6 *Eriophorum* 4 *Juncus acutiflorus* 5 *J.bulbosus* 1 *Molinia* 7 *Narthecium* 4 *Phragmites* 6 *Potentilla erecta* 1 *Aulocomnium palustre* 1 *Calliergon stramineum* 2 *Cephalozia machrostachya* 3 *Cladopodiella fluitans* 2 *Lepidozia setacea* 2 *Mylia anomala* 1 *Odontoschisma sphagni* 2 *Sphagnum capillifolium* 2 *S.papillosum* 6 *S.magellanicum* 4 *S.recurvum* 3

Sphagnum cover 60%

Depth (cm)	Troels-Smith Components	Description
0 - 50		Unconsolidated surface mat: no sample
50 - 70	Th^3 Sh^1 Dl^+	Poorly consolidated *Phragmites* peat
70 - 75	Th^3 Sh^1 Dl^+	As 50 - 70 but more consolidated
75 - 80	Th^2 Dh^1 Sh^1	Lighter *Phragmites* peat with *Molinia*
80 - 95	Ag^2 Ga^1 Th^1 Gs^+ Gg^+	Loamy clay with some gravel and *Phragmites* rhizomes penetrating from above
95 - 100	Ag^2 Ga^1 Th^1	Stiff grey loamy clay with *Phragmites* rhizomes

FORT BOG QUADRAT 143

Sphagnum lawn

Calluna 1 *Drosera intermedia* 1 *D.rotundifolia* 3 *Eleocharis* 2 *Erica tetralix* 3 *Eriophorum* 5 *Molinia* 4 *Narthecium* 4 *Rhynchospora alba* 5 *Cephalozia machrostachya* 3 *Cladopodiella fluitons* 3 *Lepidozia setacea* 3 *Odontoschisma sphagni* 2 *Sphagnum auriculatum* 1 *S.cuspidatum* 6 *S.papillosum* 6 *S.magellanicum* 4 *S.tenellum* 3

Sphagnum cover 90%

Depth (cm)	Troels-Smith Components	Description
0 - 25		Unconsolidated *Sphagnum* carpet. No sample
25 - 40	Th^2 Tb^1 Sh^1	Humified peat dominated by *Molinia* remains. Firm consistency.
40 - 50	Ag^2 Ga^1 Th^1	Brown-grey loamy clay with *Molinia* rootlets.

FORT BOG QUADRAT 144/145

Alder carr

Alnus 7 *Betula pubescens* 6 *Caltha palustris* 1 *Ajuga reptons* 1 *Carex paniculata* 3
Crataegus monogyna 1 *Epilobium montanum* 1 *E.palustre* 1 *Galium palustre* 1 *Frangula* 2 *Ilex* 2 *Hedera* 3 *Mentha aquatica* 3 *Myosotis scorpioides* 1 *Rubus* 1 *Lonicera* 3 *Quercus robur* 4 *Salix cinerea* 5 *Solanum dulcamara* 1 *Valeriana officinalis* 1 *Taxus* 2 *Dryopteris austriaca* 1 *Equisetum palustre* 1 *Brachythecium rutabulum* 1 *Calliergon cuspidatum* 1 *Calypogeia fissa* 4 *Cephalozia bicuspidata* 1 *Riccardia multificda* 1 *Thuidium tamariscinum* 2 *Lophocolea cuspidata* 2 *Sphagnum palustre* 2 *S.fimbriatum* 3 *Mnium hornum* 2

Bryophyte cover 20%

Depth (cm)	Troels-Smith Components	Description
0 - 30	Tl^2 Dl^1 Th^1 Sh^+	Granular woody peat with monocot rootlets
30 - 50	Tl^1 Th^1 Sh^2 Dl^+	More humified woody peat
50 - 60	Ag^2 Ga^1 Th^1	Loamy clay with *Phragmites* rhizomes and other monocot rootlets
60 - 75	Ag^1 Tl^3 Th^+ Ga^+	*Alnus* wood and *Phragmites* rhizomes
75 - 90	Th^2 Sh^1 Ag^1 Tl^+	Humified monocot rootlet peat with a band of *Alnus* wood at 85 - 86cm
90 - 100	Ag^3 Ga^1 Tl^+ Th^+	Stiff grey loamy clay with some penetration of *Alnus* and *Phragmites*.

FORT BOG QUADRAT 148/149

Potamogeton channel - *Molinia* tussock mosaic near carr

Carex rostrata 1 *Cirsium dissectum* 2 *Drosera rotundifolia* 3 *Eleocharis* 4 *Erica tetralix* 4 *Eriophorum* 3 *Juncus acutiflorus* 4 *J.bulbosus* 1 *Molinia caerulea* 3 *Myrica gale* 6 *Narthecium* 3 *Phragmites* 1 *Potamogeton* 7 *Potentilla erecta* 1 *Rhynchospora* 3 *Calliergon stramineum* 1 *Calypogeia fissa* 1 *Cephalozia machrostachya* 2 *Cladopodiella fluitons* 2 *Odontoschisma sphagni* 1 *Sphagnum papillosum* 5 *S.recurvum* 3

Sphagnum cover 10%

Depth (cm)	Troels-Smith Components	Description
0 - 25		Very fluid peat. No sample
25 - 40	Th^2 Dh^1 Sh^1	Poorly consolidated rootlet peat dominated by *Molinia*
40 - 50	Ag^1 Ga^1 Gh^1 Sh^1 Dl^+	Highly inorganic peat with monocot rootlets and *Betula/ Alnus* wood
50 - 85	Ag^2 Ga^2 Tl^+	Loamy clay with some wood

