SCOTTISH NATURAL HERITAGE

Bogs: The Ecology, Classification and Conservation of Ombrotrophic Mires

Bogs: The Ecology, Classification and Conservation of Ombrotrophic Mires

Richard Lindsay Scottish Natural Heritage

CONTENTS **PAGE**

Foreword		**2**
Acknowledgements		**3**
Preface		**4**
List of Figures		**5**
Part I: An Ecological Background		**7**
Section 1	**Introduction**	**8**
Section 2	**Characteristics of the Bog Habitat**	**10**
Part II: Classification and Typology of Bogs in Great Britain		**21**
Section 3	**Hierarchy of Bog Features and Vegetation in Britain**	**22**
Section 4	**Bog Types in Britain**	**38**
Section 5	**Definitions and Sub-Categories of Raised Bog**	**40**
Section 6	**Definitions and Sub-Categories of Blanket Bog**	**44**
Section 7	**Ridge-Raised/Intermediate Bog or Semi-Confined Raised Bog**	**53**
Part III: Value, Condition and Conservation of Bog Systems		**57**
Section 8	**Natural Heritage Value of Peat Bog Systems**	**58**
Section 9	**International Legislation, Conventions and Designations of Relevance to Peat Bog Systems**	**66**
Section 10	**The Nature Conservation Condition of Peat Bog Systems**	**69**
Section 11	**The Definition of Condition Classes**	**70**
Section 12	**Hydrological Implications of Habitat Change**	**95**
Section 13	**Original Extent and Distribution of Bog Types**	**103**
Section 14	**The Pattern of Land-Use Change and Habitat Loss in Britain and Europe**	**108**
References		**113**

Foreword

Peat - what images do peatlands conjure up for you? One dictionary definition of peat is 'the plant remains of bog and fen vegetation. The wetness of the substrate leads to anaerobic acid conditions, which inhibit the micro-organisms of decay...' - this is technically correct, but hardly very stimulating in conjuring an image! One popular view is that peat is an important and precious natural resource, teeming with wildlife, and needing to be conserved. A very different view is that peat is a resource that is ripe for exploitation, and should be used for horticulture, for fuel or even medicinally. Perhaps the reality is somewhere between these extreme views. Peat is a resource that is very slowly renewable, and hence there may be scope for some harvesting. However, peat is also a resource on which much of Britain's wildlife depends, and which is intimately linked into the major environmental interactions of our planet such as our changing climate.

This report is designed to provide staff in the country conservation agencies (the countryside Council for Wales, English Nature and Scottish Natural Heritage, together with the Joint Nature Conservation Committee) with a summary of scientific thinking and technical information about peat bog ecosystems. It can be used in conjunction with the recently revised Peat Bogs chapter in the 'Guidelines for the Selection of Biological SSSIs', although it is not an annex to those guidelines. It is therefore a source of information which should, for instance, prove useful when preparing site citations, drawing up management plans, preparing cases for site protection, and for a range of other activities where some additional explanation or technical back up can be of assistance.

The document has been written by Richard Lindsay, a member of the Uplands and Peatlands Branch of Scottish Natural Heritage. It is, therefore, his personal view of published studies and current thinking about mire ecology, a subject on which it is difficult to obtain a consensus. The draft report was circulated to several referees, and I acknowledge with gratitude the contributions that they have made. However, this published report represents Richard Lindsay's views, founded on his experiences over nearly two decades of work.

Perhaps the word 'sustainable' comes to mind when thinking of peatlands. We have here a very slowly renewing resource, and if we are to conserve it for future generations we cannot continue to exploit it faster than it renews itself. Peatlands are systems that change over time, both in their vegetation composition with its associated fauns, as well as in their wetness and the types of pools that exist on the surface of the peatland. We need to understand the concepts of sustainability in relation to this dynamic resource before we exploit all of it.

We in Scottish Natural Heritage are pleased to publish this report, which we hope will be of value to our colleagues in CCW, EN and JNCC, as well as to the wider community of people interested in peat and peatlands.

Michael B Usher
Chief Scientific Adviser
Scottish Natural Heritage
January 1995

Acknowledgements

A great many people have assisted in the production of this technical report and provided, in a variety of ways, valuable guidance throughout the process. Special thanks are due to my colleagues in the Uplands and Peatlands Branch of RASD, namely Philip Immirzi, Des Thompson, Eliane Reid, Sarah Ross, Stuart Gillies and Marc Duncan, in helping with the collation and analysis of data, providing valuable ideas, comments, criticisms and suggestions, and assisting in the production process. Many colleagues in SNH provided helpful comments or guidance, but particular thanks are due to Andrew Coupar, Nigel Smith and Michael Usher. Staff from other country conservation agencies were generous in their assistance, and particular thanks are due to Brian Johnson, Wanda Fojt, Rick Keymer and Frank Mawby from English Nature, Tim Blackstock from Countryside Council for Wales, and John Faulkner, Joe Furphy and Paul Corbett from Department of Environment (Northern Ireland). A review such as this inevitably relies heavily on help from colleagues in the Library Services, and I am grateful for their constant support and continued assistance. Thanks to colleagues in Publications section.

Thanks are also due to a number of mire specialists working outside the conservation agencies for their very valuable criticisms of the scientific content of this report. Peter Moore and Michael Proctor in particular devoted a considerable amount of time to providing valuable insights and helpful criticism of early drafts, and generous guidance has also been given by colleagues of the International Mire Conservation Group (IMCG) on various aspects, particularly by Michael Steiner, Marina Botch, Philippe Julve, Bent Åaby, Asbjørn Moen, Klaus Dierssen and Hans Joosten. I would also wish to extend a very grateful thanks to the academic referees of this document: John Tallis, David Sugden, Barry Wyatt, Malcolm Ogilvie and Bryan Wheeler. Their careful reading of the text and helpful suggestions for alteration and improvement have significantly enhanced both content and readability of the final document. I should also like to extend a special thanks, firstly to my former colleagues John Riggall and Fiona Burd for all their help and companionship in some pretty wild places over several years, and finally to David Goode and Derek Ratcliffe, both of whom taught me so much, with such generosity and kindness, during my early years with the Nature Conservancy Council as a peatland specialist - in many ways I am still learning from them and from what they taught me.

Preface

For many countries in the northern Boreal zone, peatlands now represent one of the most extensive, near-natural ecosystems. However, like that other great natural resource, the marine environment, current understanding of the scientific processes and conservation needs of the peatland environment is still only in its infancy. We still do not know how many sheep can graze sustainably on a bog, or how to judge fire cycles; we cannot measure water flow through the 'active' surface layer of a bog in the field; and we do not even know if erosion, one of the commonest features of a blanket bog landscape and a phenomenon which removes large quantities of material into watercourses, is natural or the result of land-use practices.
A complete review of all that is known, and all that is not known, about the peatland environment is beyond the scope of this publication, the focus of which has therefore been directed towards some of the more basic issues which underpin practical conservation action. The result is not a fully objective scientific treatise but instead a personal review of some of the most important scientific elements which might play an important part in the successful implementation of peatland conservation objectives.

List of Figures

Page

Figure 1	Profile of a confined raised bog.	13
Figure 2	Characteristics of a blanket mire complex.	14
Figure 3	Generalised sequence of raised bog development.	15
Figure 4	(a) Profile of the water table in mineral soil between two drains.	17
	(b) Profile of the water body of a raised bog.	17
Figure 5	The simple Groundwater Mound Model.	18
Figure 6	The hierarchy of features used by the country conservation agencies to classify bog systems.	23
Figure 7	Distribution and general structure of extreme bog surface patterns.	25
Figure 8	General distribution of structural features (microforms).	27
Figure 9	(a) Hierarchy of microtope and vegetation stands - Terrestrial.	31
	(b) Hierarchy of microtope and vegetation stands - Aquatic.	32
Figure 10	Hierarchy of bog types.	39
Figure 11	The main types of raised bog.	42
Figure 12	The hydromorphological and topographical characteristics of blanket bog.	47
Figure 13	The hydromorphological and topographical characteristics of eccentric bog.	51
Figure 14	The hydromorphological and topographical characteristics of ridge-raised/intermediate bog.	55
Figure 15	Predominant bog types in western Europe.	63
Figure 16	Characteristic species in the vegetation communities of ombrotrophic peat bogs in western Europe.	64
Figure 17	World distribution of blanket bog.	65
Figure 18	A summary of the general conditions in which bogs may be found in Great Britain.	
	(a) Natural primary bog.	72
	(b) Moribund primary bog.	73
	(c) Primary micro-erosion.	74
	(d) Drained primary bog.	74
	(e) Primary gully/slab erosion.	74
	(f) Wooded primary bog.	75
	(g) Active secondary bog.	76
	(h) Active secondary erosion complex.	76
	(i) Moribund secondary bog.	77
	(j) Secondary sheet erosion.	77
	(k) Archaic peat deposit.	78
Figure 19	Typical pattern of land-use conditions on a raised bog.	94
Figure 20	Changes in the groundwater mound of mineral and peat soils as a result of drainage or peat removal.	97
Figure 21	Three-dimensional groundwater mounds.	98
Figure 22	Changes in the surface and vegetation of an ombrotrophic mire with lowering of the water table.	100
Figure 23	The effect of drainage in the water table in the acrotelm.	101
Figure 24	Total area of deep peat soils for Great Britain.	104
Figure 25	The distribution of deep peat soils recorded in the NPRI for Great Britain.	105
Figure 26	The distribution of soils derived from former or existing raised bog habitat in Great Britain.	106
Figure 27	The distribution of soils derived from former or existing raised bog habitat in Great Britain (expressed as sized circles).	107
Figure 28	Number of raised bog sites classified according to their major land use.	109
Figure 29	(a) Estimated present area of primary raised bogs (expressed as sized circles).	110
	(b) Proportion of the original extent of raised bog habitat which remains either in a natural or degraded condition.	110

List of Plates

Page

Plate 1	Carpet of *Sphagnum* mosses.	33
Plate 2	Individual stem of *Sphagnum capillifolium.*	33
Plate 3	The characteristic appearance of a peatland site from the air.	33
Plate 4	Flying over the crown of a pool-dominated bog.	34
Plate 5	Surface patterns - *Sphagnum* hollows.	34
Plate 6	Surface patterns - mud-bottom hollows	34
Plate 7	Surface patterns - open water pools	35
Plate 8	Small-scale surface features - microtopography.	35
Plate 9	Typical lowland raised bog.	36
Plate 10	Typical raised bog vegetation.	36
Plate 11	Typical blanket bog landscape.	36
Plate 12	Typical north-western blanket bog vegetation.	36
Plate 13	Eccentric mire.	81
Plate 14	Intermediate or semi-confined bog.	81
Plate 15	Primary natural bog - aerial view.	82
Plate 16	Primary natural bog - ground view.	82
Plate 17	Primary moribund bog (burning).	83
Plate 18	Primary moribund bog (burning - detail).	83
Plate 19	Primary moribund bog (drying).	83
Plate 20	Primary moribund bog (drying - detail).	83
Plate 21	Primary micro-erosion - aerial view.	84
Plate 22	Primary micro-erosion - ground view.	84
Plate 23	Primary drained bog - aerial view.	85
Plate 24	Primary drained bog - ground view.	85
Plate 25	Primary eroding bog - deep gullies.	85
Plate 26	Primary wooded/active bog - aerial view.	86
Plate 27	Primary wooded/active bog - ground view.	86
Plate 28	Primary wooded/moribund bog - aerial view.	87
Plate 29	Primary wooded/moribund bog - ground view.	87
Plate 30	Secondary re-vegetating bog - aerial view of domestic peat cuttings.	88
Plate 31	Secondary re-vegetating bog - ground view of domestic peat cuttings.	88
Plate 32	Secondary re-vegetating bog - aerial view of commercial peat cuttings.	88
Plate 33	Secondary re-vegetating erosion.	89
Plate 34	Secondary moribund bog - block cutting - aerial view.	89
Plate 35	Secondary moribund bog - block cutting - ground view.	89
Plate 36	Secondary moribund bog - surface milling - ground view.	90
Plate 37	Secondary moribund bog - surface milling - aerial view.	90
Plate 38	Secondary moribund bog - sheet erosion.	91
Plate 39	Archaic agricultural deposits.	91
Plate 40	Drainage - a fresh drain.	92
Plate 41	Drainage - an old drain.	92
Plate 42	Opencast mining.	92

Part I: An Ecological Background

Part I: An Ecological Background

Section 1 Introduction

A *mire* is a wetland that supports a vegetation which is normally peat-forming. An *ombrotrophic* mire is so called because the wetland conditions, and also its nutrient supply, are derived from direct atmospheric precipitation alone (*Gk. ombros* = a storm of rain, *trophos* = feeder, nurse). In Britain such rain-fed mires have traditionally and colloquially been termed *bogs*.

This contrasts with *fens*, which receive at least some of their water and nutrients from the mineral groundwater table of the surrounding landscape and were thus termed *geogenous* (*Gk. genow* = to be born) by Sjörs (1948), although *geotrophic* (i.e. fed by the earth, rather than the sky) may strictly be more accurate. Such groundwater-fed sites are also termed *minerotrophic*. Confusingly, the term 'bog' is also commonly used for some fen types, particularly those which are generally solute poor, with low productivity and low rates of water flow (e.g. valley bogs).

Bogs, because they receive nutrients only from precipitation, are *oligotrophic* (poorly fed). As a result, they are also often very acidic environments. Their acidity is a direct consequence of the extreme oligotrophic nature of the bog waters (see Section 2). Indeed, ombrotrophic bogs represent one of the most nutrient-poor and acidic environments in the British natural landscape.

One of the unusual features of bog (and some fen) systems is the fact that a record of a site's development is preserved within the peat archive. This makes it possible to identify the various stages of development which, in many cases, extend back over many thousands of years. From this preserved record it is possible to determine whether a site was formerly geotrophic and subsequently became ombrotrophic, or whether the site developed by direct *paludification* (development of a peat layer) over the mineral ground.

Godwin (1981, Plate 5) presents a photograph of a rock on which a tiny blanket bog has developed, clearly without any significant preceding fen stage. This he identifies as 'the perfect demonstration of an ombrogenous (rain fed) (*sic*) mire'. In other cases it is very clear from the stratigraphic record that a site which is now ombrotrophic was, in former times, a geotrophic fen. The term *ombrogenous* is often incorrectly used as synonymous with *ombrotrophic*. The former refers to the conditions which originally gave rise to, and continue to maintain, the bog unit, whereas the latter describes only the present trophic status of the living surface. This may appear to be a rather fine, semantic point but the two words do relate to different processes. Both types, bog and fen, are entirely dependent upon waterlogging, either sustained or intermittent, for their development and maintenance. Where waterlogging results from flowing water, an additional term *rheotrophic* has been coined to distinguish these mires from the more stagnant (or at least very slow water movement) of other mire systems, including ombrotrophic bogs.

Bogs are specialised environments of entirely vegetable origin created by the steady growth of vegetation communities (generally dominated by *Sphagnum* bog mosses, Plates 1 and 2) and the accumulation of their remains as peat over several millennia. Much the same can be said for many fens, but the proportion of inorganic matter bound up in fen peats is generally much higher than that found in bog peat. In Britain, at least, the majority of bog systems can be shown to have been accumulating peat for somewhere between 3000 and 9000 years, although it is possible to point to many sites where bog conditions appear to have developed much more recently, or indeed are only now becoming established.

Many people not familiar with the bog environment find that they have difficulty

distinguishing, as a discrete entity, the bog and its particular characteristics from the general upland scene of mountain and moorland, or from 'popular' images of foul and hazardous swamplands. This confusion is compounded by the fact that the bog habitat as a whole, and the surface environment in particular, is in marked contrast to other habitats where a biotic element normally overlies a mineral soil base and the living vegetation interacts directly with this mineral base.