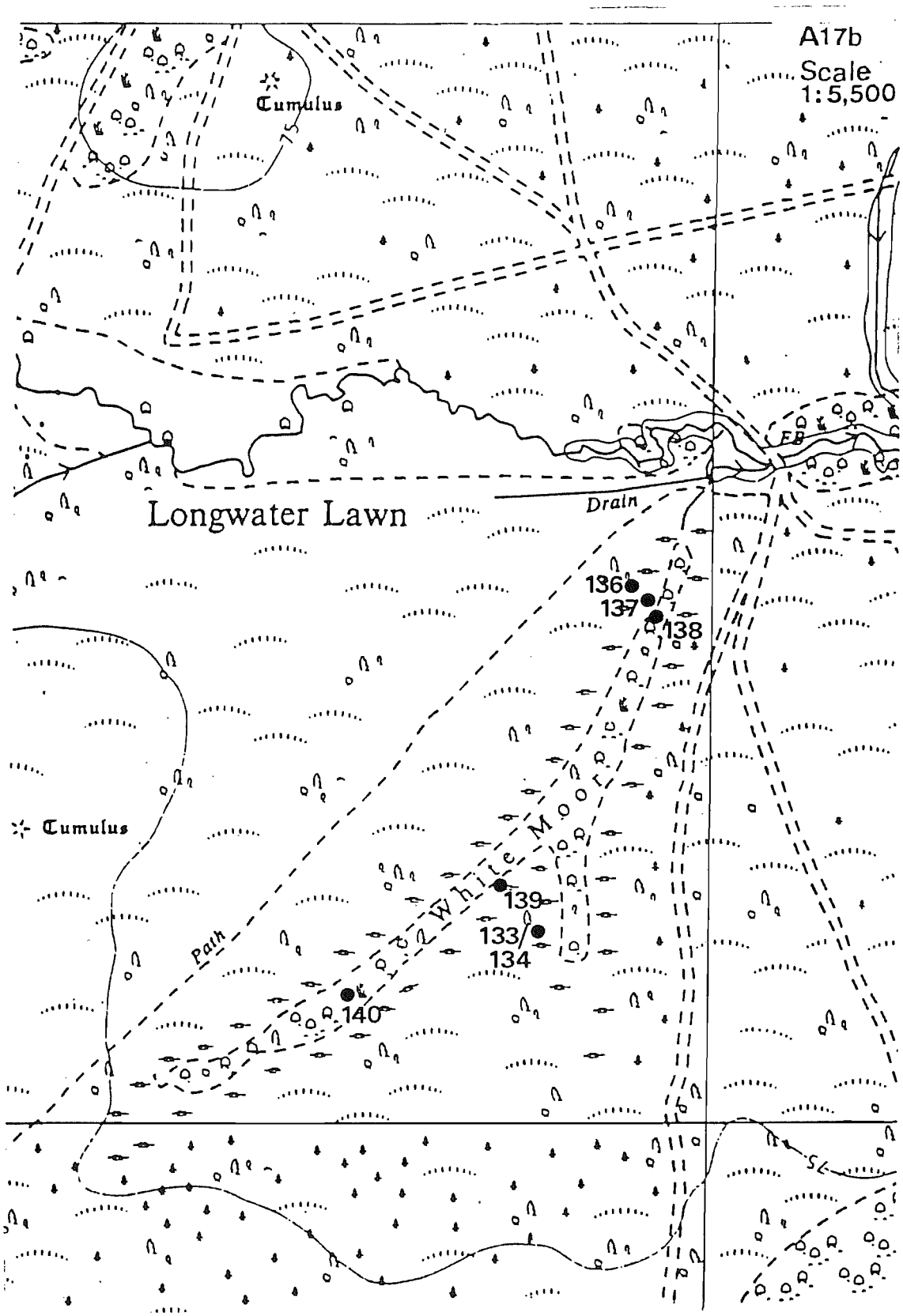
FORT BOG QUADRAT 150

Hypericum elodes stand in lower reaches of the mire

Agrostis stolonifera 1 *Alnus glutinosa* 1 *Anagalli tenella* 1 *Carex demissa* 2 *C.echinata* 1 *C.nigra* 2 *C.panicea* 3 *C.rostrata* 3 *Cirsium dissectum* 2 *Drosera rotundifolia* 1 *Eleocharis Eriophorum* 3 *Hydrocotyle vulgaris* 1 *Hypericum elodes* 4 *Juncus acutiflorus* 1 *J.articulatus* 1 *J.bulbosus* 2 *Mentha aquatica* 2 *Menyanthes* 2 *Molinia* 3 *Myrica* 1 *Pedicularis palustris* 1 *Phragmites* 1 *Potamogeton* 6 *Succisa pratensis* 1 *Equisetum fluviatile* 1 *Campylium stellatum* 1

Sphagnum cover 0%

Depth (cm)	Troels-Smith Components	Description
0 - 25	Th^3 Sh Tl^+	Poorly consolidated rootlet peat dominated by *Molinia* with some wood
25 - 35	Ag^1 Ga^1 Sh^1 Th^1 Gg^+	Peaty loamy clay with gravel and monocot rootlets
35 - 45	Ag^2 Ga^2 Gg^+ Th^+ Gs^+	Similar to 25 - 35cm but less organic
45 - 50	Ag^1 Ga^1 Gs^2	Grading into presumed Barton Sand


A17b
Scale
1:5,500
Cumulus
Longwater Lawn
Drain
FB
136
137
138
Cumulus
White Moor
139
133/
134
Path
140

WHITE MOOR QUADRAT 133/134

Potamogeton channel - *Sphagnum* lawn mosaic

Drosera rotundifolia 3 *Eleocharis* 1 *Erica tetralix* 3 *Eriophorum* 3 *Juncus acutiflorus* 1 *J.bulbosus* 1 *Myrica* 2 *Narthecium* 3 *Molinia* 2 *Phragmites* 2 *Potamogeton* 6 *Rhynchospora* 6 *Cladopodiella fluitans* 2 *Lepidozia setacea* 1 *Sphagnum auriculatum* 1 *S.papillosum* 8 *S.recurvum* 7

Sphagnum cover 40%

Depth (cm)	Troels-Smith Components	Description
0 - 20		Unconsolidated - no sample
20 - 35	Th^2 Sh^2 Tb^+ Ag^+	Humified rootlet peat
35 - 50	Ag^1 Ga^1 Gg^2 Th^+	Stony loam with traces of monocot rootlets

WHITE MOOR QUADRAT 136

Dry *Molinia* - *Myrica* - *Erica tetralix* near mire edge

Agrostis canina 1 *Calluna* 2 *Carex echinata* 2 *Erica tetralix* 4 *Eriophorum* 3 *Hydrocotyle vulgaris* 1 *Juncus acutiflorus* 1 *J.bulbosus* 1 *Menyanthes* 1 *Molinia* 6 *Myrica* 6 *Potentilla erecta* 2 *Succisa pratensis* 1 *Campylopus pyriformis* 2 *Cephalozia connivens* 2 *Cephalozia machrostachya* 2 *Cladopodiella fluitans* 2 *Lepidozia* 1 *Leucolbryum glaucum* 1 *Odontoschisma sphagni* 1 *Polytrichum commune* 1 *Sphagnum auriculatum* 1 *S.cuspidatum* 5 *S.papillosum* 3 *S.tenellum* 1

Sphagnum cover 20%

Depth (cm)	Troels-Smith Components	Description
0 - 9	Th^2 Ag^1 Ga^1	Humose soil dominated by *Molinia* rootlets
9 - 15	Ag^2 Ga^2	Loamy soil

WHITE MOOR QUADRAT 137

Narrow zone between carr and *Myrica* stand

Alnus 1 *Caltha palustris* 1 *Angelica sylvestris* 1 *Carex nigra* 1 *C.remota* 2 *C.rostrata* 2 *Cirsium dissectum* 2 *Eriophorum* 1 *Filipendula ulmaria* 2 *Galium palustre* 2 *Hydrocotyle* 2 *Ilex* 1 *Juncus articulatus* 3 *J.effusus* 1 *Glyceria fluitans* 3 *Lysimachia vulgaris* 3 *Mentha aquatica* 2 *Menyanthes trifoliata* 3 *Molinia* 4 *Myrica* 5 *Potamogeton* 3 *Ranunculus flammula* 2 *Rubus* 1 *Scutellaria minor* 2 *Succisa pratensis* 1 *Viola palustris* 1 *Sparganium erectum* 2 *Equisetum palustre* 1 *Valeriana dioica* 2 *Sphagnum auriculatum* 4

Sphagnum cover 5%

Depth (cm)	Troels-Smith Components	Description
0 - 17	Dh^1 Dl^2 Th^1 Sh^+	Wet, poorly consolidated peat dominated by *Phragmites* and *Alnus*
17 - 42	Ag^1 Ga^1 Sh^1 Th^1	Gradual transition into more humified less organic peat with *Phragmites*

WHITE MOOR QUADRAT 138

Alder carr

Agrostis tenuis 2 *Alnus* 7 *Betula pubescens* 6 *Carex remota* 2 *Lonicera* 1 *Galium palustre* 2 *Juncus bulbosus* 3 *Glyceria fluitans* 7 *Mentha aquatica* 1 *Ranunculus flammula* 2 *R.repens* 1 *Rubus* 1 *Salix cinerea* 2 *Athyrium felix femina* 1 *Dryopteris austriaca* 1

Bryophyte cover 0%

Depth (cm)	Troels-Smith Composition	Description
0 - 14	Tl^{2} Th^{1} Sh^{1}	Wet woody peat dominated by *Alnus/Betula* with some monocot rootlets
14 - 41	Tl^{1} Th^{1} Sh^{2} Ag^{+}	More humified wood and rootlet peat with *Phragmites*
41 - 50	Tl^{2} Th^{1} Sh^{2} Ag^{+} Ga^{+}	Slightly less organic peat with *Betula/Alnus* wood and monocot rootlets
50 - 60	Ag^{1} Ga^{1} Tl^{1} Sh^{1} Th^{+}	Similar to 41 - 50 but less organic still
60 - 63	Ag^{1} Ga^{1} Tl^{1} Sh^{1} Gg^{+}	Becoming stony