It is sometimes helpful to make use of an analogy which helps at least the bare bones of the picture to be grasped. Given the important caveat that no analogy is ideal, it is nevertheless possible to suggest that a useful picture of a peat bog can be obtained if it is thought of as a form of compressed, long-lived tree. A bog has a great mass of formerly living but now-dead plant tissue (the peat) which provides gross shape, structure and hydrological functions, much as do the trunk and branches of a tree. Forming an outer protective layer, equivalent to both bark and leaves on a tree, is a mat of mosses and higher plants which rely for their full expression on being completely independent from underlying soils or bedrock. The leaves of a tree are isolated from the mineral ground by trunk and branches, whereas in a bog this separation is provided by the considerable quantity of dead plant material, built up over several thousands of years, which lies between the present living surface and the soils or geology beneath. The most significant failure of this analogy is that in a tree the general flow of water and inorganic nutrients is upwards from the roots to the leaves, whereas in a bog these fall from the sky onto the bog surface and then seep sideways and downwards under the effects of gravity until finally flowing down into the regional groundwater table.

The accumulation of dead plant material which gives the bog its overall shape, and which may be up to 10 m deep, is called the ***catotelm***. Hydrological processes within the catotelm are very slow. The thin protective surface layer of a bog, sealing the catotelm from the atmosphere, is termed the ***acrotelm.*** It is usually no more than 30 cm deep and provides the bog with a surface pattern of small-scale relief (some of which penetrates into, or influences, the lower *catotelm*) as well as a cover of living vegetation. Hydrological processes in this layer are extremely rapid, with rates of water flow up to 1000 times greater than those recorded for the *catotelm* (Ingram & Bragg 1984).

Under the humid, oceanic climate of Britain, *ombrogenous* mires (i.e. rain-*generated* peat-forming systems) are a characteristic element in the post-glacial range of climax vegetation formations. They are a notable feature of western and northern areas, where measurable rain falls on two days out of three.

In order to understand the ecology and conservation of ombrotrophic bogs, it is important to be clear about these differing terms and concepts, and also to have a sound understanding of the features by which ombrotrophic mires are classified. Furthermore, the present condition of the habitat, in both Britain and the rest of Europe, provides the context within which conservation priorities and actions can be identified. Such understanding is also of value if the nature and importance of particular sites, or the habitat as a whole, are to be communicated to others.

This report therefore considers:

- the characteristics of the bog environment;
- methods of classification;
- the nature conservation value of bogs;
- the evaluation process;
- impacts and management implications; and
- the present condition of bogs in Britain and Europe.

Section 2 Characteristics of the Bog Habitat

Davis and Anderson (1991) provide a table which summarises what they term 'true bogs' and fens (see Table 1).

Table 1. General features of bogs and fens (adapted from Davis and Anderson 1991)

Features	Bogs	Fens
Geographical distribution	Primarily boreal, moist climates	World-wide, moist locations
Abundance	Less numerous	Numerous
Surface topography	Convex or raised	Concave or flat
Peat depth	Mainly deep (> 1 m)	Shallow
pH	3.5 - 4.5	4.0 - 9.0
Nutrient source	Atmosphere	Groundwater and atmosphere
Productivity	Low	Low/high
Decomposition	Low	Relatively high
Floristic diversity	Low	Low/high

The two most important factors which *together* characterise a bog habitat are that:

- the living vegetation is raised above the underlying mineral soil by a layer of peat which is derived from the vegetation itself, and is of sufficient thickness to prevent plant roots from reaching the comparatively solute-rich influence of either the normal groundwater table or the underlying mineral sub-soil; and
- instead of the decomposition cycle typical of most habitats, a bog gradually accumulates its own dead plant material through time because waterlogging from direct precipitation or 'occult' sources (mist, fog or cloud) partially inhibits decomposition.

These two general characteristics are influenced by a number of factors outlined below, which in combination give rise to conditions unique to the peat bog environment.

Climate

Mires are a zonal phenomenon...they are affected by local differences in natural conditions, among which climate and relief play a leading part. (Ivanov 1981).

Ombrotrophic bog develops and survives because water losses through seepage and surface evaporation are matched or exceeded by regular precipitation input. Wickman (1951), summarised by Gore (1983), demonstrated that a minimum measured rainfall for domed bogs in north-central Europe is closely linked to the model of bog shape, and indicates a minimum annual rainfall requirement of 475 mm. This limit, or this approach, has been taken by some to provide an absolute rainfall limit for bog growth, but in fact Wickman's figures are only meaningful for that specific geographical region and are in any case based only on total rainfall.

Total rainfall is not a reliable measure of water inputs when considering the development and survival of bog systems. A domed bog, for example, whether a raised bog or a blanket bog covering a watershed, constantly loses water precisely because it is domed. Gravity draws water sideways and downwards away from the crown of the bog towards the regional groundwater table because water will always naturally flow downhill. Evapotranspiration is an additional source of water loss during dry periods. The regularity of water supply is thus the most important factor in bog development, and Backéus (1988) demonstrated that the *distribution* of precipitation and moisture conditions during any given time period are more important for *Sphagnum* growth than either total or average values for rainfall. On a global scale, therefore, bogs are not generally found at latitudes which experience long dry spells, or in the low-rainfall deserts of both high and low latitudes.

Backéus (1988) has shown that moisture conditions in August of the previous year represent the most important single factor controlling the growth of bog *Sphagna* and that temperature is not significant. However, *Sphagnum growth* is not the same as peat *accumulation*. A possible relationship between all these various factors - rain days (or, more accurately, *consecutive dry days*), total precipitation, temperature and bog growth - is under development at Leeds University and demonstrates the marked sensitivity of peat growth to small changes in any one of these factors (Kirkby *et al.* in press).

Ratcliffe (1968) demonstrated a broad belt of eastern England which now experiences fewer than 120 'wet days' per annum, and the index of oceanicity provided by Macdonald *et al.* (1957) suggests that parts of the south-east and the upper Severn Valley may be less favourable for bog development and survival than most parts of Britain. However, Conrad's Index of Continentality indicates that even the extreme south-east of Britain scores only 12 from a possible maximum of 100 for 'continentality' (Tout 1976, Daniels 1985), and on the basis of this it could be argued that conditions are so oceanic in Britain that bog development is possible anywhere in the country. It is clear that conditions were climatically suitable for raised bog growth near Cambridge as recently as 1855, because it is still possible to find very evident remains of bog rosemary (*Andromeda polifolia*) and cranberry (*Vaccinium oxycoccos*) in the dry surface peats of Holme Fen National Nature Reserve. In that year the last of the great meres and bogs of the Cambridgeshire Fens were drained, and the remaining bog vegetation at Holme Fen gave way to encroaching woodland. The change to woodland appears to have been entirely due to drainage rather than climate change because the present climate of Cambridgeshire lies well within the range experienced by the bog during its previous 2000-3000 year existence.

Temperature is undoubtedly also a factor influencing peat accumulation because it affects evapotranspiration, production and decomposition. The balance between production and decomposition can be significantly influenced by temperature, an important consideration when annual peat accumulation rarely exceeds 10% of annual production. A balance must also be reached between temperature and regularity of rainfall such that evapotranspiration does not exceed the rate of input for any significant length of time.

It is thus important not to draw conclusions about the suitability or otherwise of the present climate for bog growth in parts of Britain solely on the basis of the present distribution and condition of bog habitats, or on rainfall totals alone. It is impossible to say whether or not a critical climatic limit for bog

conditions now exists in Britain because no natural sites survive in the drier zones. The few which do exist in such areas are currently subject to substantial drainage programmes. Any indications of instability or degeneration are therefore as likely to be associated with active impacts as with unsuitable climatic conditions. There is therefore no clear evidence to indicate that any part of Britain is inherently unsuitable for ombrotrophic bog growth, although those parts which have fewer than 120 wet days *and* fall within the most continental of Conrad's categories for Britain are certainly the least suitable, particularly when allied to a freely draining limestone or chalk geology.

The importance of climate in determining bog type and expression is well recognised. Lindsay *et al.* (1985) demonstrated the link between the range of surface patterning on bogs and climate, while Lindsay *et al.* (1988) made considerable use of bioclimatic zones defined by Birse (1971) in the identification of peatland sites meriting protection in Caithness and Sutherland. The use of climatic or bioclimatic zones to delimit regions within which sites are selected is a feature of many established national peatland protection programmes (e.g. Cowardin *et al.* 1979, Zoltai & Pollett 1983, Ruuhijarvi 1983, Moen 1985, Steiner 1992) because it is recognised that differing regional climates give rise to significant variation in the expression of particular bog types.

Development sequence

Sjörs (1983) identified the two major paths of peat bog formation as *terrestrialisation* and *paludification*. The former describes the process by which a shallow lake becomes overgrown by fen vegetation, steadily infills with fen peat and is then overwhelmed by a rising mound of rain-fed bog peat. Paludification, on the other hand, represents peat formation directly over a soil or rock surface under suitable climatic conditions, and may not involve any fen precursor prior to bog development. When, through terrestrialisation or paludification, the vegetation can no longer root deeply enough through the peat layers to tap geogenous minerals and water, the freshly formed, entirely rain-fed material is termed bog peat, rather than fen peat. The 'classic' description of bog development is that of the simple raised dome formed by terrestrialisation (see Figure 1). Other bog types, particularly blanket bog, which covers whole landscapes with peat (see Figure 2), may show different sequences of development, but most of the basic principles of waterlogging, peat accumulation and hydrological balance are common to all.

Many raised bogs began life as a shallow basin formed in relatively impermeable glacial clays, although others have been shown to have formed over a more varied terrain. Flooded by groundwater in early post-glacial times, the basin then became a lake with a fringe of fen vegetation (see Figure 3). Over perhaps the next 2000 years the lake became overgrown by fen plants whose remains failed to decay completely and thus tended gradually to accumulate, filling the basin with fen peat and trapped sediment. Once the basin was entirely full the plants at the centre were largely cut off from solutes either from the basal sediments or from the lake margins. Such conditions are intolerable to most plant species other than the genus *Sphagnum*, with the result that bog moss carpets came to dominate the vegetation.

Sphagnum is more resistant to decay than the majority of plant material because much of its chemical composition is resistant to decomposer microbes. Steady accumulation of dead *Sphagnum* and the litter of other bog species is not matched by the overall rate of decay, causing the living layer to be gradually raised above the surrounding geotrophic fen

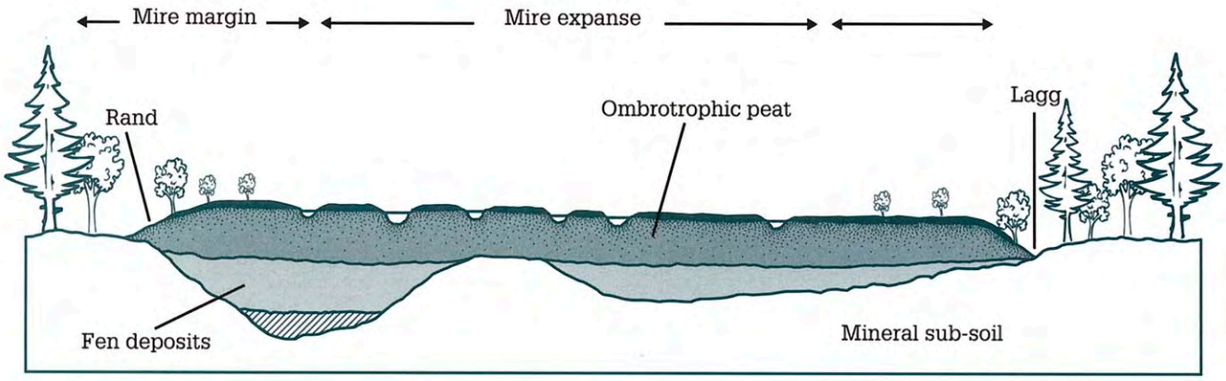


Figure 1.
Profile of a confined raised bog. The example given here is a 'plateau-type' of confined raised bog for the continental region. In the oceanic region, raised bogs are typically somewhat more domed throughout their profiles and may be entirely treeless on the margins, but otherwise the components making up the profile in the two types are similiar. (Adapted from Grünig *et al.* 1986)

by up to 2 mm per year (Clymo & Reddaway 1971). After 5000 - 7000 years of such accumulation the central parts may rise more than 10 m above the geotrophic fen deposits, now completely smothered beneath a single great mound of undecayed peat.

Hydrology

Perhaps the most remarkable thing about this mound is that it remains completely waterlogged, often more so than the adjoining mineral ground, despite being perched several metres above the surrounding land. This waterlogged state arises because water enters the site as precipitation (it is not drawn up by suction or capillary action as was once thought) but its downward progress through the peat is then slow, and upward losses by evapotranspiration are limited only to the thin surface acrotelm. So effective is this water retention that, during development of the bog, the peat matrix gradually sheds less water than it receives. The resulting bog thus represents a mixture of some 95-98% rainwater bound together by some 2-5% peat solids, by weight, in what appears to be a dramatic swelling of the local groundwater but is in fact a considerable quantity of trapped rainwater which has yet to reach the regional groundwater table.

The slow rate of water released from the peat results largely from the amorphous nature of the peat matrix and the water-retaining properties of even dead *Sphagnum* remains. More recently it has been suggested that water movement is also restricted because a proportion of the interstitial spaces between peat particles is blocked by microscopic bubbles of methane, which is held in a stable form in the peat-water matrix (Brown 1989).

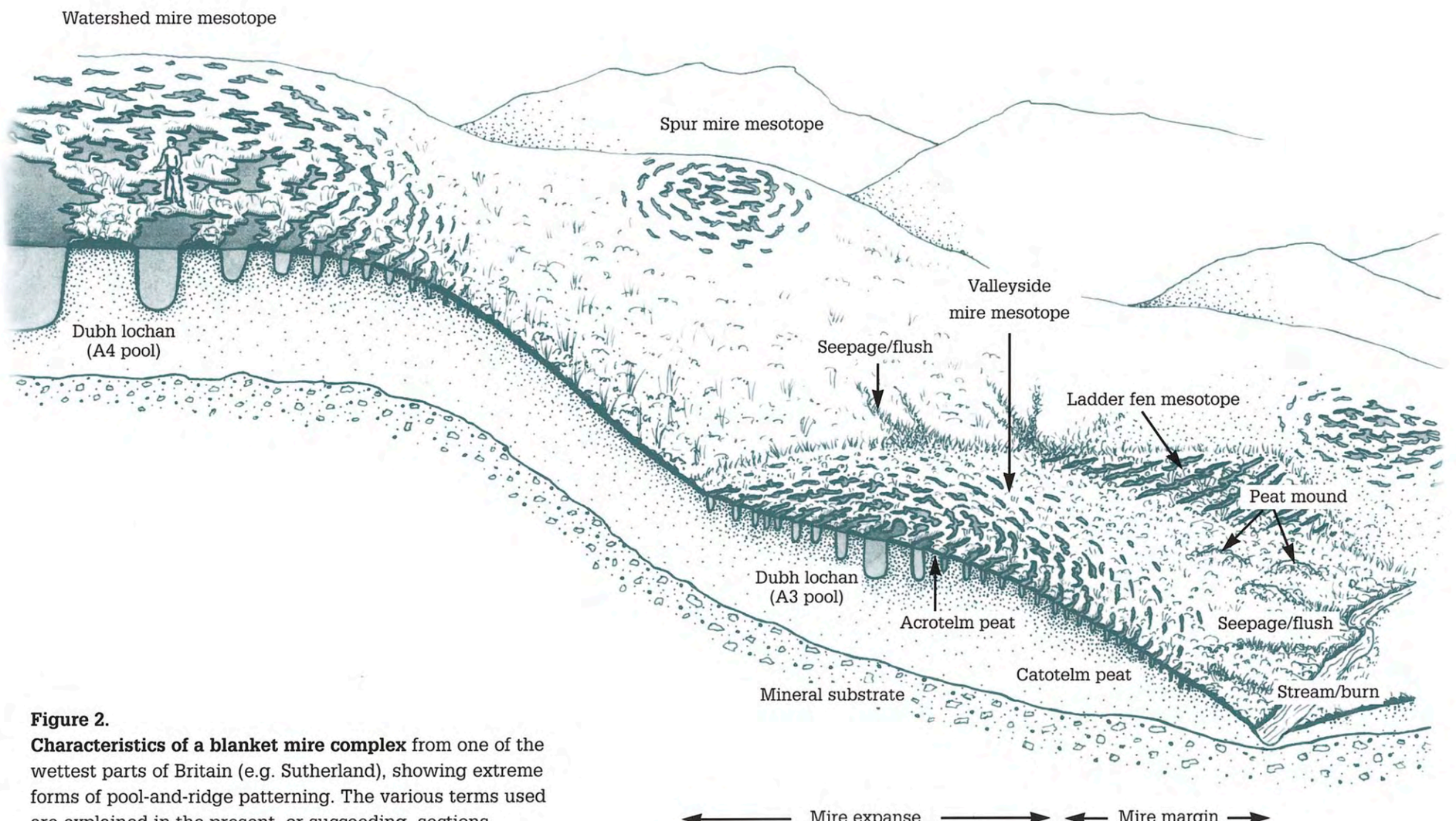


Figure 2.
Characteristics of a blanket mire complex from one of the wettest parts of Britain (e.g. Sutherland), showing extreme forms of pool-and-ridge patterning. The various terms used are explained in the present, or succeeding, sections. (Adapted from Lindsay *et al.* 1988)