WHITE MOOR QUADRAT 139

Tussocky *Molinia* - *Myrica* near carr

Alnus 1 *Drosera rotundifolia* 2 *Eleocharis* 2 *Erica tetralix* 3 *Eriophorum* 4 *Juncus acutiflorus* 2 *J.bufonius* 1 *Molinia* 4 *Myrica* 5 *Narthecium* 3 *Potentilla erecta* 2 *Rhynchospora* 1 *Calypogeia fissa* 2 *Cephalozia machrostachya* 2 *Cladopodiella fluitans* 2 *Odontoschisma sphagni* 2 *Sphagnum auriculatum* 2 *S.cuspidatum* 3 *S.papillosum* 7 *S.tenellum* 1

Sphagnum cover 50%

Depth (cm)	Troels-Smith Components	Description
0 - 19	Th^2 Tb^2	Fluid *Sphagnum* - monocot peat
19 - 45	Th^2 Dh^1 Sh^1 Gg^+	Humified greasy peat with *Phragmites* and *Molinia* remains
45 - 50	Th^2 Dh^1 Sh^1 Gg^+ Tl^+	Similar to 19 - 45 but with *Alnus* wood
50 - 62	Ag^1 Ga^1 Sh^2 Th^+ Tl^+	Highly humified loamy clay with *Phragmites* and *Alnus*

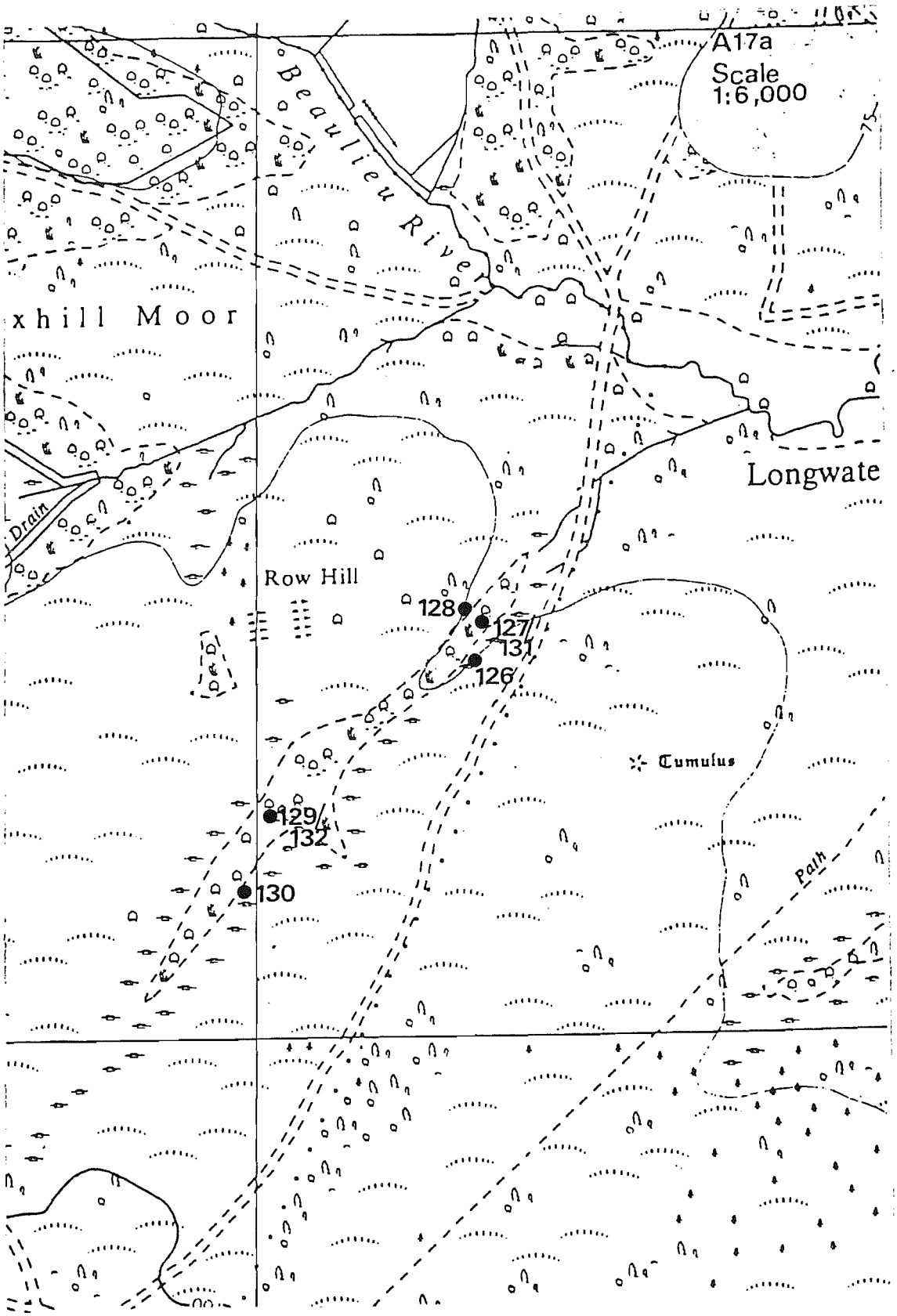
WHITE MOOR QUADRAT 140

Alder carr

Alnus 8 *Carex remota* 4 *C.paniculata* 2 *Cirsium palustre* 1 *Fraxinus* 1 *Betula pubescens* 2 *Lysimachia vulgaris* 3 *Rubus* 1 *Solanum dulcamara* 1 *Silene dioica* 2 *Poa trivialis* 3 *Dryopteris austriaca* 2 *Thelypteris thelypteroides* 7 *Brachythecium rivulare* 4 *Pohlia nutons* 2 *Plagionium undulatum* 2

Bryophyte cover 5%

Depth (cm)	Troels-Smith Components	Description
0 - 6	Th^3 Sh^1 Tl^+	Wet humified monocot rootlet peat
6 - 25	Th^2 Tl^1 Sh^1 Ag^+	Firmer rootlet peat with *Phragmites* and *Betula/alnus* wood
25 - 40	Th^2 Sh^2 Ag^+	Lighter monocot rootlet with *Phragmites*
40 - 50	Th^1 Tl^2 Sh^1 Ag^+	Similar to 25 - 40 but with large pieces of *Alnus* wood
55 - 60	Ag^1 Ga^1 Tl^1 Th^+ Sh^1	Becoming less organic
60 - 63	Ag^2 Ga^1 Sh^1 Th^+ Gg^+	Stony loamy grey clay with some *Phragmites* remains


A17a
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Beaulieu River
xhill Moor
Longwate
Drain
Row Hill
128
127
131
126
Tumulus
129
132
130
Path

ROW HILL BOG QUADRAT 126

Molinia - Erica tetralix - Carex echinata tussocks marginal to mire

Carex echuiata 5 *Cirsium dissectum* 3 *Drosera rotundifolia* 1
Erica tetralix 4 *Eriophorum* 5 *Juncus acutiflorus* 4 *Menyanthes* 2
Molinia 4 *Myrica* 3 *Narthecium* 2 *Phragmites* 1 *Potamogeton* 4
Scutellaria minor 1 *Calypogeia fissa* 2 *Cladopodiella fluitans* 2
Riccardia pinguis 2 *Sphagnum capillifolium* 1 *S.papillosum* 3
S.recurvum 2 *S.subnitens* 2

Sphagnum cover 10%

Depth (cm)	Troels-Smith Components	Description
0 - 47	Th^3 Sh^1 Tl^+	Wet poorly consolidated peat with *Phragmites* and other finer monocot roots
47 - 50	Th^2 Sh^1 Ag^1 Ga^+ Gg^+	Becoming less organic