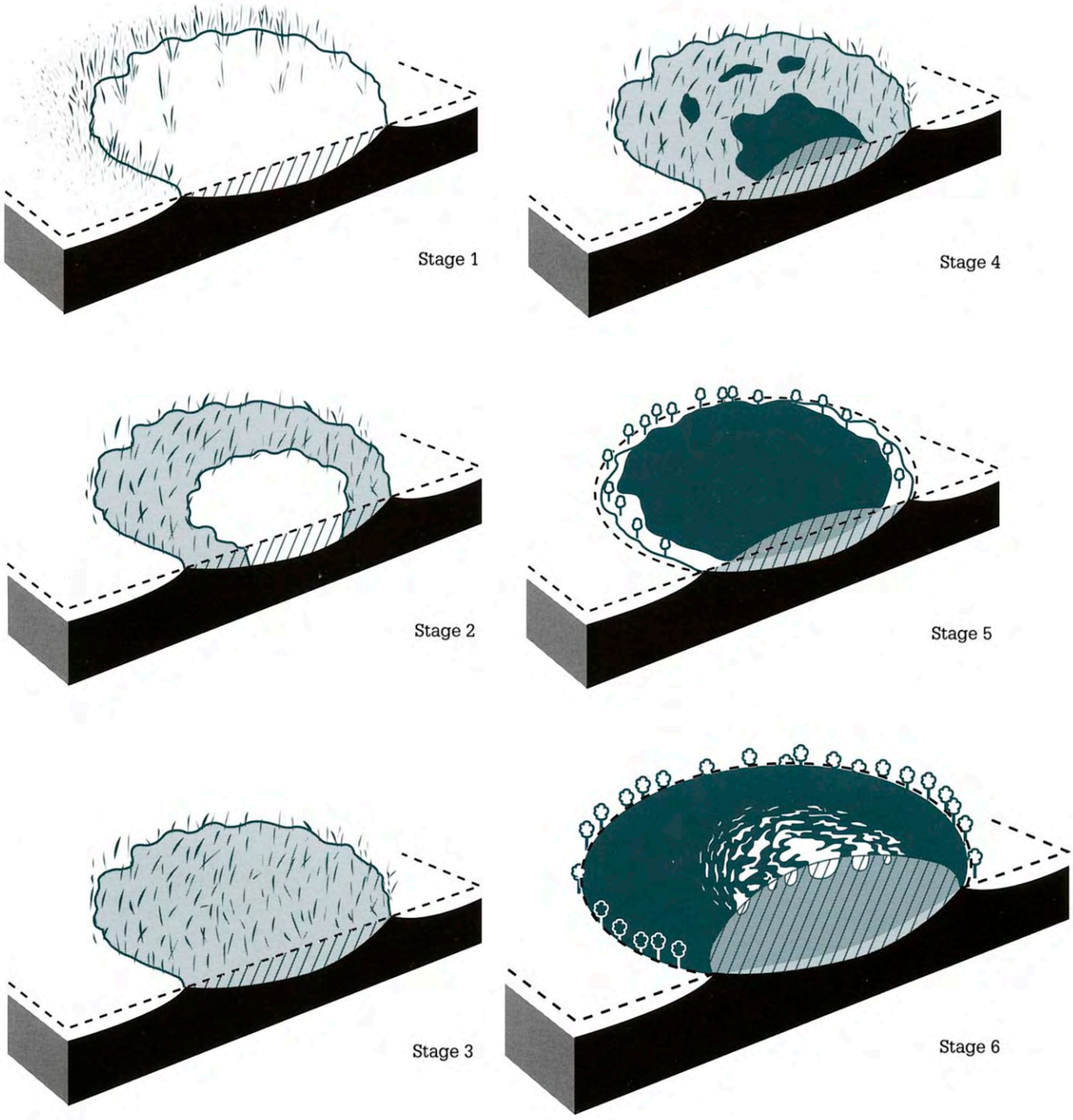


Figure 3.
Generalised sequence of raised bog development. Vegetation and raised bog are not shown at the same scale - typically a site may extend to a kilometre or more in diameter. **Stage 1**: Water-filled depression (lake/loch) with emergent fen vegetation around the edge. **Stage 2**: Gradual infilling of lake/loch with fen peat. **Stage 3**: Depression completely infilled with fen peat - feeding is still minerotrophic and the vegetation consists of fen species. **Stage 4**: Initiation of bog formation as the predominant inputs of water and inorganic ions switch from minerotrophic to ombrotrophic sources. **Stage 5**: Raised oligo/ombrotrophic elements coalesce. **Stage 6**: Raised bog dome showing typical features including central microform patterning, steep rand and marginal lagg fen. Prominent bog pools are more typical of Irish, rather than British, raised bogs.

Much as each species of tree has its own characteristic branch and leaf shape, so the development of this rainwater reservoir as an ombrotrophic dome of peat is not a process of haphazard growth but rather a steady movement towards a broadly predetermined shape for which the climate provides the template (Ingram 1982). This template may be altered by long-term climate changes and gives rise to corresponding homoeostatic changes in the character of the bog (Barber 1981).

However, the single most important long-term factor controlling the peat 'template' of a bog is drought. The longest dry conditions experienced by the peat bog during its development are the major determinants of the final stable shape and maximum height of the dome, although this shape may alter somewhat to reflect climate shifts. The shape of the dome can be described using standard models from soil hydrophysics which, when applied to bogs, have been called the 'groundwater mound theory' (Ingram 1982).

In essence, the groundwater mound theory is based on the recognised fact that all soils, even domed bog soils, contain a water table profile, and that this profile behaves similarly whether in peat or mineral soils. The water table between two open or sub-surface drains in a mineral soil settles into the shape of a half-ellipse (e.g. Hillel 1971) (see Figure 4a). The dome of water in a peat bog can be regarded as a similar system, the natural peripheral stream (lagg stream) replacing the artificial drains while the aerated soil zone above the constant ellipse is replaced by the very much thinner acrotelm layer. The swollen mass of rainwater which represents the bog water table thus tends to adopt a similar half-ellipse to that seen in mineral soils. The height and curvature of the bog ellipse are determined by local climate, but heights of 9-10 m are often reached (see Figure 4b, Plates 3 and 4).

The division of the bog into two layers, the surface acrotelm and lower catotelm, is an important element in the hydrological balance of a bog. The *acrotelm* may be only 20-30 cm deep but is composed of largely vertical stem structures which permit rapid lateral flow. It consequently represents the major zone of water exchange with the environment. If conditions become extreme, the bleaching of dehydrated *Sphagnum* mats reflects much solar energy, thus further reducing losses to evapotranspiration quite considerably (Clymo & Hayward 1982). Near its base it is relatively impermeable and permits only gentle seepage, but towards the surface it becomes increasingly open and permits rapid dissipated flow of excess water. In conditions of high water level, therefore, the erosive power of large volumes of water is dissipated by the varying conductivity of the *acrotelm* profile.

The catotelm resembles the lower layers of a tropical rain forest, or the abyssal depths of the ocean - an environment which enjoys constant, unvarying conditions because it is protected from the turbulent environment above by a relatively thin upper layer or canopy. Water exchange takes place slowly with the acrotelm and also possibly with the basal sediments or the marginal fen, but the catotelm always remains completely saturated. It remains so because it is protected and supplied by the acrotelm. If catotelm peat becomes exposed to air because the acrotelm is damaged or the bog water table is lowered over any part, the catotelm material will oxidise and waste away until it has sunk below the new level of the bog water table. If, however, the bog water table continues to sink, so too will the catotelm.

Peat and mineral soils react differently to exposure to the atmosphere. When peat soils dry out they rapidly oxidise and are lost as carbon dioxide and water. At the famous Holme Fen Post in Cambridgeshire, the soil surface was lowered in this way by 11-12 cm

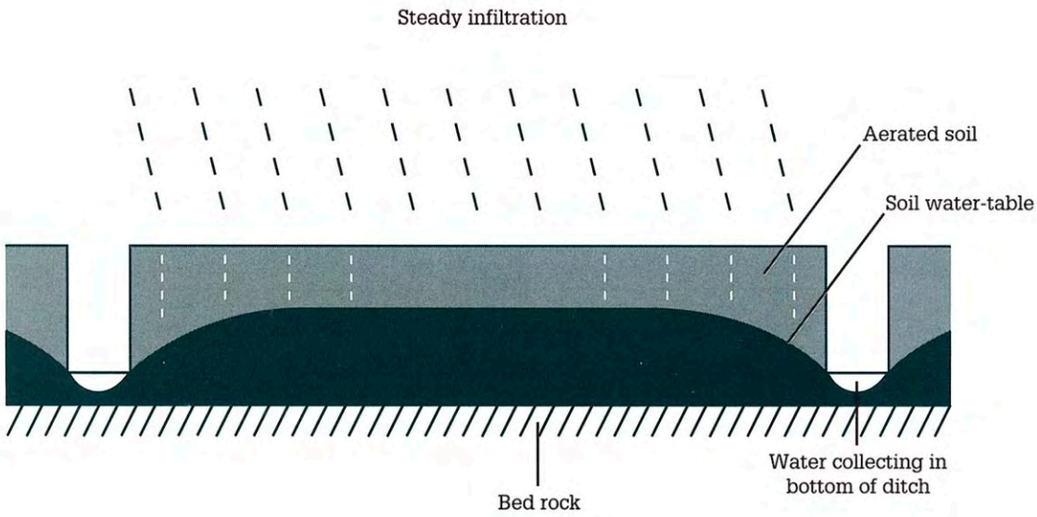


Figure 4(a).
The shape adopted by the water table in a mineral soil under the influence of two open or sub-surface drains, and which receives steady recharge from the surrounding soil matrix either from rainfall or lateral seepage. The resulting elliptical water table draw-down produces a deeper zone of soil aeration which is, of course, the objective of drainage.

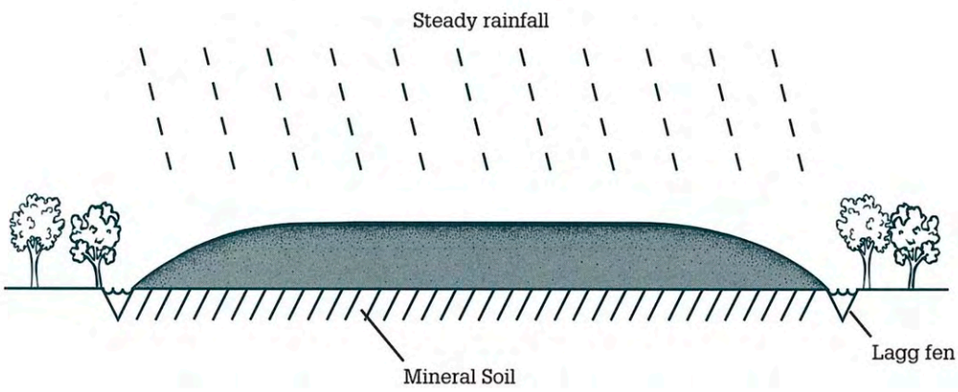


Figure 4(b).
The water body of a raised bog also adopts the profile of a half-ellipse which is drawn down towards the margins by the lagg fen stream surrounding the site. The water body represents a swelling of the local water table but is not an upwelling of groundwater; it is instead an accumulated reservoir of rainwater which sits on top of the mineral groundwater table. In a bog, the living surface of *Sphagnum* bog mosses acts as a further hydrological regulator permitting relatively rapid runoff following heavy rainfall and stemming excessive desiccation during dry periods. The lagg fen is the zone in which the bog water-table and local ground-water come into contact. (Ingram 1982, Bragg 1982, Ingram & Bragg 1984, Ingram 1992, Bakker 1992).

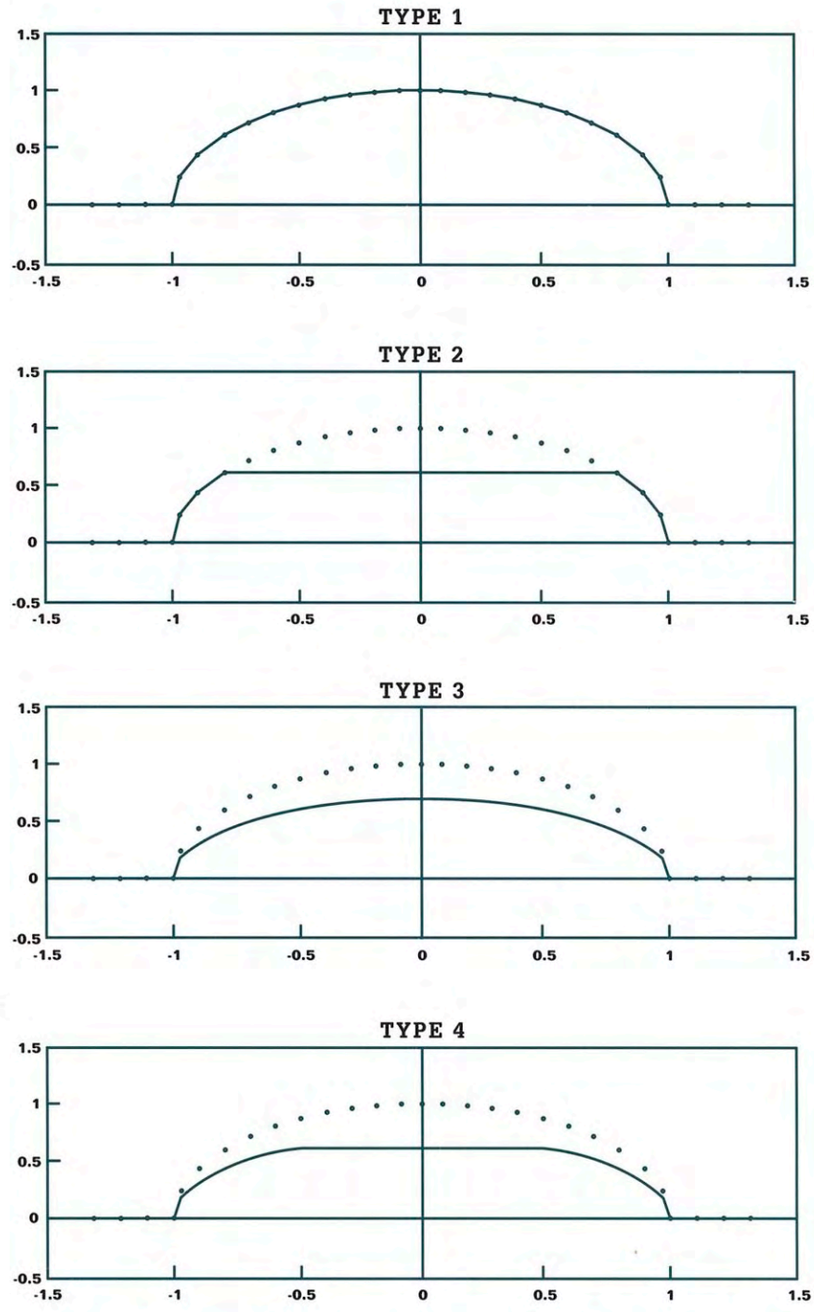


Figure 5.
The simple Groundwater Mound Model, together with variants. **Type 1** has attained the maximum climatic potential profile and mire growth is hydrologically limited throughout. **Type 2** is hydrologically limited at the margins, but has reached a biological decomposition 'ceiling' in the centre, thus conforming to the shape of a 'plateau or continental' raised bog. **Type 3** is a relatively young bog which has reached netiher a hydrological nor decomposition limit. It may develop into either a Type 1 or Type 2. **Type 4** is also a relatively young bog but has already reached a decomposition limit. It may develop into a Type 2. (Taken from Bragg and Brown 1992.)

per year in the two decades after drainage (Hutchinson 1980). Such oxidative losses are negligible or absent in dry mineral soils. Furthermore, species typical of bogs, particularly *Sphagnum*, are unable to survive unless they lie very close to this water table. The living, growing surface of the bog thus remains closely tied to the shape of the water table. Consequently it is impossible for catotelm peat to be formed or maintained above the summer drought level of the bog water table. Old ideas that a bog 'outgrew' its water table and dried out at the crown to form climax woodland are now known to be wrong - i.e. drying out only occurs as a result of (generally human) extrinsic factors. The whole shape of the bog constantly mirrors the shape of the swollen mound of water, and the final climax shape remains hydrologically stable. Indeed, Barber (1981) has shown how a bog is capable of subtly altering its shape and character in response to climate change in such a way as to maintain this overall stability.

A smooth half-ellipse is not always formed, however, because the other factor influencing the shape of even the simplest bogs is decomposition. The mean accumulation rate of boreal peat is generally quoted to be only around 2 mm per year (Clymo & Reddaway 1971, Clymo 1978). However, growth is limited to the surface layers only, but decomposition occurs throughout the whole bog profile of several metres. If, in a total depth of 7 m, decomposition, slow though it may be, accounts for a mere 2 mm loss of peat thickness, this would exactly match an accumulation rate of 2 mm per year at the bog surface.

The maximum height of the half-ellipsoid shape predicted by the groundwater mound theory for such a bog may not have been reached, but the decomposition 'ceiling' in such examples prevents further height gain and results in a truncated groundwater mound (see Figure 5) (Clymo 1984, Bragg & Brown 1992, Kirkby *et al.* in press).
The general process of growth to a limiting profile occurs on all raised bog sites and may do so for blanket bogs, although the mechanisms are much less well understood in this more topographically complex environment. This growth to a limit is an important characteristic of bog dynamics, but, where the terrain is anything other than flat, the simple model in Figure 4b must be modified to take account of additional hydrological gradients imposed by the underlying relief. This can be achieved using what is termed 'finite-element modelling', which effectively involves reducing the site to a series of small units which are then integrated together to produce an overall model. Furthermore, where the climate permits peat development to become extensive, individual domes may coalesce, particularly where paludification is a major contributor to peat formation. Under such circumstances the overall shape of the resulting blanket of peat then becomes a complex product of the individual units.

Conditions in the bog environment

In Britain the main expanse of a bog is characterised by an open landscape dominated by vegetation in which low growth forms are typical. Mosses, small-sedge species and dwarf shrubs form the major part of the vegetation cover, and it is unusual to find any species attaining much more than 50 cm in height. Only in a few cases in the far north-east of Britain does a light scatter of pines (*Pinus sylvestris*) appear to be natural. In practically all other cases the spread of species such as tall grasses, herbs or trees across a bog can be attributed to some form of disturbance. In continental Europe a large proportion of bogs are naturally wooded, and the influence of the trees on their microclimate is profound (Geiger 1965, Eurola 1975, Moore 1984). Interception by the canopy can, for example, mean that up to

30% of rainfall never reaches the bog surface (Hornung & Newson 1986). In contrast, the open bog expanses of Britain are generally subject to a microclimate of smooth, uninterrupted airflows which reach almost to the ground layer. Interception of precipitation is also minimal except in cases where a dense dwarf shrub layer has developed.

The wettest part of a bog other than the surrounding lagg fen is generally found on the highest part of the dome. Indeed Ingram (1983), Hobbs (1986) and Tolonen *et al.* (1988) emphasise that the crowns of such convex bogs usually contain more than 90% water by weight, often represented by a zone of open water pools or *Sphagnum* hollows, the configuration of which is related to the local climate. Bragg (1982) has also demonstrated that over the central area of a natural bog the water table resides within 5 cm of the annual mean water level for more than 95% of the year. The structure of the bog surface consists of such small-scale relief (see section 3) that generally all components of the living vegetation lie within 25-30 cm of this very stable water table.

The characteristic acidity of the bog environment results in part from ion exchange between the bog waters and the living vegetation, particularly *Sphagnum* bog moss, in that the few cations available are taken into the plant and exchanged for hydrogen ions. Shotyk (1988), however, points to the early work of Stremme (1908) and others, who argued that dissolved carbon dioxide can account for at least a proportion of the acidity in bogs. With few metal cations to provide buffering, the carbon dioxide dissociates into a solution of carbonic acid to give bog pore-waters of around pH 4. A wide range of complex humic acids may also contribute in varying amounts to this acidity.

In Britain the chemistry of bog waters is heavily influenced by wind-blown marine salts (Moore & Bellamy 1974). Even sites on the east coast have significantly higher levels of sodium and chloride than do similar bogs in more continental Europe. Throughout the world, typical pore-water in the oxygenated surface layer of peat bogs (Moore & Bellamy 1974, Davis & Anderson 1991, M.C.F. Proctor, personal communication) is characterised by:

- low calcium (0.5 ppm)
- low phosphorus (0.005 ppm)
- low nitrate-N (0.005 ppm)
- high ammonium-N (0.05-0.1 ppm)
- high sulphate-S (0.3 ppm)
- high H^+ (0.10 ppm)

Plant species typical of bogs are adapted to low ionic concentrations in a variety of ways. Many also thrive in better conditions, but their competitive ability against more aggressive and demanding non-bog species is lost under these less hostile conditions.

Part II: Classification and Typology of Bogs in Great Britain

Part II: Classification and Typology of Bogs in Great Britain

Section 3 Hierarchy of Bog Features and Vegetation in Britain

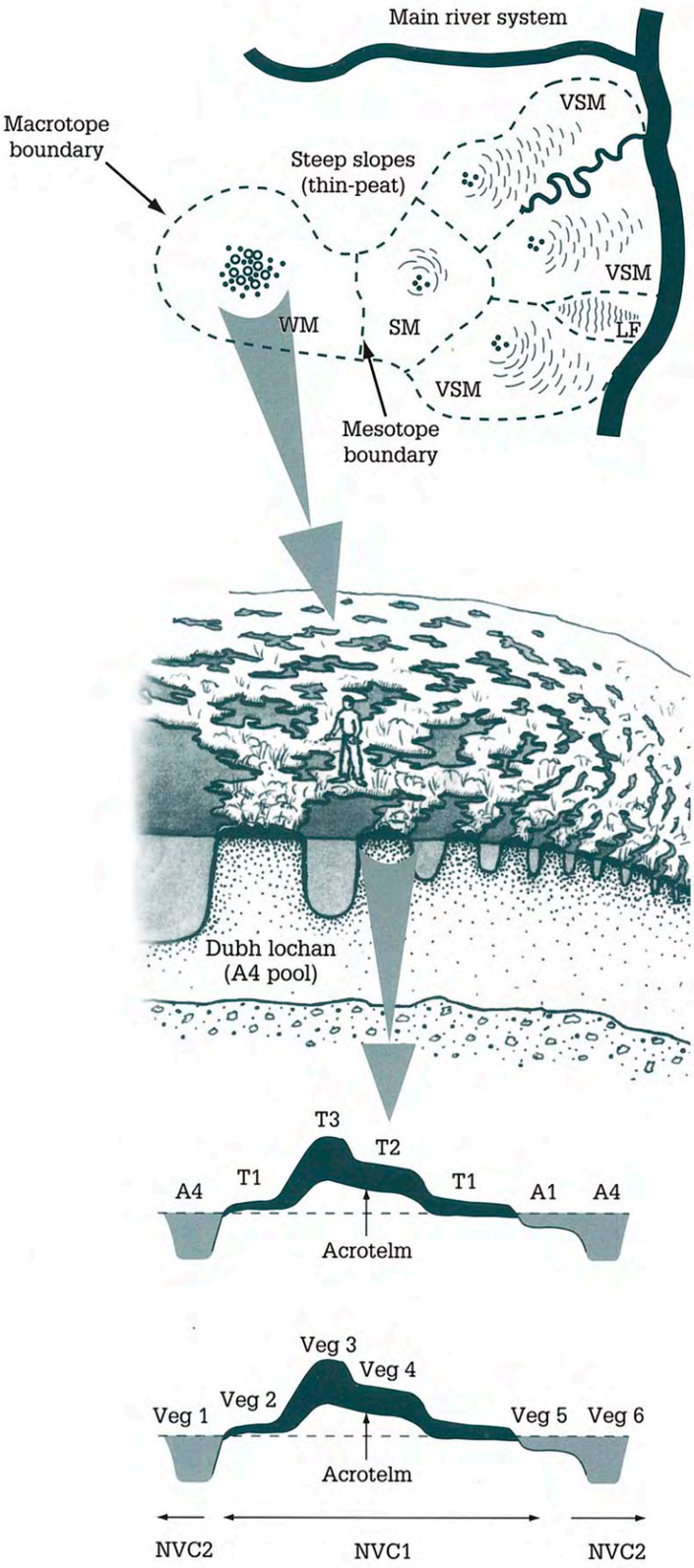
Bogs have been classified for scientific purposes in a greater variety of ways than is perhaps the case for most other habitats. Systems of classification have used, for example, hydrotopography, hydromorphology, vegetation, peat type, stratigraphy, pollen record and general peat archive (see, for example, Dierssen 1982, Moore 1984).

Table 1 shows that low floristic diversity is a particular characteristic of bogs. It is perhaps not surprising therefore that the greater number of classification systems devised for bogs are based not on floristics but on hydromorphological characteristics. Ivanov (1981) provided a hierarchy of hydrological structures which reflects this emphasis on hydromorphology in mire classification. The typical ecological gradients described by Sjörs (1948) can be combined with those proposed by Ivanov. From this combination it is then possible to construct a reasonably comprehensive hierarchy of most features generally used in mire classification. This hierarchy encompasses all or most of the commoner non-floristic methods used to describe peatland systems (e.g. Goode & Ratcliffe 1977, Cowardin *et al.* 1979, Succow 1980, 1981, Masing 1982, Sjörs 1983, Zoltai & Pollet 1983, Eurola 1984, Steiner 1984, 1992, Moen 1985). Lindsay *et al.* (1988) summarised this hierarchy as follows (see also Figure 6).

Mire mesotope, or hydrological unit, represents the basic site unit as a complete hydrological entity. It is not the highest level of the hierarchy, that being the *macrotope*, but is equivalent to the most generally recognised concept of an individual bog 'unit'. It encompasses all necessary inputs and outputs of water, plus the hydrological characteristics necessary for the normal dynamics of the system. In the lowlands it represents what is generally recognised as a discrete named bog (e.g. Glasson Moss, Wedholme Flow), including the necessary catchment of any lagg fen. For raised bogs, therefore, the morphometric type occurs at the mesotope level. In the uplands a mesotope more usually refers to the individual hydrological components of blanket bog, for example a watershed bog, or a saddle bog, which then make up a larger system complex or macrotope.

Mire macrotopes, or mire complexes, represent the highest level of the hierarchy, but are more varied in their expression and thus are somewhat more difficult to grasp initially. They occur when two or more mire units or mesotopes (see above) are hydrologically connected. The individual components may be viewed as separate sites - they may have different names for example - but are nevertheless clearly linked into a continuous peat system. Mire complexes are most frequently encountered in the uplands, where several hydrotopographical units (e.g. spur bog, saddle bog, valleyside bog and ladder fen) fuse to form an extensive complex cloaking the landscape with peat. In Caithness and Sutherland, for example, some macrotope complexes extend for at least 6000-8000 ha. For blanket bogs and ridge-raised/intermediate bogs the morphometric type thus occurs at the level of macrotope or complex.

Mire margin-mire expanse is a gradient which can generally be observed within a single bog mesotope or hydrological unit. The term was derived from observations in Sweden (Sjörs 1948) where the margins of bogs tend to be wooded, in contrast to the central expanse, which is usually treeless. This distinction is not as evident on British sites because naturally wooded bogs are much rarer in Britain. The gradient itself, however, is generally still present because it represents a genuine change in environmental characteristics, from the strongly acidic, very stagnant conditions of the main mire area to the zone of steeper gradients, thinner peat and increased water seepage at the mire margin. Animal and plant communities



Macrotope and component mesotopes: [Plan view of macrotope complex illustrated in Figure 2.]
VSM = valleyside mire, SM = spur mire, WM = watershed mire, LF = ladder fen.

Part of the watershed mire **mesotope,** displaying **microtope pattern** with open-water pools (T3/T4)

Microforms, coded according to Lindsay *et al.* (1988): T3 = hummock, T2 = high ridge, T1 = low ridge, A1 = *Sphagnum* hollow, A4 = permanent pool. (A2 & A3 pools are not present in the area taken from Figure 2.)

Vegetation. 'veg' groups represent the range of variation shown by the vegetation within the microtope and microform pattern, compared with the broader classification of the NVC.

Figure 6.
The hierarchy of features used by the country conservation agencies to classify bog systems. Terms are derived from Ivanov (1981) and are described in the accompanying text.

often differ quite markedly between these two areas, and in hydrological terms the mire margin forms a crucial part of a bog's integrity.

Microtope or surface pattern identifies the fact that bog surfaces tend to develop a range of specialised features at least in part because the main peat-forming species have characteristic growth forms. The *repeated, distinctive arrangement and combination* of such features, combined with particular vegetation stands, represents the microtope pattern. There appears to be a relationship between climate and the form of microtope patterns, a relationship explored by Lindsay *et al.* (1985, 1988) (see Figure 7 and Plates 5-7). It seems that the most extreme forms of patterning within a given region display increasing amounts of open water, in the form of bog pools, with increasing wetness of climate.

This is not particularly surprising in the light of Ivanov's (1981) observation that water bodies represent zones of very rapid hydraulic conductivity. Extensive bog pools thus permit large volumes of excess water to be transported across and away from a site rapidly because the proportion of the bog surface covered by elements possessing high hydraulic conductivities is greater than for a bog which is dominated by low-conductivity ridges. The ability to shed large volumes of water rapidly is an important feature of sites in regions of very high rainfall. In contrast, ridges and hummocks represent features which permit relatively slow water movement, and are thus appropriate for the surfaces of bogs where little rain falls and such rainwater must therefore be retained within the site for as long as possible (for an extended description of the origins and character of these surface patterns, see Ivanov 1981 or Lindsay *et al.* 1988).

The microtope pattern is generally most pronounced and varied in the area of the mire expanse, and at its simplest within the mire margin. Thus the margin may consist of only a single growth form and vegetation stand; no pattern as such may be evident, but the area nonetheless represents a microtope. In contrast, the mire expanse may display a striking range of patterns consisting variously of alternating terrestrial and aquatic elements (e.g. T2 ridge and A2 pool, or T3 hummock and A1 hollow - see Table 2). Where aquatic elements do not exist, as in the case of many raised bogs in Britain, the pattern may instead consist of T3 hummock and T2 high ridge or T2 high ridge and T1 low ridge, thus maintaining the characteristic undulations of a bog environment but without any true 'hollows' or 'pools'.

Mire microform/mire element represents the individual features which make up the surface pattern of a bog. These have been described for Britain by Lindsay *et al.* (1988) as peat mounds, erosion haggs, hummocks, high ridges, low ridges, *Sphagnum* hollows, erosion gullies, mud-bottom hollows, drought-sensitive pools and permanent pools. Few sites have all these features - indeed most have no more than three, and some may consist, for example, of an undulating surface with only high ridge and low ridge. These small-scale patterns have been recognised since earliest times as features particular to bogs and certain fens. Osvald (1923, 1925, 1933, 1949) explored many of the relationships between the broad classes of surface feature and existing vegetation classifications. A more detailed description of the small-scale features was provided, and refined into a classification system in the late 1940s, by Sjörs (1948). The various 'ecological gradients' described by Sjörs have gained increasingly widespread acceptance in the intervening decades. In an attempt to clarify some of the confusion arising from the use of local or regional names for these features, Lindsay *et al.* (1983, 1985, 1988) proposed a simple coding system which can be used to identify unambiguously the type of Sjörs feature being described (see Figure 8, Plate 8 and Table 2).