ROW HILL BOG QUADRAT 127/131

Alder carr

Alnus 8 *Caltha palustris* 1 *Carex remota* 5 *C.paniculata* 3 *Frangula* 2 *Galium palustre* 2 *Ilex* 3 *Hedera* 3 *Juncus effusus* 1 *Lonicera* 2 *Lysimachia vulgaris* 2 *Mentha aquatica* 2 *Ranunculus repens* 1 *Salix cinerea* 4 *Rosa sp.* 1 *Viburnum opulus* 2 *Blechnum spicant* 2 *Dryopteris austriaca* 1 *Calypogeia fissa* 2 *Hypnum cupressiforme* 2 *Riccardia pinquis* 3 *Mnium harnum* 3 *Pellia epiphylla* 2

Bryophyte cover 5%

Depth (cm)	Troels-Smith Components	Description
0 - 10	Th^2 Sh^2 Tl^+ Ag^+	Humified wet peat with some *Alnus*
10 - 36	Th^2 Dl^1 Sh^1 Ag^+	Firmer peat with *Phragmites* and *Alnus* twigs at 30 - 35cm
36 - 56	Th^1 Tl^1 Sh^1 Ag^1 Ga^+ Gg^+	Becoming less organic and more humified
56 - 62	Sh^2 Ag^1 Ga^1 Th^+ Tl^+	Very humified black loamy clay with fine monocot root-lets and some wood
62 - 64	Ag^2 Sh^1 Ga^1 Th^+	Less organic but slightly more abundant monocot root-lets

ROW HILL BOG QUADRAT 128

Flushed zone marginal to carr

Betula pendula 1 *Caltha palustris* 1 *Carex echinata* 3 *C.panicea* 4 *Cirsium dissectum* 3 *Erica tetralix* 3 *Eriophorum* 3 *Galium palustre* 2 *Hydrocotyle vulgaris* 5 *Hypericum elodes* 5 *Juncus acutiflorus* 5 *Juncus articulatus* 3 *Juncus bulbosus* 5 *Mentha aquatica* 2 *Menyanthes* 2 *Molinia* 6 *Myrica* 5 *Potamogeton* 4 *Potentilla erecta* 3 *Ranunculus flammula* 1 *Salix cinerea* 1 *Scutellaria minor* 2 *Calypogeia fissa* 2 *Cephalozia connivens* 2 *Riccardia pinquis* 2 *Sphagnum papillosum* 5

Sphagnum cover 20%

Depth (cm)	Troels-Smith Components	Description
0 - 6	Tb^2 Th^1 Tl^1	*Sphagnum* - monocot - *Myrica* peat, very wet and poorly consolidated
6 - 15	Th^2 Tb^1 Sh^1 Ga^+	More compacted peat
15 - 40	Ag^1 Ga^1 Sh^1 Th^1 Gg^+	Humified loam with fine monocot rootlets and some gravel
40 - 48	Ag^1 Ga^1 Gs^1 Th^1 Sh^+	Grey-brown loamy sand
48 - 55	Gs^1 Ga^2 Ag^1 Th^+	Light green-grey loamy sand with less organic staining

ROW HILL BOG QUADRAT 129/132

Alder carr coppice

Alnus 8 *Betula pendula* 1 *Caltha palustris* *Carex paniculata* 2 *C.remota* 4 *Cirsium palustre* 1 *Digitalis purpurea* 1 *Epilobium montanum* 1 *Holcus lanatus* 1 *Frangula alnus*1 *Juncus effusus* 2 *Ilex* 3 *Glyceria fluitans* 1 *Lysimachia vulgaris* - *Mentha aquatica* 3 *Ranunculus flammula* 1 *R.repens* 3 *Ribes nigrum* 1 *Salix cinerea* 2 *Stellaria alsine* 1 *Viola riviniana* 1 *Lonicera* 2 *Athyrium felix-femina* 1 *Blechnum spicant* 1 *Dryopteris austriaca* 1 *Calliegon cuspidatum* 2 *Calypogeia fissa* 2 *Mnium hornum* 3

Bryophyte cover 5%

Depth (cm)	Troels-Smith Components	Description
0 - 50	Tl^1 Th^1 Ag^1 Ga^1	Uniform peaty soil with a well developed granular crumb structure. Some *Betula/Alnus* wood

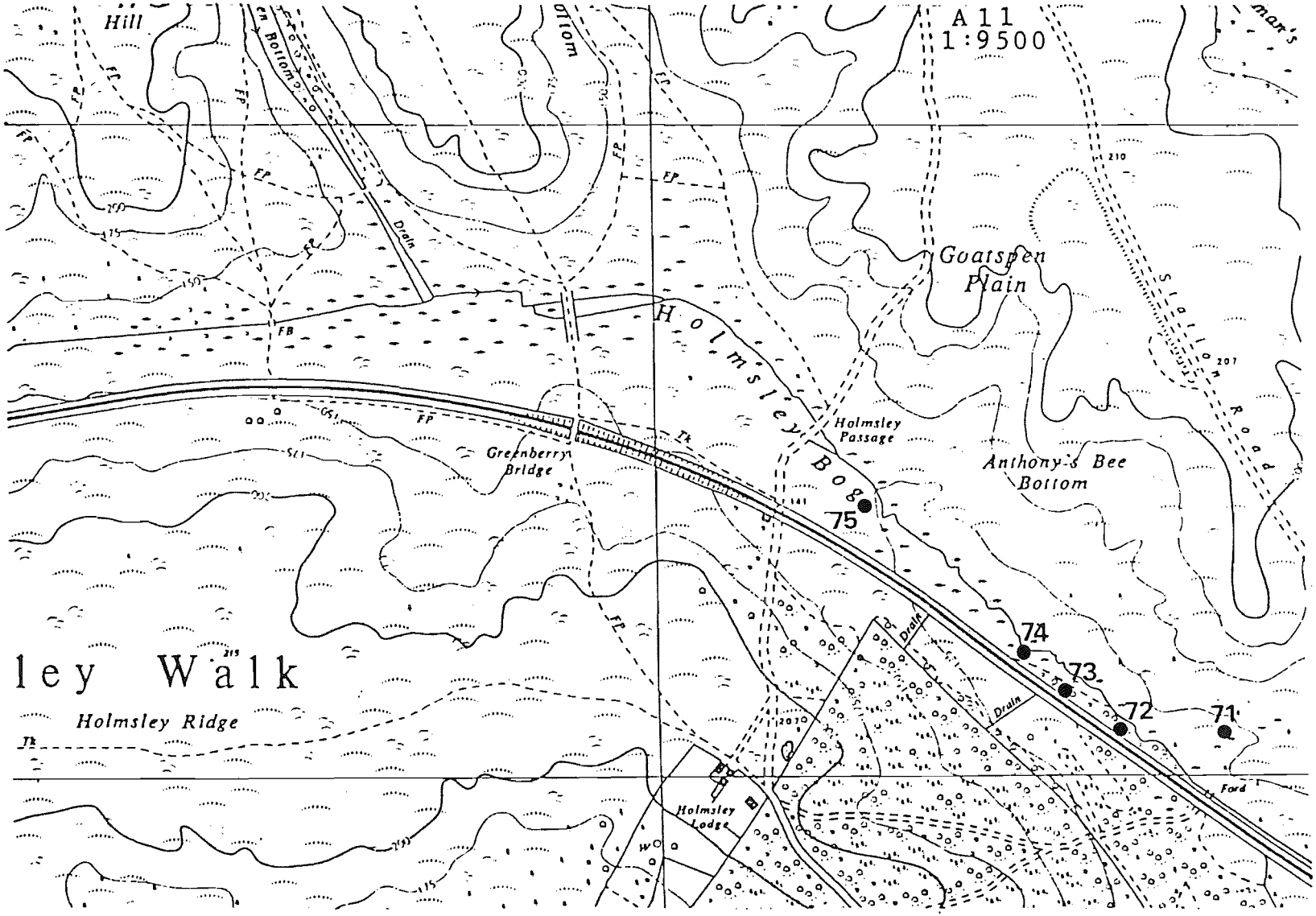
ROW HILL BOG QUADRAT 130

Rhynchospora dominated zone, peripheral to carr

Carex rostrata 1 *Drosera rotundifolia* 3 *Eleocharis* 1 *Erica tetralix* 5 *Eriophorum* 2 *Menyanthes* 1 *Molinia* 3 *Myrica* 1 *Narthecium* 4 *Phragmites* 1 *Potamogeton* 1 *Rhynchospora* 7 *Cladopodiella fluitans* 2 *Sphagnum auriculatum* 3 *S.cuspidatum* 1 *S.papillosum* 4 *S.recurvum* 2 *S.tenellum* 2