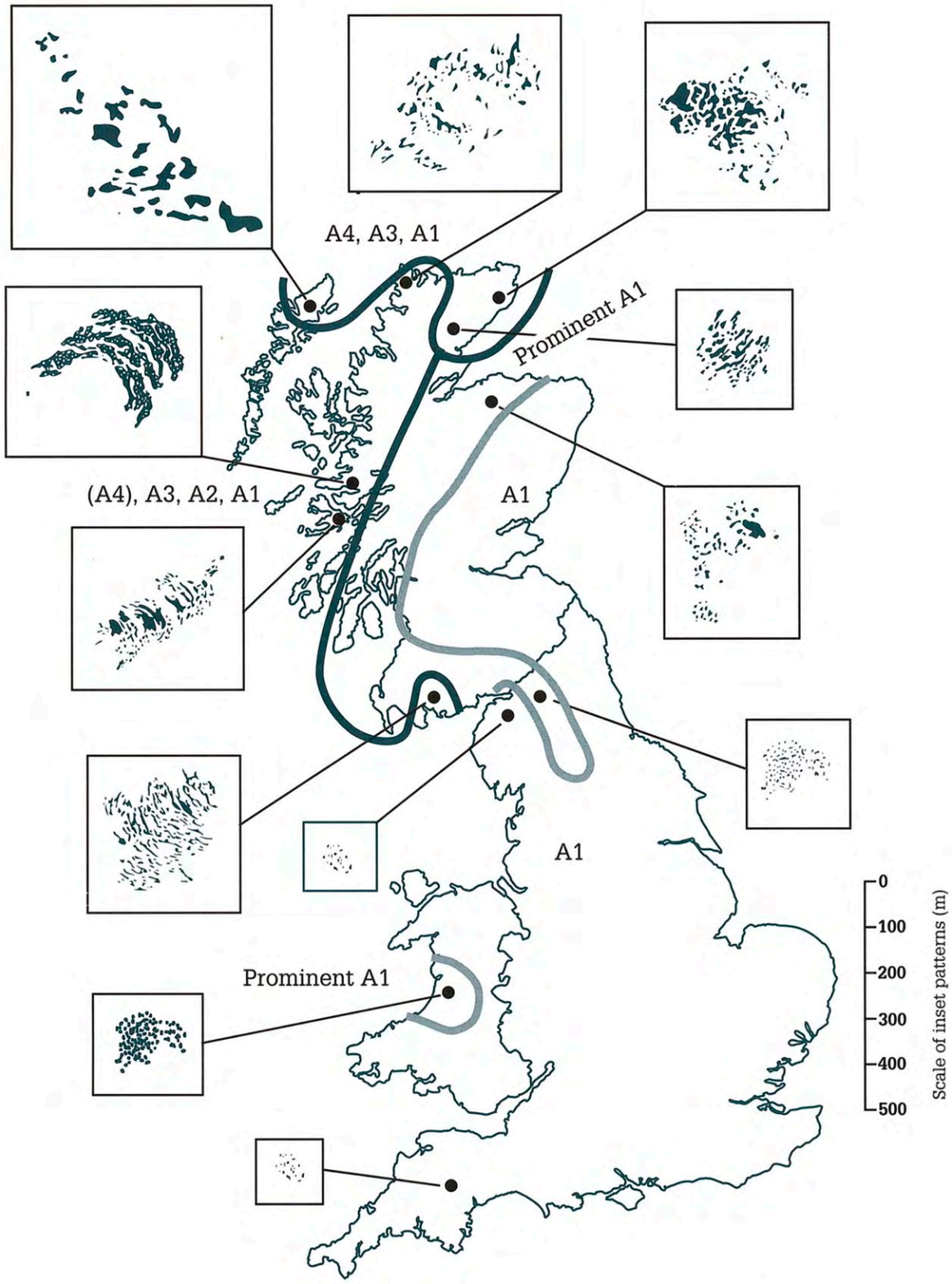


Figure 7.
Distribution and general structure, seen from above, of the most extreme forms of bog surface patterns observed from a range of sites throughout Britain. Patterns have been mapped directly from aerial photographs standardised to the same scale. Pools and/or hollows are shaded black, ridges and/or hummocks white. The observed pattern may differ from the natural pattern because of human impacts. Shaded lines give a tentative indication of the range of aquatic zones (indicated by zone codes illustrated in Figure 8, page 27, and described in Table 2, page 28) typically found in different regions of Britain. (Adapted from Lindsay *et al.* 1988 and SNH unpublished data).

The classification of bog vegetation

Bog vegetation is characterised by a dominance of acidophilous plants. Undisturbed surfaces typically possess an almost continuous mixed carpet of *Sphagnum* species adapted to highly stagnant, waterlogged and acidic conditions, and growing within this carpet are higher plants such as *Erica tetralix* and *Eriophorum angustifolium*. Surfaces which are either disturbed or naturally drier have less *Sphagnum* and a greater abundance of vascular plants such as *Calluna vulgaris, Eriophorum vaginatum* and *Scirpus cespitosus* rooted in the upper peat or discontinuous moss layer. Bog mosses usually show some degree of hummockiness, and often there is differentiation into, for example, drier hummocks or wetter hollows as described above in relation to microtope and microform. Associated with this microrelief are distinct but fine-scale vertical zonations of vegetation which have been described by, for example, Osvald (1923, 1925, 1949), Sjörs (1948), Dierssen (1982), Masing (1982), Eurola *et al.* (1984), Dierssen and Dierssen (1985), Lindsay *et al.* (1985, 1988) and Moen (1985).

The vegetation of mire (peatland) systems in Britain has been described by a considerable number of authors since the turn of the century (e.g. McVean & Ratcliffe 1962, Ratcliffe 1964, Moore 1968, Birks 1973, 1980, 1984, Goode & Ratcliffe 1977, Daniels 1978, Goode & Lindsay 1979, Doyle & Moore 1980, Lindsay *et al.* 1985, Rodwell 1991). However, the majority of these generate only a limited number of classes for bog vegetation. This broad-brush approach to vegetation classification is very effective when describing whole bog units, complexes or entire regions, but the sampling used to produce these classifications is not generally appropriate for describing the fine-scale variations provided by the microtope, or surface pattern, which is so particular to peat bog systems and has been recognised since earliest times. Few British authors have used these small-scale features as an integral part of vegetation classification.

The National Vegetation Classification (NVC) (Rodwell 1991) defined only eight major bog communities (including three bog-pool communities and one 'mire margin' type) within the 38 'mire' communities identified for Britain. The remaining 31 (apart from two 'wet heath' types) are fen communities, to which of course can be added all of the tall herb fen and swamp communities. It is hardly surprising therefore that vegetation should play such a major part in fen classification, and such a minor part in the classification of bogs.

The NVC gives a valuable summary of mire plant communities at the site level, but its vegetation units are not intended to be used in defining the intricate finer scale mosaics of patterned surfaces recognised by Osvald, Sjörs and subsequent workers. NVC vegetation units can, however, be related to Sjörs's mire margin/mire expanse gradient, the mire margin generally being assigned to one NVC unit, the mire expanse to another, possibly two, especially where pools are present.

Recognition is increasingly being given to the vegetation types which can be identified *within* the smaller scale microtope, or surface pattern. Moen (1985) for example, described how such a system is being developed for Norwegian mires, while Masing (1982) gives a detailed account of Estonian mires using such features. The CORINE Classification adopts a similar approach; particularly for raised bogs, it recognises the small-scale nature of many bog vegetation communities. It divides the vegetation between *bog hummocks, ridges and lawns* (Code 51.11), *bog hollows* (51.12), *bog pools* (51.13) and a few associated marginal communities. Within these, it then separates *colourful Sphagnum hummocks* (51.111) from *green Sphagnum*

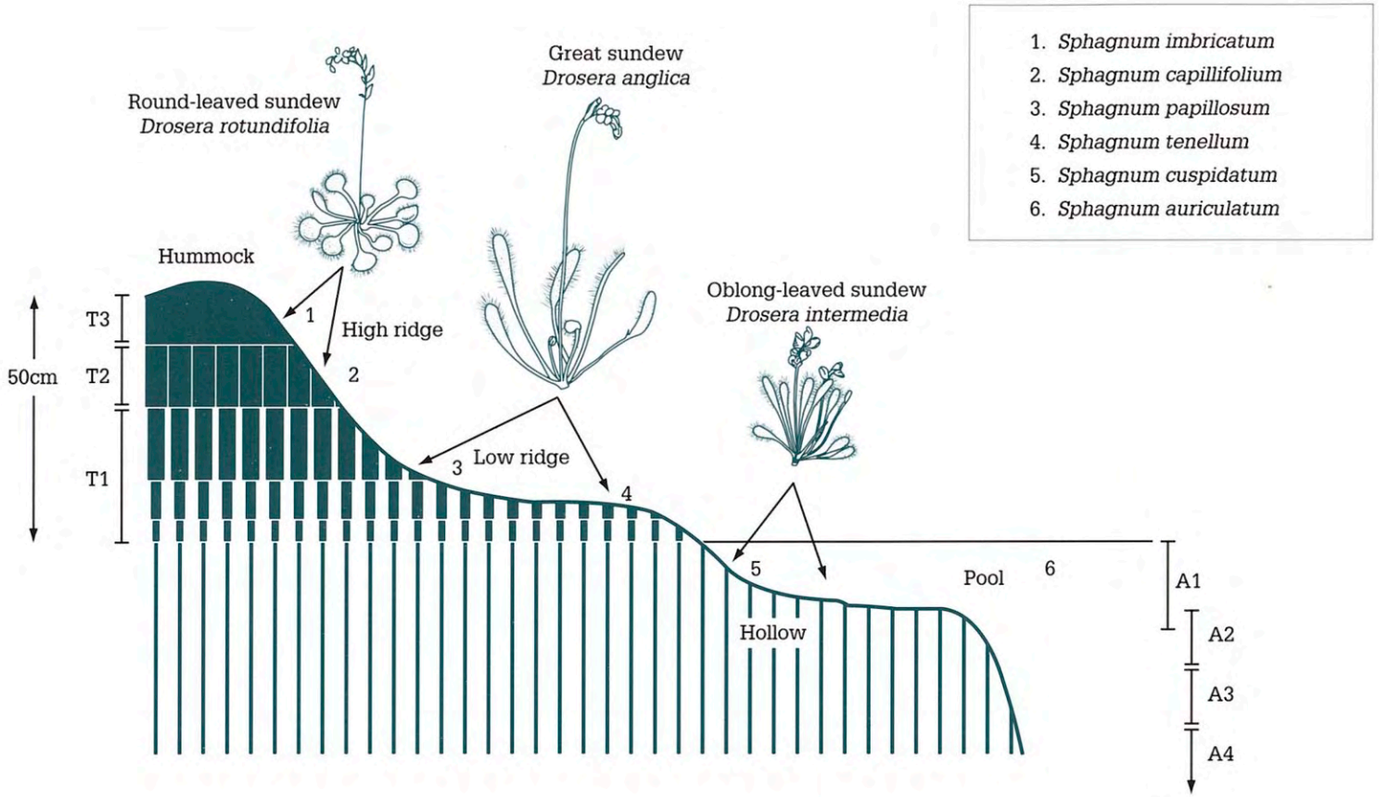


Figure 8.
Generalised distribution of structural features (microforms) and the idealised distribution of species within the pattern (few sites, for example, contain all three *Drosera* species). All natural bogs have some form of pattern, at least across their mire expanse, although in some sites the pattern may consist only of T3 hummocks alternating with T2 high-ridge. Many sites towards the southern and eastern limits of the present bog distribution in Britain have no aquatic (A) zones and consist only of terrestrial (T) zones. (Taken from Lindsay *et al.* 1988. See also Sjörs 1948, Eurola, Hicks & Kaakinen 1984, Moen 1985.)

Table 2. Mire microforms

The range of structural 'microforms' which can be found on ombrotrophic bogs in Britain are described here. In existing literature these have been identified in a variety of ways and, as a result, some confusion in terminology has arisen. Lindsay, Riggall & Burd (1985) provide a table of synonyms for various terms used, but also propose a simple coding system. This is expanded in Lindsay *et al.* (1988).

Terrestrial (T) zones

T1	Low ridge ('lawn': Sjörs 1948) - common on mire areas which are free from damage; 1-10 cm above the mean water table; generally the richest zone for characteristic mire species
T2	High ridge - the general level of many mire surfaces, particularly outside pool systems; 10-20 cm above the mean water table
T3	Hummock - normally the highest element in the pattern and always bryophyte formed; 20 cm to 1 m above the mean water table
T4	Peat hagg - associated with erosion; 1-2 m above the mean water table
T5	Peat mound - occurs only in Shetland, Caithness, Sutherland and the Outer Hebrides; 1-3 m above the water table and possibly linked to incipient 'palsa' form, though the origins are as yet obscure

Aquatic (A) zones

A1	*Sphagnum* hollow ('carpet': Sjörs 1948) - a true hollow (i.e. aquatic phase) of dense *Sphagnum cuspidatum*; 0-10 cm below the mean water table
A2	Mud-bottom hollow (Sjörs 1948) - a hollow dominated by a relatively solid bare peat base, but with some aquatic *Sphagna*; 5-20 cm below the mean water table; not recorded from eastern Britain (including Caithness)
A3	Drought-sensitive pool (Lindsay *et al.* 1988) - an area of open water with an unconsolidated peat base which remains flooded for much of the time but in drought conditions will dry up; 20-50 cm below the mean water table
A4	Permanent pool (Lindsay *et al.* 1988) ('summer pool': Tubridy 1984) - an area of open water which is sufficiently deep to remain flooded even during extreme drought; 1-4 m deep; restricted to north-west Strathclyde, Tayside and regions north of them
TA2	Erosion gullies, resembling mud-bottom hollows but with flowing water

These surface features are arranged into patterned areas in various combinations. The range of surface patterns contributes significantly to variability within and between sites. The distribution and abundance of particular levels or zones in areas of patterning provide one level of variation, but in addition the form and orientation taken up by the patterns are an important factor. Figure 7 indicates in general terms the geographical variation displayed by these patterns across Britain. A site may, for example, consist purely of low ridge (T1) and high ridge (T2) without any true aquatic phase. Increasing wetness of climate gives rise to patterned areas of increasing complexity. In the driest areas of bog formation in Britain the aquatic phase, if it exists at all, tends to form small unaligned hollows (A1/A2), but with increasing wetness these hollows become markedly linear. Open-water hollows (A3) demonstrate extreme linear patterning towards the north and west of Scotland, whilst open-water pools (A4) are characteristically rounded, formed on the top of watersheds and restricted to the most northerly oceanic areas of Britain.

Erosion patterns and features can also be important characters in comparisons of mire mesotopes and macrotopes. The most obvious features are the deep erosion gullies and haggs typical of many plateau and watershed sites. Further north, erosion features include empty pools, leaving exposed beds of peat or even bedrock. Deep gully erosion is a well-known feature of peat in the Pennines, with gullies attaining depths of 2-3 m. However, if an erosion complex forms only in the surface skin of peat comprising the top few centimetres, both the gullies and the hags tend to be extremely small, with hags no more than 20-25 cm high and with diameters of 10-30 cm, surrounded by a network of interconnecting shallow channels. This is not intense erosion, as many channels support a wet matrix of *Sphagnum* and peat; nor, however, is it completely intact mire. The term 'microerosion' has been coined to classify this particularly abundant mire feature. On aerial photographs the mire surface appears to be dimpled or covered with a dense mass of rounded papillae, rather than with the dramatic linear patterns or heavy reticulate networks associated with hag and gully erosion. This stage may later develop into more serious gullying or sheet erosion.

Table 3. National Vegetation Classification: - bog communities and subdivisions (Rodwell 1991) within microforms (Lindsay *et al.* 1985, 1988)

1. Mire margin and smooth blanket mire

NVC	category
M15	*Scirpus cespitosus* - *Erica tetralix* wet heath
M15a	*Carex panicea* sub-community
M15b	Typical sub-community
M15c	*Cladonia* spp. sub-community
M15d	*Vaccinium myrtillus* sub-community
M16	*Erica tetralix* - *Sphagnum compactum* wet heath
M16a	Typical sub-community
M16b	*Succisa pratensis* - *Carex panicea* sub-community
M16d	*Juncus squarrosus* - *Dicranum scoparium* sub-community
M17	*Scirpus cespitosus* - *Eriophorum vaginatum* mire
M17b	*Cladonia* spp. sub-community
M17c	*Juncus squarrosus* - *Rhytidiadelphus loreus* sub-community
M18	*Erica tetralix* - *Sphagnum papillosum* raised and blanket mire
M18a	*Sphagnum magellanicum* - *Andromeda polifolia* sub-community
M18b	*Empetrum nigrum* ssp. *nigrum* - *Cladonia* spp. sub-community
M19	*Calluna vulgaris* - *Eriophorum vaginatum* blanket mire
M19a	*Erica tetralix* sub-community
M19b	*Empetrum nigrum* ssp. *nigrum* sub-community
M19c	*Vaccinium vitis-idaea* - *Hylocomium splendens* sub-community
M19ci	*Betula nana* variant
M19cii	Typical variant
M19ciii	*Vaccinium uliginosum* variant
M20	*Eriophorum vaginatum* blanket and raised mire
M20a	Species-poor sub-community
M20b	*Calluna vulgaris* - *Cladonia* spp. sub community
M21	*Narthecium ossifragum* - *Sphagnum papillosum* valley mire
M21b	*Vaccinium oxycoccos* - *Sphagnum recurvum* sub-community
M2	*Sphagnum cuspidatum / recurvum* bog pool community
M2b	*Sphagnum recurvum* sub-community

2. Mire expanse

2.1 Hummock/high ridge (T2-T4)

M17	*Scirpus cespitosus* - *Eriophorum vaginatum* mire
M17b	*Cladonia* spp. sub-community
M18	*Erica tetralix* - *Sphagnum papillosum* raised and blanket mire
M18a	*Sphagnum magellanicum* - *Andromeda polifolia* sub-community
M18b	*Empetrum nigrum* ssp. *nigrum* - Cladonia spp. sub-community
M19	*Calluna vulgaris* - *Eriophorum vaginatum* blanket mire
M19a	*Erica tetralix* sub-community
M19b	*Empetrum nigrum* ssp. *nigrum* sub-community
M19ci	*Betula nana* variant

2.2 Low ridge (T1)

M2	*Sphagnum cuspidatum / recurvum* bog pool community
M2a	*Rhynchospora alba* sub-community
M15b	*Scirpus cespitosus-Erica tetralix* wet heath, typical sub-community
M16c	Ericetum tetralicis wet heath, *Rhynchospora alba-Drosera intermedia* sub-community
M17	*Scirpus cespitosus - Eriophorum vaginatum* mire
M18a	*Sphagnum magellanicum - Andromeda polifolia* sub-community

2.3 Hollows (A1, A2)

M1	*Sphagnum auriculatum* bog pool community
M2	*Sphagnum cuspidatum / recurvum* bog pool community
M3	*Eriophorum angustifolium* community
M16c	Ericetum tetralicis wet heath, *Rhynchospora alba-Drosera intermedia* sub-community

2.4 Pools (A3, A4)

M1	*Sphagnum auriculatum* bog pool community
M3	*Eriophorum angustifolium* community
M4	*Carex rostrata-Sphagnum recurvum* mire
M16c	Ericetum tetralicis wet heath, *Rhynchospora alba-Drosera intermedia* sub-community

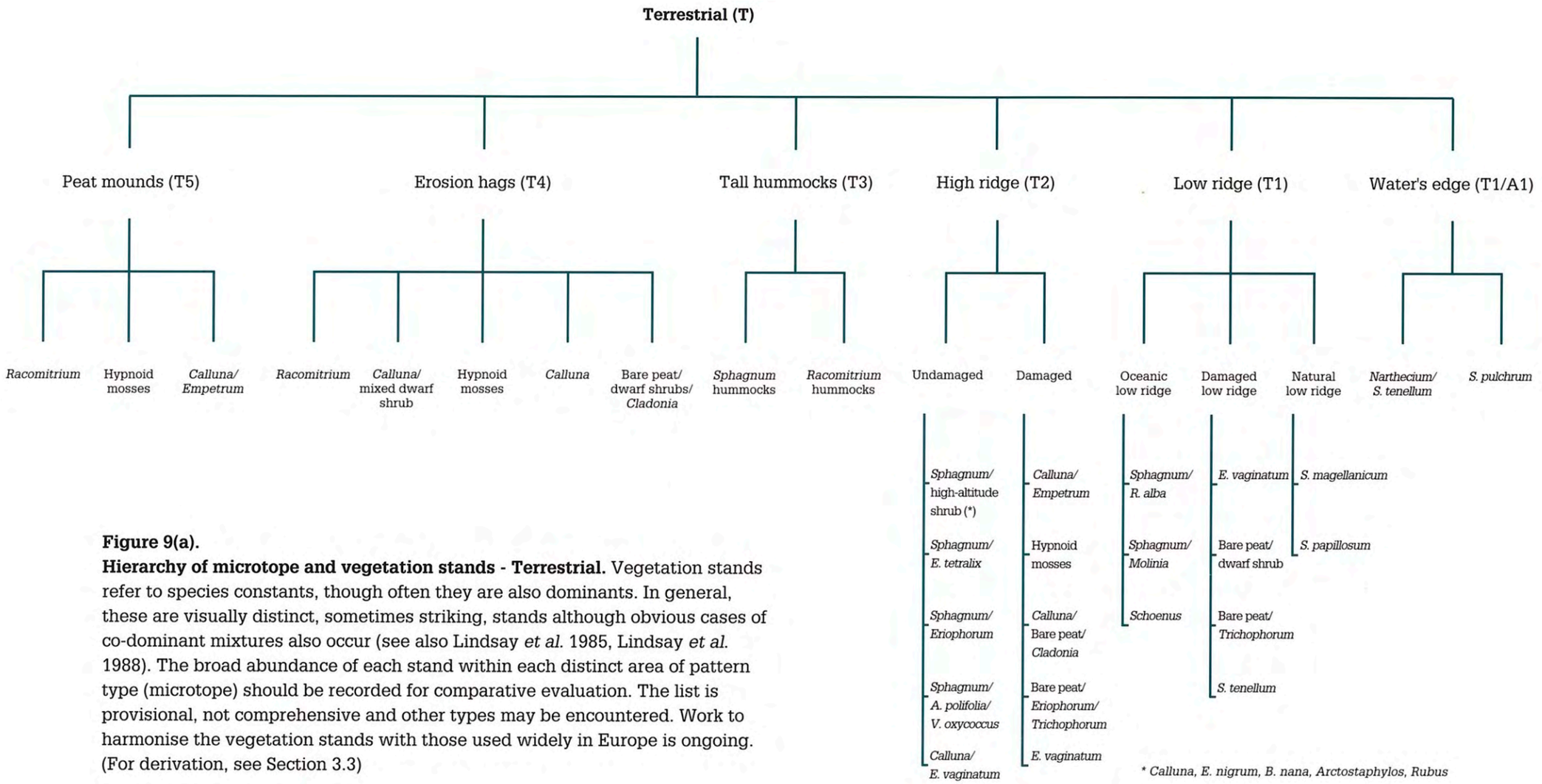


Figure 9(a).
Hierarchy of microtope and vegetation stands - Terrestrial. Vegetation stands refer to species constants, though often they are also dominants. In general, these are visually distinct, sometimes striking, stands although obvious cases of co-dominant mixtures also occur (see also Lindsay *et al.* 1985, Lindsay *et al.* 1988). The broad abundance of each stand within each distinct area of pattern type (microtope) should be recorded for comparative evaluation. The list is provisional, not comprehensive and other types may be encountered. Work to harmonise the vegetation stands with those used widely in Europe is ongoing. (For derivation, see Section 3.3)

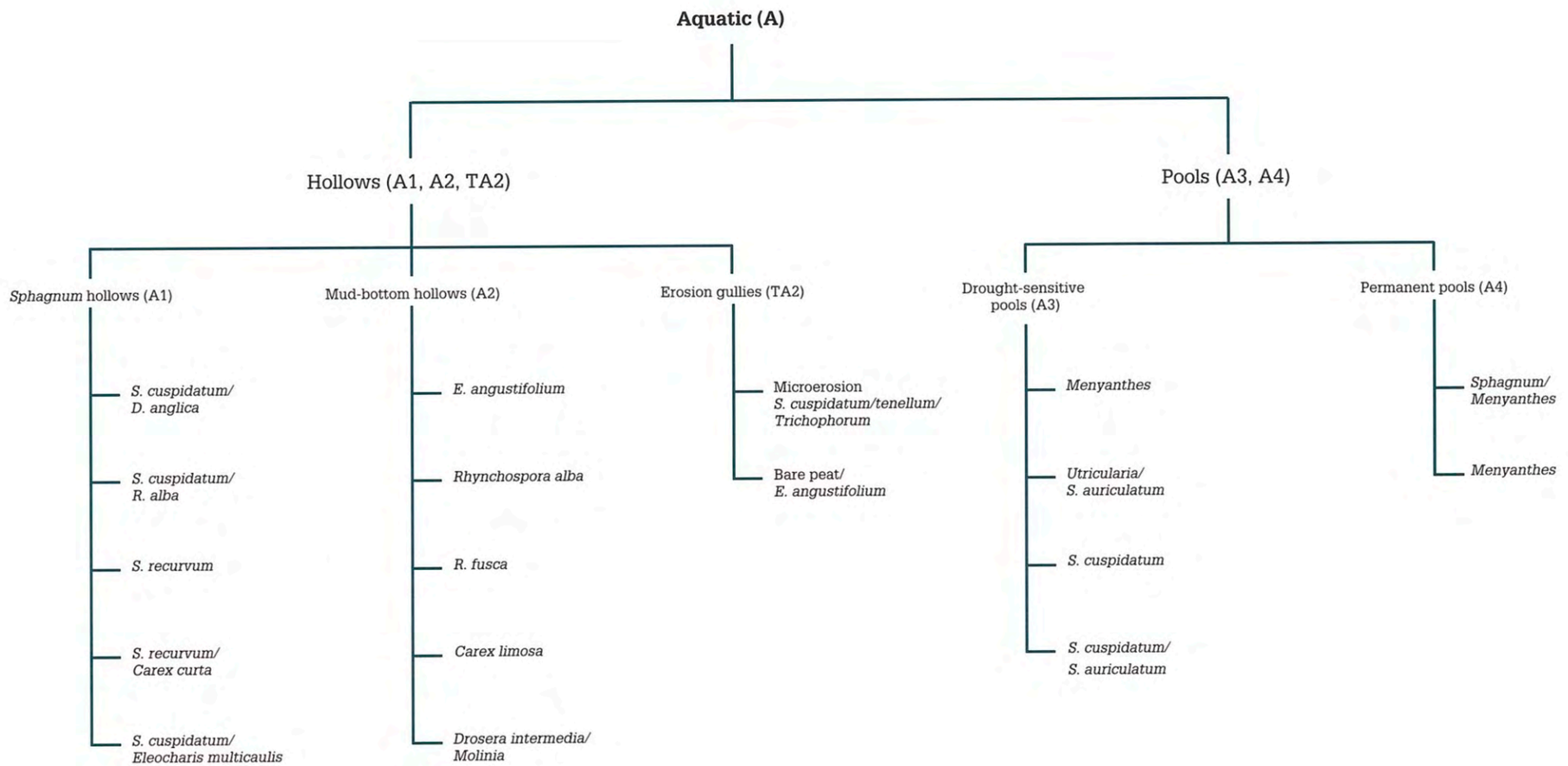


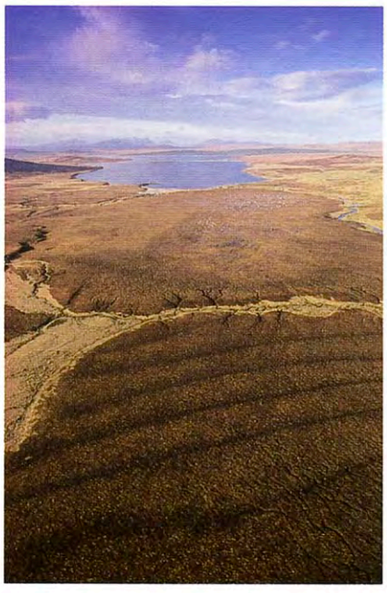
Figure 9(b).
Hierarchy of microtope and vegetation stands - Aquatic. Vegetation stands refer to species constants, though often they are also dominants. In general, these are visually distinct, sometimes striking, stands although obvious cases of co-dominant mixtures also occur (see also Lindsay *et al.* 1985, Lindsay *et al.* 1988). The broad abundance of each stand within each distinct area of pattern type (microtope) should be recorded for comparative evaluation. The list is provisional, not comprehensive and other types may be encountered. Work to harmonise the vegetation stands with those used widely in

R.A. Lindsay

Plate 1.
Carpets of *Sphagnum* plants form the building blocks of most peat bogs. Species include *Sphagnum magellanicum* (red), *S.pulchrum* (golden) and *S.papillosum* (khaki).

R.A. Lindsay

Plate 2.
Individual stem of *Sphagnum capillifolium*. Growth is from the apical bud in the crown, or *capitulum*, although buds in the axils of the branches up to 15cm below the capitulum can grow if the apical bud is killed or removed. Two sorts of branches are visible; the spreading branches with pigment, and the pendant or hanging branches which lie close to the stem and assist in creating the wick-like properties of the plant, drawing water up from below to maintain a water-filled capitulum. Leaves consist mainly of huge water-storage cells (*hyaline cells*).

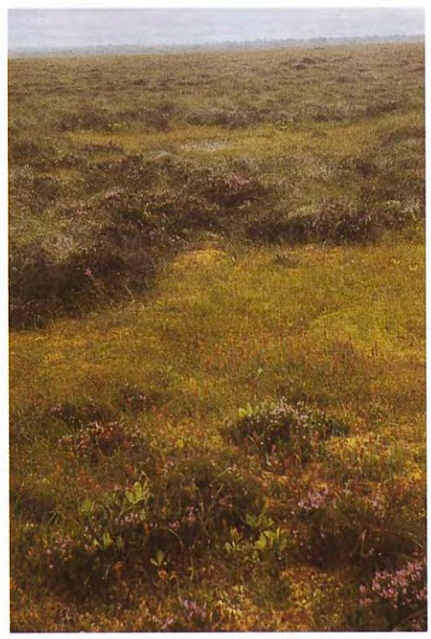


S.G. Moore

Plate 3.
The characteristic appearance of a peatland site from the air. In the foreground is a dome of peat which has been drained. The lines of drains are picked out by narrow bands of heather (*Calluna vulgaris*), but the more widespread effect of the drainage can be seen as the extensive development of *micro-erosion* (see Section 11). In the middle distance is another dome which is formed partly from peat growth and partly because the underlying mineral soil is domed; this is part of a blanket bog complex. A series of small blue pools is just visible on the crown of this dome.

S.G. Moore

Plate 4.
Flying over the crown of the pool-dominated bog in Plate 3, it is possible to see that the bog consists of a large dome of water on which a series of ridges appear to 'float' like a thin skin of vegetation holding the large mass of water in place. In fact the ridges do not 'float' in a strict sense, but are underlain with considerable depths of 'ridge' peat. The overall shape of the bog water-table is accurately displayed here.

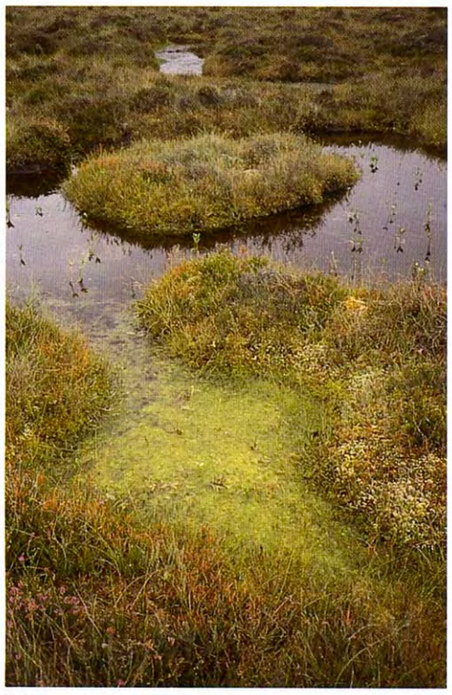


D.A. Goode

Plate 5.
Surface patterns - *Sphagnum* hollows. The paler orange depressions in this photograph indicate the soft carpets of aquatic *Sphagnum* which form continuous dense mats directly over the bog water-table. However, these mats are not sufficiently dense to stand on, as anyone attempting to cross the bog by stepping on these will discover to their cost.