Sphagnum cover 30%

Depth (cm)	Troels-Smith Components	Description
0 - 46	Th^2 Tb^1 Sh^1	Wet unconsolidated monocot *Sphagnum* peat
46 - 49	Gs^2 Ga^1 Gg^1	Presumed Barton sand and gravel colluvium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Hill
Bottom
Drain
Holmsley Bog
Goatspen Plain
Holmsley Passage
Anthony's Bee Bottom
Greenberry Bridge
Holmsley Ridge
Holmsley Lodge
Ford
75
74
73
72
71
ley Walk

HOLMSLEY BOG QUADRAT 71

Rhynchospora alba dominated seepage zone

Calluna 1 *Cirsium dissectum* 1 *Drosera intermedia* 1 *D.rotundifolia* 2 *Eleocharis* 1 *Erica tetralix* 2 *Eriophorum* 3 *Menyanthes* 1 *Molinia* 4 *Myrica* 2 *Narthecium* 2 *Pinus* 1 *Potamogeton* 1 *Rhynchospora* 8 *Cephalozia macrostachya* 2 *Cladopodiella fluitans* 3 *Odontoschisma sphagni* 3 *Riccardia pinguis* 2 *Sphagnum auriculatum* 2 *S.papillosum* 8

Sphagnum cover 60%

Depth (cm)	Troels-Smith Components	Description
0 - 20		Unconsolidated - no sample
20 - 45	Th^2 Tb^1 Sh^1	Poorly consolidated peat dominated by monocot rootlets
45 - 50	Th^2 Tb^1 Sh^1 Ag^+	Becoming less organic
50 - 55	Ag^1 Ga^1 Sh^2 Th^+	Humified loamy clay with some monocot remains
55 - 80	Ga^1 Gs^3	Fluid grey loamy sand

HOLMSLEY BOG QUADRAT 72

Alder - Willow - Birch carr

Agrostis canina 3 *Alnus* 4 *Carex paniculata* 2 *Cirsium palustre* 1 *Galium palustre* 2 *G.uliginosum* 2 *Betula pubescens* 5 *Holcus lanatus* 4 *Juncus effusus* 1 *Frangula alnus* 1 *Ilex* 1 *Lychnis flos-cuculi* 1 *Lysimachia vulgaris* 1 *Mentha aquatica* 1 *Molinia* 3 *Salix cinerea* 5 *Equisetum palustre* 1 *Campylopus pyriformis* 2 *Cepholozia connivens* 2 *Cephalozia macrostachya* 2 *Hypnum cupressiforme* *Sphagnum palustre* 6 *S.recurvum* 7

Sphagnum cover 75%

Depth (cm)	Troels-Smith Composition	Description
0 - 20		Unconsolidated - no sample
20 - 50	Th^2 Dl^1 Sh^1	Granular peat with *Phragmites* and other finer monocot rootlets, and *Betula/Alnus* wood
50 - 66	Th^1 Sh^3 Ag^+ Ga^+	Stiff, highly humified peat with fine monocot rootlets
66 - 90	Tl^3 Sh^1 Th^+	Compacted peat with *Alnus* and *Molinia* rootlets

HOLMSLEY BOG QUADRAT 73

Carr margin

Betula pubescens 1 *Cirsium palustre* 1 *Erica tetralix* 2 *Juncus acutiflorus* 4 *Molinia* 9 *Myrica* 7 *Narthecium* 2 *Phragmites* 1 *Potentilla erecta* 1 *Salix cinerea* 1 *Equisetum palustre* 1

Sphagnum cover 0%

Depth (cm)	Troels-Smith Components	Description
0 - 25		Unconsolidated - no sample
25 - 45	Th^2 Sh^2 Ag^+	Monocot rootlet peat dominated by *Molinia* with some *Juncus* remains
45 - 50	Ag^1 Ga^2 Gg^1	Clayey silt with flint fragments

HOLMSLEY BOG QUADRAT 75

Wet open mire near stream

Carex rostrata 1 *Cirsium dissectum* 1 *Drosera rotundifolia* 1 *Eleocharis* 1 *Erica tetralix* 3 *Eriophorum* 4 *Juncus acutiflorus* 2 *Molinia* 8 *Myrica* 5 *Narthecium* 5 *Phragmites* 2 *Rhynchospora* 1 *Aulocomnium palustre* 1 *Calypogeia fissa* 2 *Cephalozia connivens* 2 *Cladopodiella fluitans* 1 *Hypnum ericetorum* 1 *Lepidozia setacea* 1 *Sphagnum papillosum* 6 *S.recurvum* 1

Sphagnum cover 30%

Depth (cm)	Troels-Smith Components	Description
0 - 15		Unconsolidated - no sample
15 - 50	Th^3 Sh^1	Monocot rootlet peat with *Molinia* and a little *Phragmites*
50 - 55	Th^2 Sh^1 Ag^1	Similar to 15-50 but with some clay
55 - 80	Th^3 Sh^1 Dl^+	Rootlet peat as above with some *Erica tetralix* stems and *Betula*(?) wood
80 - 95	Th^3 Sh^1 Dl^+	Pure fine monocot rootlet peat with some *Betula* wood
95 - 100	Ag^1 Ga^1 Sh^2 Th^+ Tl^+	Humified loamy peat with *Molinia* rootlets, *Phragmites* rhizomes and *Betula* wood