R.A. Lindsay

Plate 6.
Surface patterns - mud-bottom hollows.
Strictly, the bottom of these shallow hollows is not mud, being largely composed of semi-decomposed plant debris (predominantly in Britain the leaves of *Molinia caerulea*) which has blown into the hollow and then been trapped by the surface tension of the water. On ombrotrophic sites this type of feature is particularly characteristic of the far west, but occurs widely as the typical form of pool (or *flark*) found in patterned fens.



(a) R.A. Lindsay

(b) R.A. Lindsay

Plate 7.
Surface patterns - open water pools. These pools vary from about 25 cm in depth to more than 4 m. The pool sides are generally quite sheer and are composed of relatively humified peat. Water tables which leave more than 25 cm of vertical pool-side face exposed can be taken to indicate a degree of hydrological instability in the system. Drought-sensitive pools shown in (a) are shallower than the deep permanent pools in (b).

R.A. Lindsay

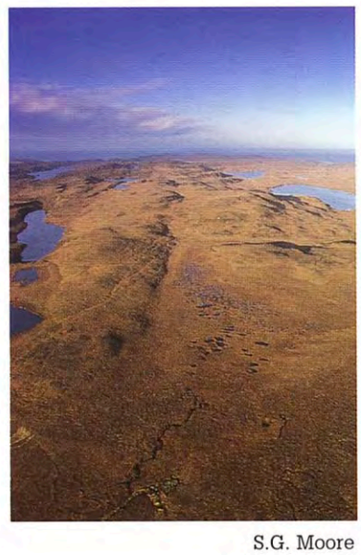
Plate 8.
Small-scale surface features - microtopography. This photograph demonstrates a characteristic arrangement of surface features in a bog which has patterning of the hummock-ridge-hollow type. In the centre foreground, a shallow [A2] mud-bottom hollow is bordered by two pale bands of [T1] low ridge dominated by *Sphagnum papillosum*, while to the extreme bottom-right, a darker [T3] hummock of *Sphagnum capillifolium* can be seen. In the very centre of the photograph, an island surrounded by [A2] hollows can be seen to have a fringe with variable amounts of [T1] *Sphagnum magellanicum* at the water table and a broader band of [T2] *S.papillosum* above this. It is crowned by a [T3] hummock of *Sphagnum capillifolium* on which cross-leaved heath (*Erica tetralix*), heather (*Calluna vulgaris*) and *Cladonia* lichens are the dominant species.

L. Gill

Plate 9.
Typical lowland raised bog. The original dome of peat has been reduced in extent by encroaching marginal farmland. All trace of any lagg fen has been lost, but the fields in the foreground are still waterlogged partly because they are on peat soils and partly because the bog water-mound raises the adjoining mineral soil water-table. Old drains can be seen cutting into the site, and associated with these there has been significant tree-encroachment.

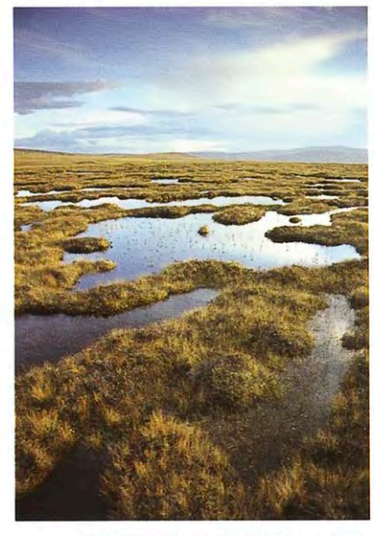
D.A. Goode

Plate 10.
Typical raised bog vegetation. Growing in a [T1] low ridge, or lawn, of *Sphagnum papillosum* are several species typical of the raised bog habitat. The red berries are the fruits of cranberry (*Vaccinium oxycoccos*), the pale pink flowers and narrow dark leaves are the bog rosemary (*Andromeda polifolia*), the pale green scimitar leaves are those of bog asphodel (*Narthecium ossifragum*) and the taller grassy stems are the common cotton grass (*Eriophorum angustifolium*).



S.G. Moore

Plate 11.
Typical blanket bog landscape. Most of the landscape here is covered with varying thicknesses of peat. The deepest parts tend to support the most extreme form of surface pattern characteristic of the climatic region - in this case very evident [T3] and [T4] pools. The thinnest areas of peat, usually on the steepest slopes, are slightly darker, indicating a greater abundance of heather (*Calluna vulgaris*).



S.G. Moore and R.A. Lindsay

Plate 12.
Typical north-western blanket bog vegetation. The predominant species visible is deer-hair grass (*Trichophorum cespitosum = Scirpus cespitosus*). Beneath this pale sward is a mixture of *Sphagnum, Erica tetralix, Narthecium ossifragum, Pleurozia purpurea* and *Campylopus atrovirens* with scattered *Racomitrium lanuginosum*. In the pools there are *Sphagnum subsecundum, S.cuspidatum* and bog bean (*Menyanthes trifoliata*).

hummock bases and lawns (51.112). Finally, it identifies the vegetation of individual microforms, such as *Sphagnum magellanicum hummocks* (51.1111).

For Britain the nine kinds of microform recognised by Lindsay, *et al.* (1985, 1988) can be related to vegetation types, corresponding especially with a vertical zonation of adaptation to water table. The NVC treatment for ombrotrophic mires is presented in Table 3. A first provisional classification for the small-scale approach, based on the collection of some 25000 samples from a total of 65 sites across Britain, can be seen in Figure 9. Work is currently ongoing, in conjunction with the Department of Plant Sociology, University of Vienna, to refine this classification, and also to provide a matrix whereby phytosociology, the NVC, CORINE and the small-scale system can be integrated.

In order to provide an adequate description of a site it is thus vital to ensure that sampling is carried out in such a way as to permit the small-scale pattern to be identified. Otherwise only the broadest, most generalised conclusions can be derived from the data.

Section 4 Bog Types in Britain

Goode and Ratcliffe (1977) gave only two morphological bog types for Britain, *raised bog* and *blanket bog*, although a *transitional* type is also mentioned. Hulme (1980) identified three types for Scotland - confined (raised), unconfined (blanket) and semi-confined (transitional). Moore and Bellamy (1974) also identify three types for Britain - raised, blanket and ridge-raised, whereas Goodwillie (1980) also records three types but classes them as continental raised bog, oceanic raised bog and blanket bog.

For Norway Moen (1985) provided a large number of bog types which accord more closely with the types recognised throughout continental Europe. His four morphological classes - typical raised bog, Atlantic raised bog, plateau raised bog and blanket bog - are grouped into 11 sub-types. Moore and Bellamy (1974) gave a shorter version of Moen's list for Europe as a whole, according more closely with the types identified by Eurola *et al.* (1984) for Europe, and by Davis and Anderson (1991) for Maine. Two main morphological types and one minor type, generally recognised by these and other authors (e.g. Ruuhijarvi 1960, Masing 1982, Sjörs 1983, Wells & Zoltai 1985, Steiner 1992), are identified.

The major types so identified are *raised bog* and *blanket bog*. These two types represent the recognisable end-points of an ecological continuum but are, for the most part, fairly distinctive. Sites can generally be assigned to one or the other type without difficulty. Both types have sub-categories, some of which have already been mentioned, but these are described in detail in subsequent sections. Their overall relationships, in terms of both bog sub-types and characteristic microform zones, can be seen in Figure 10.

This report does not deal with valley fens (often termed 'valley bogs'), basin fens (often termed 'basin bogs'), nor floating mats or *Schwingmoor* fenland (*sensu* Wheeler 1984) (as opposed to *Schwingmoor* raised bog - *sensu* Moore 1990).

There are, however, sites termed *Übergangsmoore* by Du Rietz (1954), which are transitional between ombrotrophic and minerotrophic conditions, particularly when the upper layers of a *Schwingmoor* develop sufficient thickness to approach an ombrotrophic condition. Such sites generally either form part of a larger blanket mire complex, in which case they can be considered as a component of the complex, or else they occur as incipient raised bogs in the lowlands, where they are sufficiently rare to merit particular attention.

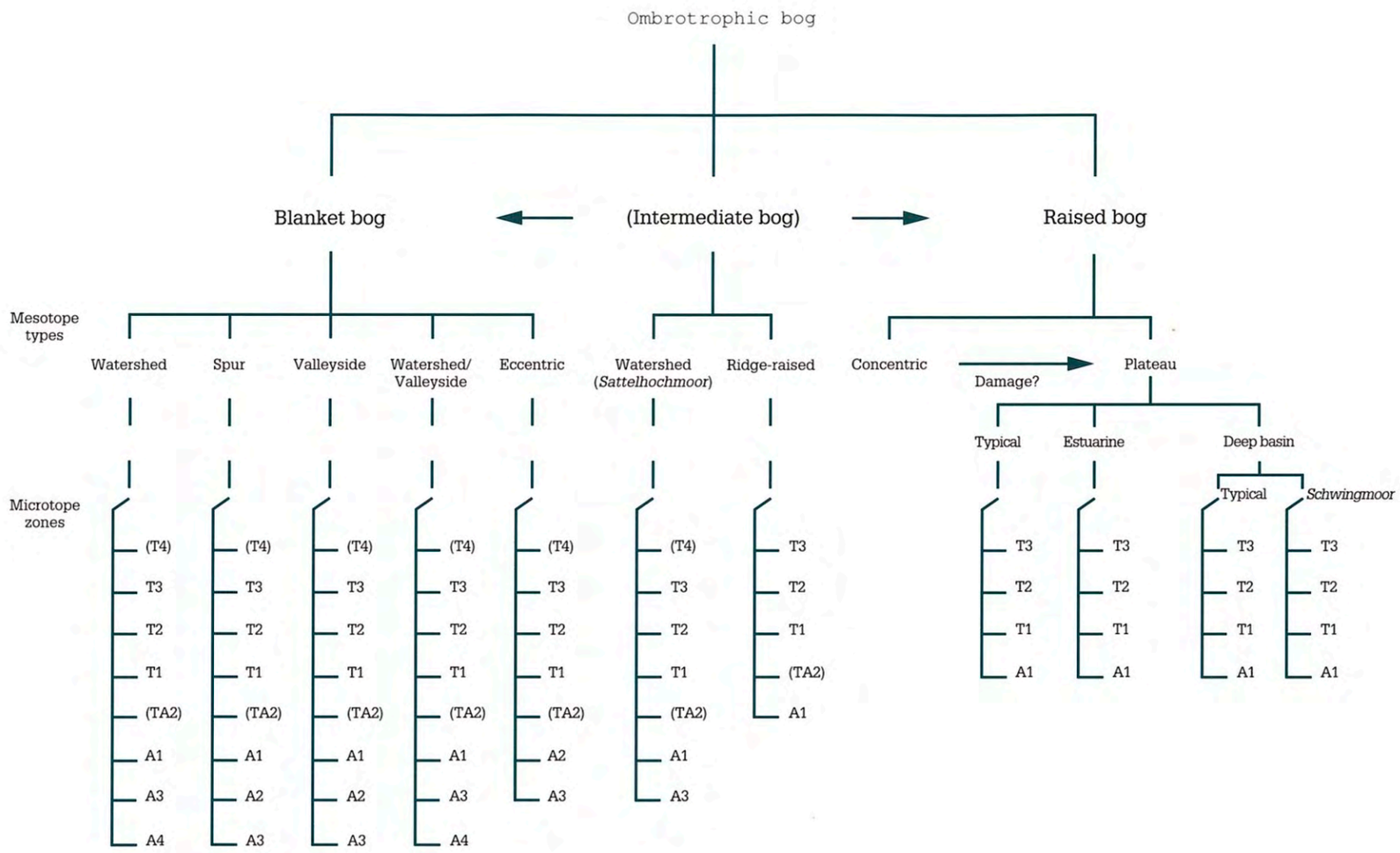


Figure 10.
Hierarchy of bog types, with associated small-scale microtope zones. The various types are described in Sections 4, 5, 6 and 7. Intermediate bog is shown as a type transitional between the two main types, and sites will generally be assigned to one or other of these main types, with a note that intermediate characteristics are present. The distribution of microtope zones between types is indicative rather than absolute.

Section 5 Definition and Sub-Categories of Raised Bog

Raised bog takes the shape of a relatively simple dome, the surface contours of which are largely independent of the mineral-soil contours beneath the peat (Plates 9, 10). The basal contours may show undulations, but rarely are these of sufficient magnitude to exceed the depth of peat which forms the bog. Such bogs are thus frequently found on low plains or broad valley floors. Raised bogs form under a range of conditions from strongly oceanic to relatively dry continental climates, and are widespread in boreal regions. Many overlie sites of shallow glacial lakes which became infilled and occupied by fen, and which under the influence of the climate subsequently continued to develop into the classic dome of a raised bog. Raised bog types therefore generally contain evidence of earlier geotrophic phases within their stratigraphic record.

The typical raised bog occurs in the lowlands and is frequently referred to as 'lowland raised mire'. As such it represents an isolated unit, or small complex of units, of ombrotrophic peat lying within a landscape not dominated by bog peat. Raised bogs can be found lying within a larger area of fen peat. On flood-plains it is not uncommon to have a group of raised bogs, but in such circumstances each dome is a discrete entity and is separated from its neighbours by a lagg stream. The individual domes are never fused. Usually the sites in Britain are surrounded by agricultural land, although some of this land may once have formed part of the original bog.

An intact raised bog usually has a gently domed profile with peat depths greatest beneath the mire expanse then decreasing gradually towards the margins. It overlies at least some geotrophic fen peat, usually corresponding to the deepest parts of the bog, though such deposits may be localised. The edges are marked by a steeper *rand* (sloping mire margin) which is sometimes bounded by a geogenous fen or *lagg*.

Typically a raised bog in Britain may contain hummocks, high ridge, low ridge and *Sphagnum* hollows, although, instead of the whole spectrum from T3 to A1, it is commoner to find only a selection of these. Peat mounds and the aquatic zones A3 and A4 do not occur on raised bogs in Britain but are a common feature of such sites in regions of Fennoscandia and occur occasionally on raised bogs in Ireland. True mud-bottom hollows (A2) are not found on raised bogs in Britain, although they do occur commonly in western Ireland. Major erosion features are also unknown except for rare cases of damage resulting from bog 'bursts' (for a dramatic sixteenth century account of such an event, see Smith 1910).

The features typical of an undisturbed raised bog can therefore be summarised as:

- a single dome of ombrotrophic peat;
- the dome tends towards a half-ellipse in vertical section, with the margin (rand) showing a more pronounced gradient than the centre;
- apart from the lagg fen, the wettest part of the dome is generally to be found on the highest point, at the centre;
- the dome is produced entirely by peat growth and owes little or nothing to the underlying terrain;
- the dome overlies a greater or lesser extent of fen peat deposits, having developed at least in part by terrestrialisation;
- at the margins the bog water table links with the groundwater table; the mixed hydrology gives rise to fen (lagg fen) which may surround the dome of peat;
- the dome may adjoin other similar domes in a raised bog complex, but the individual lenses remain separate entities and generally do not fuse with adjoining lenses;
- the domes in such complexes are linked hydrologically only through their lagg

fens or streams; and

- the dome, or complex of domes, generally now lies within a non-peat landscape (usually agriculture), although remnants or evidence of other semi-natural habitat, including fen peat, may persist within this landscape.