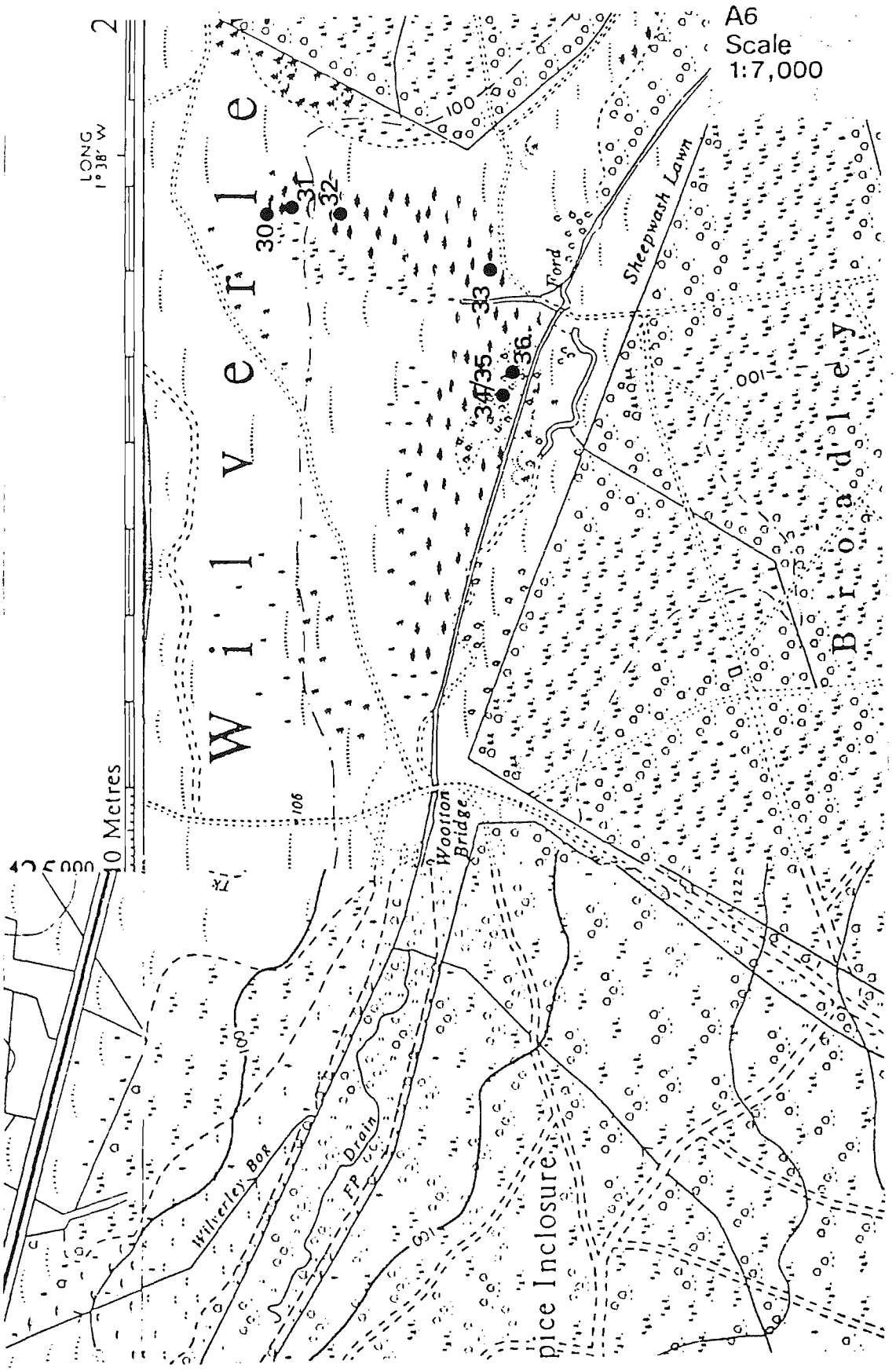
HOLMSLEY BOG QUADRAT 74

Open mire expanse

Carex paniculata 1 *C.rostata* 3 *Erica tetralix* 4 *Eriophorum* 1
Juncus acutiflorus 4 *Molinia* 9 *Myrica* 5 *Narthecium* 3 *Phragmites* 1
Potentilla erecta 1 *Calypogeia fissa* 2 *Cephalozia macrostachya* 1
Hypnum ericetorum 2 *Lepidozia setacea* 1 *Sphagnum auriculatum* 3
S.cuspidatum 2 *S.palustre* 4 *S.papillosum* 4 *S.recurvum* 2
S.subnitens 2

Sphagnum cover 20%

Depth (cm)	Troels-Smith Components	Description
0 - 22		Unconsolidated - no sample
22 - 60	Th^3 Sh^1 Dh^+	Poorly consolidated peat dominated by *Molinia* and *Eriophorum* with a little *Phragmites*
60 - 70	Th^2 Dh^1 Sh^1	*Molinia* dominated peat
70 - 80	Th^2 Tl^1 Sh^1	*Molinia* rootlet peat with some wood *(Alnus?)*
80 - 90	Ag^2 Ga^1 Sh^1 Th^+ Tl^+	Loamy clay with some monocot rootlets and wood (*Alnus*?)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Willerley
Broadley
Sheepwash Lawn
Ford
Wootton Bridge
Wilherley Bog
FP
Drain
pice Inclosure
30
31
32
33
34/35
36
100
106
10 Metres

WILVERLEY BOG (EAST) QUADRAT 30

Flushed seepage zone in side-arm

Anagallis tenella 2 *Carex echinata* 2 *C.panicea* 4 *Cirsium dissectum* 3 *Drosera intermedia* 1 *D.rotundifolia* 1 *Eleocharis* 2 *Eriophorum* 6 *Hypericum elodes* 4 *Juncus acutiflorus* 4 *J.bulbosus* 3 *Molinia* 2 *Myrica* 2 *Pedicularis palustris* 5 *Potamogeton* 8 *Ranunculus flammula* 2 *Salix cinerea* 1 *Sphagnum auriculatum* 1

Sphagnum cover 0%

Depth (cm)	Troels-Smith Components	Description
0 - 16	Th^3 Sh^1 Dh^+	Fine monocot rootlet peat with *Juncus* stems
16 - 27	Ag^2 Sh^2 Th^+	Humified and clayey peat
27 - 73	Ag^1 Th^1 Sh^2	Humified monocot peat but less inorganic sediment
73 - 90	Ag^1 Ga^1 Th^1 Sh^1	Grading into basal sediments
90 - 100	Ag^1 Ga^1 Sh^2 Th^+ Gg^+	Humified stony loam with monocot rootlets

WILVERLEY BOG (EAST) QUADRAT 31

Mire expanse in side-arm

Carex echinata 5 *C.panicea* 1 *Cirsium dissectum* 3 *Dactylorhiza incarnata* 1 *Erica tetralix* 4 *Eriophorum* 5 *Juncus acutiflorus* 6 *Molinia* 8 *Myrica* 2 *Narthecium* 1 *Potentilla erecta* 2 *Salix cinerea* 1 *Scutellaria minor* 1 *Aulocomnium palustre* 3 *Calliergon stramineum* 1 *Calypogeia fissa* 3 *Sphagnum auriculatum* 4 *S.subnitens* 6

Sphagnum cover 35%

Depth (cm)	Troels-Smith Components	Description
0 - 15		Unconsolidated - no sample
15 - 25	Ag^2 Sh^2 Th^+	Humified clayey peat
25 - 65	Ag^2 Sh^1 Th^1	Humified clayey peat with more abundant monocot rootlets

WILVERLEY BOG (EAST) QUADRAT 32

Sphagnum lawn with schwingmoor effect (probable peat cutting)

Anagallis tenella 2 *Cirsium dissectum* 5 *Drosera rotundifolia* 3 *Eleocharis* 4 *Erica tetralix* 6 *Eriophorum angustifolium* 5 *Molinia* 5 *Myrica* 4 *Narthecium* 4 *Potamogeton* 1 *Rhynchospora* 5 *Cephalozia macrostachya* 4 *Cladopodiella fluitans* 3 *Lepidozia setacea* 4 *Odontoschisma sphagni* 1 *Riccardia pinguis* 2 *Sphagnum papillosum* 8 *S.magellanicum* 6 *S.subnitens* 2

Sphagnum cover 90%

Depth (cm)	Troels-Smith Components	Description
0 - 65		Vegetation mat over highly fluid peat with stony sediment below. No sample

WILVERLEY BOG (EAST) QUADRAT 33

Tussocky *Molinia* - *Myrica*

Calluna vulgaris 1 *Carex echinata* 3 *Erica tetralix* 5 *Juncus acutiflorus* 4 *J.effusus* 1 *Molinia* 9 *Myrica* 8 *Aulocomnium palustre* 3 *Calliergon stramineum* 1 *Calypogeia fissa* 2 *Cephalozia connivens* 2 *Hyprum jutlandicum* 1 *Odontoschisma sphagni* 2 *Sphagnum palustre* 1 *S.papillosum* 2 *S.recurvum* 8

Sphagnum cover 60%

Depth (cm)	Troels-Smith Components	Description
0 - 15	Th^3 Tl^1	Surface mat of roots, no peat preserved, with gravelly sediment below

WILVERLEY BOG (EAST) QUADRAT 34/35

Birch - willow - alder - oak woodland

Agrostis canina 5 *Alnus* 2 *Betula pubescens* 5 *Juncus acutiflorus* 4 *Fagus* 1 *Frangula alnus* 2 *Molinia* 4 *Myrica* 3 *Quercus robur* 4 *Salix cinerea* 5 *Taxus* 2 *Ilex* 5 *Lonicera* 3 *Blechnum spicant* 1 *Dryopteris austriaca* 2 *Osmunda* 1 *Polytrichum commune* 1 *Sphagnum palustre* 4 *S.recurvum* 9

Sphagnum cover 80%

Depth (cm)	Troels-Smith Components	Description
0 - 13		Unconsolidated - no sample
13 - 27	Th^2 Tb^1 Sh^1 Dl^+	Monocot rootlets and *Sphagnum* peat with *Myrica* and *Betula* wood
27 - 82	Th^2 Tb^1 Sh^1 Dl^+	Similar to above but more compacted and becoming more decomposed towards base. *Betula* twig found at 48cm

WILVERLEY BOG (EAST) QUADRAT 36

Birch - alder woodland

Agrostis canina 3 *Alnus* 3 *Betula pubescens* 2 *Carex paniculata* 3 *Hydrocotyle vulgaris* - *Fagus* 1 *Frangula alnus* 2 *Lysimachia vulgaris* 8 *Molinia* 4 *Quercus robus* 2 *Dryopteris austriaca* 2 *Calypogeia fissa* 2 *Sphagnum recurvum* 8 *S.palustre* 4

Sphagnum cover 75%

Depth (cm)	Troels-Smith Components	Description
0 - 15		Unconsolidated - no sample
15 - 20	Th^2 Tb^1 Sh^1 Dl^+	Fine monocot rootlets with *Sphagnum* and *Alnus* wood
20 - 75	Sh^2 Th^1 Tl^1 Tb^+	Monocot rootlets with *Phragmites* rhizomes and *Alnus*. More humified

WILVERLEY BOG (WEST) QUADRAT 160

Species - poor *Phragmites*

Calluna 1 *Erica tetralix* 5 *Juncus acutiflorus* 4 *Molinia* 8
Myrica 6 *Phragmites* 8 *Calypogeia fissa* 2 *Sphagnum palustre* 5
S.subnitens 1

Sphagnum cover 10%

Depth (cm)	Troels-Smith Components	Description
0 - 40		Very fluid peat - no sample
40 - 60	Th^2 Sh^1 Ag^1 Ga^+ Gg^+	Clayey, humified peat with *Molinia* rootlets and *Phragmites* rhizomes

WILVERLEY BOG (WEST) QUADRAT 161

Phragmites - *Molinia* with wet hollows

Carex echinata 3 *C.panicea* 3 *C.lasiocarpa* 7 *C.rostrata* 2
Eleocharis 1 *Eriophorum* 4 *Menyanthes* 5 *Molinia* 2 *Myrica* 1
Narthecium 1 *Pedicularis sylvatica* 4 *Phragmites* 7 *Potamogeton* 7
Utricularia minor 1 *Cephalozia connivens* 3 *C.macrostachya* 3
Lepidozia setacea 2 *Odontoschisma sphagni* 2 *Riccardia multifida* 2

Sphagnum cover 0%

Depth (cm)	Troels-Smith Components	Description
0 - 25	Th^3 Sh^1	Highly fibrous monocot peat
25 - 45	Th^2 Sh^2	More humified monocot rootlet peat
45 - 50	Sh^2 Th^1 Ag^1	Clayey, humified peat

WILVERLEY BOG (WEST) QUADRAT 163

Molinia tussock - *Sphagnum* lawn

Calluna 3 *Drosera rotundifolia* 4 *Eleocharis* 2 *Erica tetralix* 6 *Eriophorum* 6 *Molinia* 8 *Myrica* 7 *Narthecium* 3 *Cephalozia connivens* 3 *C.macrostachya* 4 *Hypnum ericetorum* 3 *Lepidozia setacea* 4 *Odontoschisma sphagni* 4 *Sphagnum palustre* 2 *S.papillosum* 8 *S.recurvum* 4 *S.tenellum* 2

Sphagnum cover 50%

Depth (cm)	Troels-Smith Components	Description
0 - 20		Unconsolidated - no sample
20 - 35	Th^2 Tb^1 Sh^1 Dl^+	Fluid monocot rootlet peat with *Sphagnum*, *Erica tetralix* and *Myrica*.
35 - 45	Th^2 Sh^1 Ag^1	Becoming inorganic
45 - 50	Ag^2 Ga^2 Gg^+ Th^+	Stony loam with some fine rootlets

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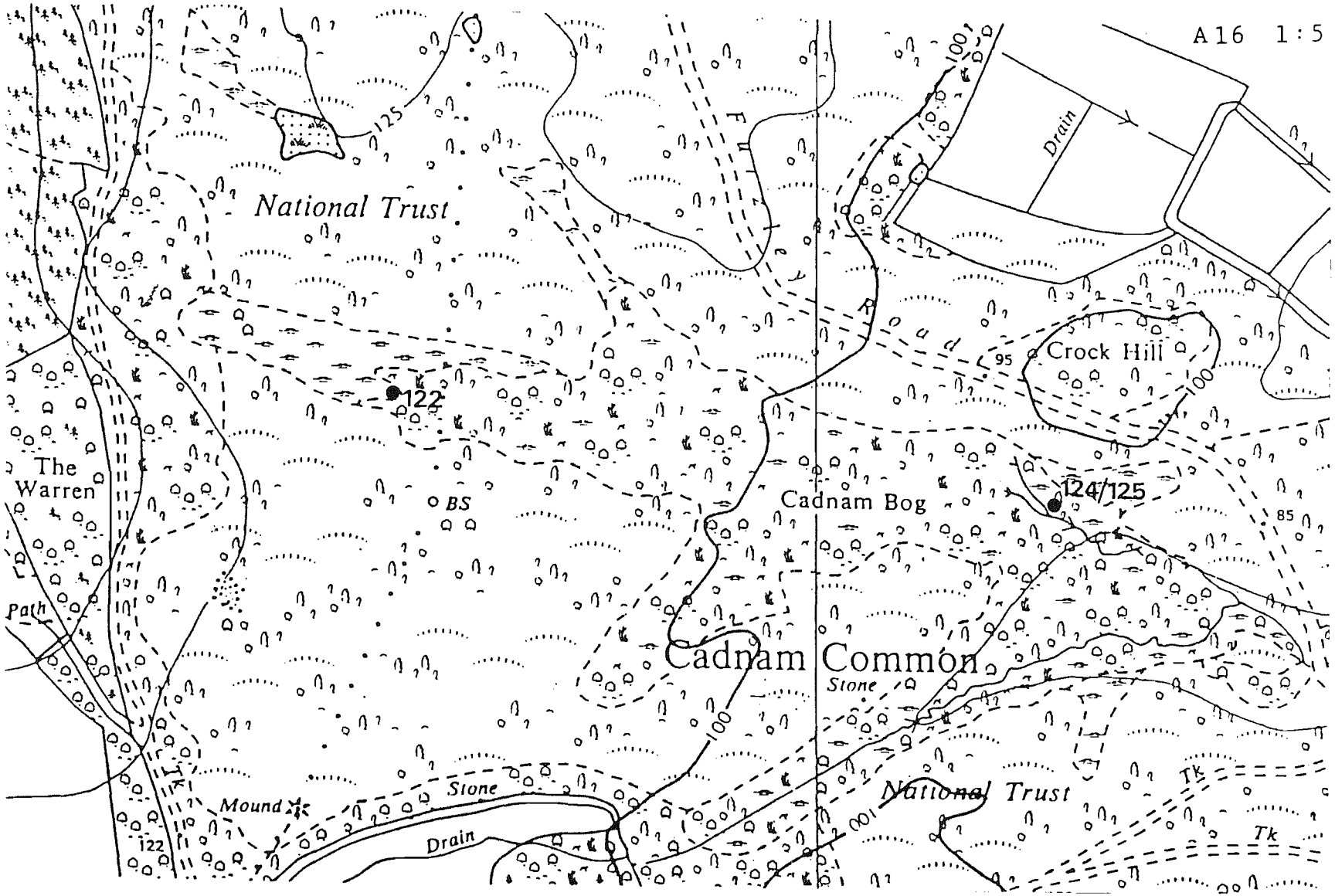

National Trust
125
122
BS
The Warren
Path
Mound
Stone
Drain
Cadnam Bog
Cadnam Common
Stone
National Trust
Tk
Tk
Drain
Crock Hill
95
100
85
124/125

CADNAM BOG QUADRAT 122

Molinia - *Sphagnum* hummocks on schwingmoor-like area

Carex nigra 5 *Drosera rotundifolia* 2 *Erica tetralix* 3
Eriophorum 4 *Juncus acutiflorus* 4 *J.bulbosus* 1 *Molinia* 6
Narthecium 1 *Cladopodiella fluitans* 4 *Sphagnum cuspidatum* 2
S.palustre 6 *S.papillosum* 4 *S.recurvum* 3

Sphagnum cover 60%

Depth (cm)	Troels-Smith Components	Description
0 - 28		Unconsolidated - no sample
28 - 37	Th^2 Tb^1 Sh^1 Dl^+	Fluid peat dominated by rootlets with *Sphagnum* and *Erica tetralix*
37 - 45	Ag^1 Ga^1 Th^1 Sh^1 Gg^+	Humified peaty loam with rootlets
45 - 50	Ag^3 Ga^1 Gg^+ Th^+	Unconsolidated wet clay with gravel

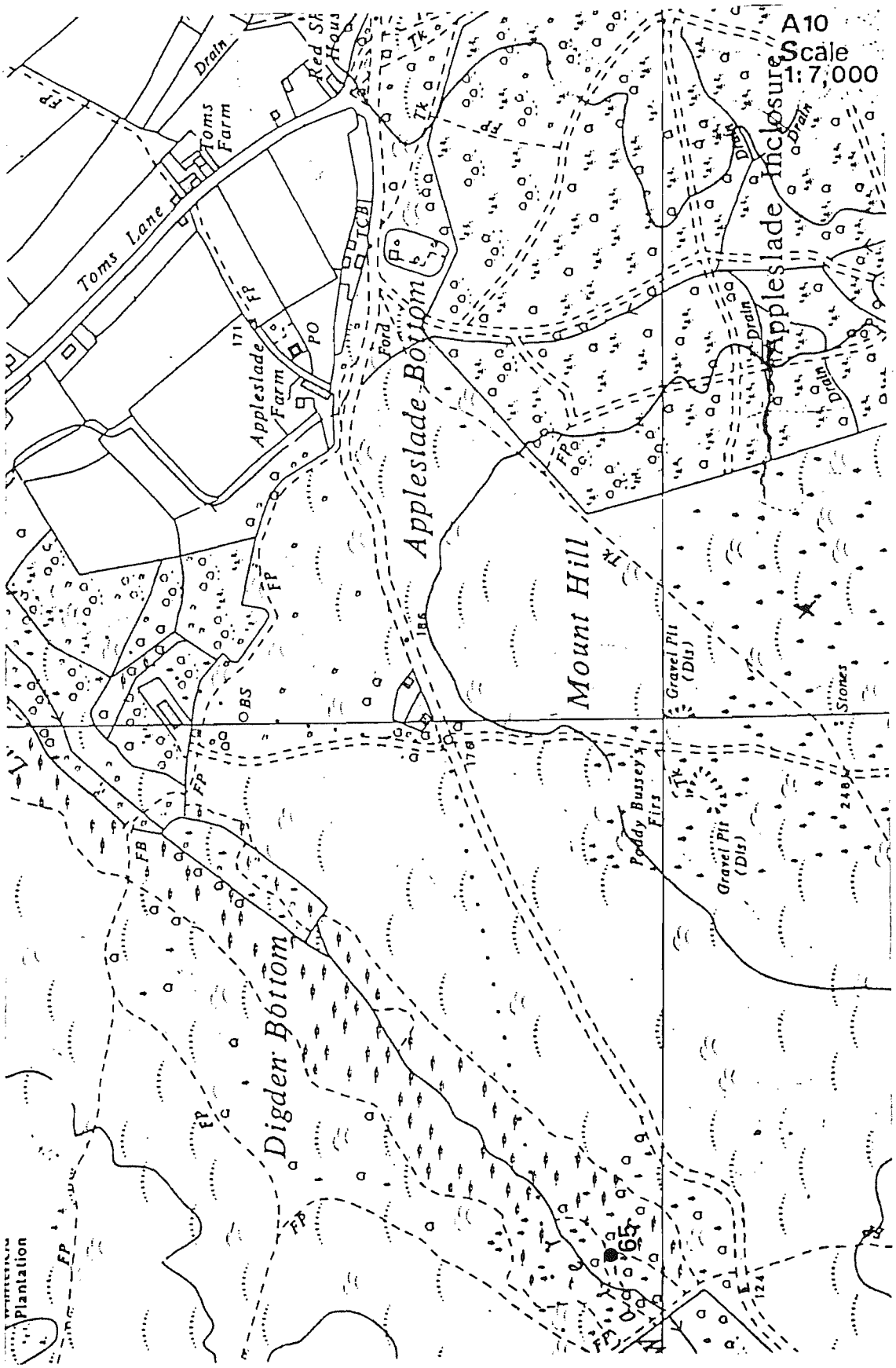
CADNAM BOG QUADRAT 124/125

Betula - Salix - Frangula - Alnus carr

Agrostis canina 6 *Alnus* 1 *Betula pendula* 5 *Betula pubescens* 6 *Juncus acutiflorus* 1 *J.effusus* 2 *Frangula* 5 *Lonicera* 3 *Ilex* 3 *Molinia* 3 *Myrica* 2 *Quercus robur* 1 *Rubus* 2 *Salix cinerea* 6 *Sorbus aucuparia* 2 *Dryopteris austriaca* 2 *Lepidozia setacea* 2 *Polytrichum commune* 2 *Sphagnum recurvum* 7

Sphagnum cover 40%

Depth (cm)	Troels-Smith Components	Description
0 - 3	Ag^2 Th^1 Sh^1 Ga^+	Stony, peaty clay with fine rootlets
3 - 6	Ag^3 Sh^1 Th^+ Tl^+ Ga^+	Becoming less organic with some wood fragments
6 - 15	Ag^4 Th^+ Ga^+	Clay
15 - 46	Sh^3 Tl^1 Ag^+	Highly consolidated and humified wood peat. 20cm - charcoal. 37cm - thin sandy horizon.
46 - 50	Tl^3 Sh^1	*Alnus* wood
50 - 68	Th^1 Tl^1 Sh^2 Ag^+	Monocot rootlet peat (*Carex*?) with wood (*Betula*?)
68 - 80	Tl^4	Wood (*Betula*? roots)
80 - 120	Tl^3 Sh^1	Wet unconsolidated granular wood peat, becoming very wet at base
150 - 190	Ag^2 Ga^1 Gg^1 Gs^+	Blue-grey sticky clay with sand and gravel
190 - 215	Ga^1 Gs^2 Gg^1	Coarse unconsolidated sand


A10
Scale
1:7,000
Toms Lane
Toms Farm
Appleslade Farm
Appleslade Bottom
Mount Hill
Appleslade Inclosure
Digden Bottom
Poddy Bussey's Firs
Gravel Pit (Dis)
Gravel Pit (Dis)
Stones
Drain
Ford
Plantation

DIGDEN BOTTOM QUADRAT 65

Flushed area near stream (incised)

Agrostis canina 5 *Carex echinata* 3 *Drosera rotundifolia* 1 *Erica tetralix* 2 *Eriophorum* 3 *Hydrocotyle vulgaris* 5 *Juncus acutiflorus* 4 *J.bulbosus* 6 *J.effusus* 2 *Lotus uliginosus* 3 *Molinia* 4 *Myrica* 3 *Ranunculus flammula* 3 *Sphagnum auriculatum* 7 *S.cuspidatum* 2 *S.recurvum* 5

Sphagnum cover 50%

Depth (cm)	Troels-Smith Components	Description
0 - 25	Th^2 Sh^2 Tb^+ Tl^+ Ag^+	Monocot rootlets with *Erica* wood
25 - 45	Th^1 Sh^2 Ag^1	Humified rootlet peat with clay
45 - 50	Ag^1 Ga^1 Gs^2 Sh^+ Th^+	Loamy sand with some rootlets