Morphological sub-types of raised bog

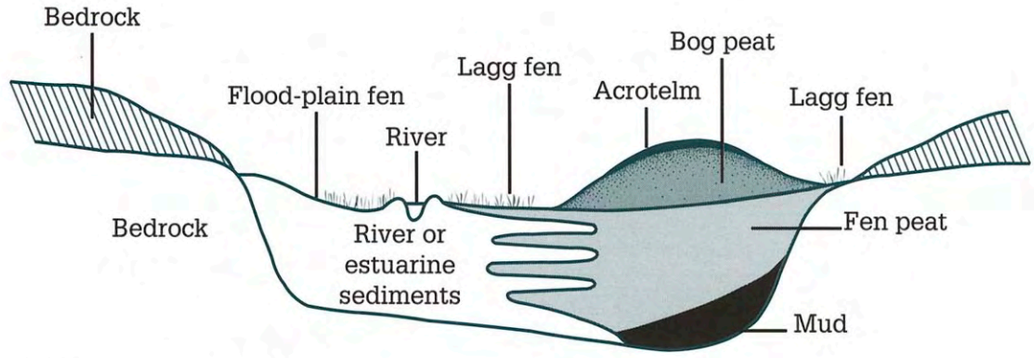
Published classifications show reasonable agreement leavened with some confusion in Europe about the range of bog types which exist, as well as the particular features which can be used to distinguish, classify and describe them (Moore & Bellamy 1974, Goodwillie 1980, Sjörs 1983, Eurola *et al.* 1984, Moen 1985). In particular, there is confusion about one of the types of bog which characterises the western seaboard of Europe. Goodwillie (1980) provided a description of *oceanic raised bog*, which he describes as isolated units of peat which are tending to escape the confines of their natal basins, and often possessing some concentric patterning. Moen (1985) described a type called *Atlantic raised bog* which has often been taken to be synonymous with Goodwillie's type. It is not. It describes units of peat which lie within blanket mire landscapes, are contiguous with surrounding blanket peat and are *demonstrably* convex because of peat growth alone. These two types were both described by Hulme (1980), who called the first *semi-confined mire*, and Moen's type *unconfined mire*. Following the 6th International Mire Conservation Group Symposium, in Norway, 1994, it has been proposed that the following approach be adopted:

- all bogs where the dome is created largely by peat growth alone, and the peat thickness exceeds any underlying variation in the terrain, be called *raised bog*;
- those examples which form relatively simple, discrete units of such domed peat, and which are most prevalent in the lowlands, be called *confined raised bogs*;
- those which form discrete units, though spilling beyond their natal basins and typically showing greater altitudinal variation, either towards their margins or across their points of fusion (if two lenses fuse), than is possible through peat growth alone, be called *semi-confined raised bogs*; and
- those which lie within a continuous mantle of blanket mire be called *unconfined raised bog units*.

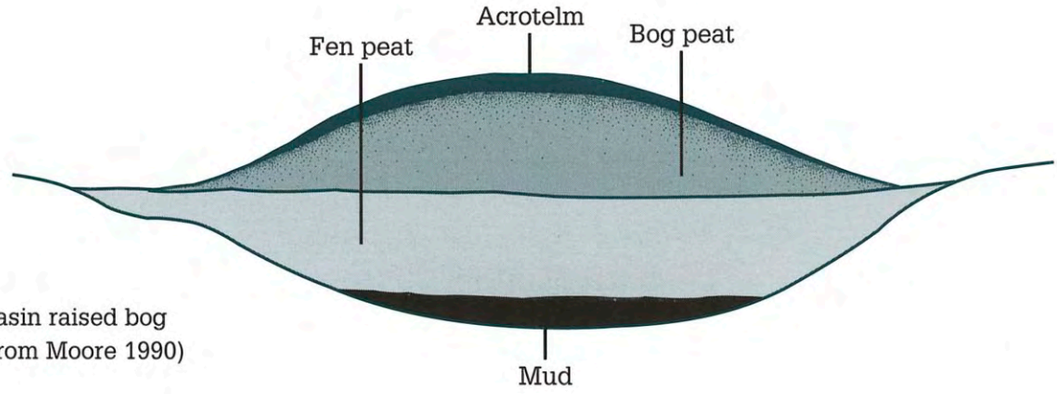
Consideration in this section will be focussed on the *confined raised bog* and the characteristic sub-types which it displays. Unfortunately it is impossible to determine the original distribution of morphological sub-types for raised bog in Britain because the resource is now so universally damaged. In particular the two most likely raised bog types originally to have existed in Britain, *plateau bogs* and *concentric bogs*, can no longer be distinguished. From what remains today it seems that, throughout lowland Britain, only Moen's (1985) *plateau raised bogs* predominate. Some of these may once have been concentric bog, but the scale of damage is now such that concentric patterning is no longer evident. Plateau/flat raised bog is a form of raised bog consisting of a flattened ellipse on which any surface patterning is distributed without either eccentric or concentric orientation. Central parts of the dome have little gradient, although close to the margin a distinct sloping edge, or rand, is evident.

Sub-categories of confined (plateau) raised bog

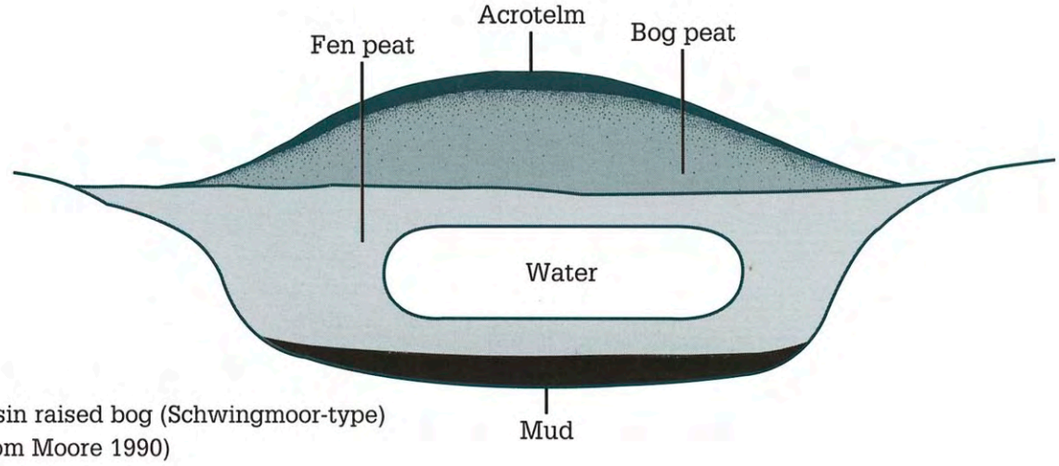
Having established the broad morphological sub-type, it is then possible to identify further sub-categories on the basis of hydrology, topography and development sequence. Such differences contribute significantly to the



Flood-plain or estuarine raised bog
(adapted from Steiner 1992)



Basin raised bog
(from Moore 1990)



Basin raised bog (Schwingmoor-type)
(from Moore 1990)

Figure 11.
The main types of raised bog, based on profiles provided by Steiner (1992) and Moore (1990). Flood-plain and estuarine raised bogs show the same general profile, except in the former there is evidence of freshwater incursion whereas the latter contains intermittent marine sediments. Schwingmoor is a special form of basin raised bog which retains an occluded lens of water.

process of defining the overall scientific interest of a raised bog (figures 1 and 11).

Typical raised bog

This occurs as discrete areas of raised bog peat surrounded by mineral ground, usually formed on alluvial or fluvioglacial flood plains but always beyond the influence of marine incursions. It may be found from a few metres above sea level up to a little under 300 m Ordnance datum (OD). It typically possesses late-glacial sediments and has a relatively uninterrupted post-glacial stratigraphy. It may display a development history which follows the 'classic' sequence of lake terrestrialisation followed by ombrotrophic bog growth, or may have formed over more undulating terrain in which a number of small basins have coalesced, sometimes over quite low ridges, to form a single dome. Typically the depth of peat forming the dome exceeds, and therefore obliterates evidence of, any such sub-surface undulations. Transitions with fenland or freshwater bodies such as lakes or rivers may also be evident.

This type is the commonest form of raised bog in Europe, occurring from south-central Scandinavia to the southern Alpine region, and from central Ireland to Siberia. However, two types possessing rather different characteristics are to be found on coastal plains and in 'dead ice' terrain (characterised by frequent kettle-holes).

Estuarine/lower flood-plain raised bog

This type occurs below 100 m OD and is generally formed over estuarine sediments resulting from ancient land/sea level changes. Evidence of such changes is usually to be found in the somewhat discontinuous peat archive and can be very important in determining the nature and chronology of these events. The duration of peat growth is often shorter than in the case of typical raised bog, depending on the timing of land/sea level changes. Transitions with maritime habitats may still be evident today, providing a now extremely rare ecological boundary zone.

Basin raised bog (including raised bog *Schwingmoor)*

These sites should not be confused with basin fens, although a mosaic of the two often occurs within a single topographic basin. Developed usually from a floating *'Schwingmoor'* mat in deep basins or more often over kettle-holes, these sites have usually undergone an extended period of seral succession through lake and fen phases. Evidence for the fen phase may persist as a very pronounced lagg around the central peat dome and/or an occluded water body beneath the present dome of peat. The stratigraphic record of bog peat tends to be shorter than that for 'typical' raised bogs because the process of fenland terrestrialisation takes longer in such deep basins. However, because of this extended lake and floating fen phase of terrestrialisation, the archive may contain much more extensive and larger artefacts than is usual for most raised bog types, particularly where, for example, animals may have drowned during the original swamp and fen *schwingmoor* phase of such sites.

Where a significant proportion of the original kettle-hole lake survives beneath the raised bog peat, the surface of the bog may be significantly less stable than in other types. Such types have been termed *schwingmoor raised bogs* by Moore (1990), but care must be taken to distinguish between these and sites where the living surface remains little more than a thin floating raft and is thus at least occasionally geotrophic - such geotrophic sites are the poor-fen and transitional rich-fen basin mires of Wheeler (1984) and the Übergangsmoore of Du Rietz (1954), (see also Steiner 1992, Figure 12, p.45). Peat coring and topographic survey would be needed to be confident that the living surface is significantly domed above the groundwater régime of the basin.

The other major morphological type of bog is *blanket bog*, a peat formation which probably reaches its extreme world development in western and northern Britain and in western Ireland, reflecting the cool, intensely oceanic climate. The tendency to conditions of soil waterlogging favourable to *Sphagnum* growth and peat formation (paludification) in such areas are such that bog development is no longer confined to level terrain or basins, but occurs on all but the more steeply sloping ground. It therefore covers many of the gentler uplands in a smothering mantle; hence the descriptive name (Plates 11, 12).

As gradients of climate increasingly create a water surplus by causing the ratio of precipitation to evaporation to rise, so, in a north-westerly direction across Britain, conditions for extensive bog formation become more favourable. A prevalence of hard, acidic rocks and base-deficient soils also favours the development of acidophilous bog vegetation, while the cool humid climate promotes leaching and podsolisation which reinforce these edaphic tendencies. The blanket peat formed under these conditions is nutrient poor and highly acidic. The phosphorus and nitrogen balance of such soils is particularly critical, which, in contrast to fen peat soils, makes them an intractable medium for cultivation (Williams 1992).

Peat growth is related to degree of waterlogging and stagnation, and hence to angle of slope, but in the north-west Highlands significant peat development can be found on slopes of up to 35° on shady aspects, and in the wettest parts of Scotland and Ireland chemical/edaphic limitations can be so overridden that acidic peat forms even over limestone. Blanket bog has a much more complex topographic form than raised bog because of the more varied conditions under which it develops. It may change suddenly at a mire margin formed by a rock face, or grade imperceptibly into the vegetation of drier mineral soils through a transition of wet heath or grassland.

Blanket bog arises through a combination of both paludification and terrestrialisation. Basins in the topography undergo terrestrialisation and eventually form raised domes of peat, but given a climate typical of blanket bog the process of paludification is capable of covering gentle slopes and plateaux with peat as quickly as, or more quickly than, the adjoining basins develop domed bogs. Although, as discussed above in relation to raised bogs, elements within the blanket bog landscape may be domed, these convex units may be domed because the underlying terrain is domed. In cases where the convex shape is derived purely from peat formation, the unit falls into the category of *unconfined or Atlantic raised bog*, but can only be so defined when its profile has been determined conclusively, which therefore tends to restrict the class to a limited number of sites. Furthermore, in such fused blankets of peat it is more logical to consider such areas with the more similar surrounding matrix of blanket bog than with lowland examples of raised bog. The significantly harsher and wetter conditions typical of blanket bog regions mean that such domed elements are generally very different from lowland raised bog in character. They have a more humified peat, a distinctive hydrological budget and a species complement indistinguishable from the surrounding blanket bog. Species generally or entirely restricted to blanket bog as opposed to lowland raised bog in Britain include *Betula nana, Arctostaphylos uva-ursi, Eleocharis multicaulis, Carex limosa, Rubus chamaemorus, Cetraria islandica, Pleurozia purpurea*, and the breeding bird assemblage of dunlin (*Calidris alpina*), golden plover (*Pluvialis apricaria*), merlin (*Falco columbarius*), hen harrier (*Circus cyaneus*) and short-eared owl (*Asio flammeus*). The entire complement of

hydrological units which make up the peat-covered landscape should therefore be regarded as sub-units of blanket mire. Such an approach is in accord with classification systems from other parts of the globe which support blanket mire, such as Norway (Moen 1985), Ireland (Cross in press), and Canada (Zoltai & Pollett 1983).

The question of ombrotrophy, minerotrophy and geotrophy in blanket mire, is, however, far more intractable. Moen (1985) is careful to distinguish between blanket *mire* and blanket *bog*. The latter he identifies as the clearly ombrotrophic parts of a peat-dominated landscape as exemplified by watershed summits. Peat formed on slopes may be quite thin and is often subject to flushing either from surface runoff or from upwellings of the mineral groundwater table. In continental literature much of this is regarded as various types of *sloping fen*, although the term is not widely used in Britain nor in Ireland. Moen (1985) defines blanket *mire* as the entire landscape, which includes such sloping fens and ombrotrophic hill summits.

Within the blanket bog complex there are widespread features, generally known as *flushes*, where water is channelled over the bog surface into distinct lines of water collection and transport. This may or may not incorporate geotrophic water, but such features are widely recognised as *soligenous* and *rheotrophic* (i.e. derived from and fed by moving water) fenland rather than ombrotrophic bog. Where no such obvious water-tracks exist it is generally still possible to identify the presence of true geogenous fen within areas of sloping blanket bog because the vegetation is dominated by *Carex* species or 'brown mosses' (such as *Calliergon cuspidatum, Campyllium stellatum* and *Scorpidium scorpioides*), and is associated at its upslope limit with either a distinct point source or a wide band of seepage cutting across the slope. Steiner (1992) (see Figure 9, p.42 and Figure 11, p.44) distinguished the two types as 'surface flush' Überrieselungsmoor and 'percolation mire' Durchströmungsmoor.

Most difficult of all to define is the type of sloping ground where there is *no* evident source, the water does *not* appear to be geotrophic, but the vegetation on the slope is evidently flushed by a general *surface* seepage. It is equivalent to an amalgam of Steiner's (1992) 'surface flush' and 'percolation mire' but with neither an evident emergence of groundwater nor any distinct water-track. Scandinavians tend to describe such ground as a form of sloping fen (e.g. Moen 1985), but much of the background blanket bog vegetation is anyway fen-like because it is flushed by both salt spray and considerable quantities of rain. Distinguishing the more typical examples of Scandinavian 'sloping fen' - Austrian 'percolation mire' - of which there are several good examples in Britain, from peat enriched by these various other factors occasionally presents considerable difficulties. In such circumstances the effort of positive separation into oligotrophic sloping fen and slightly flushed blanket bog gives few additional conservation benefits.

The major mire mesotopes (or units) representing the 'building blocks' within blanket bog complexes are described below (see also Figures 2 and 12). Separate mesotopes are defined on the basis of hydromorphology and topography. They may merge across areas of thin peat, but generally consist of deeper peat occupying distinct topographic positions within the landform. Stereoaerial photographs provide the most effective and most commonly used technique for identifying such units.

Component mesotopes are watershed, valleyside, spur, saddle and intermediate mires (among bog types) and soligenous and topogenous fen units. Non-peatland features include wet heath and grassland, dry heath and grassland, streams and rivers, tarns and lakes, and rock outcrops.

Where pool and hummock systems are developed, mesotope units often appear well defined, but where such patterning is absent they may be difficult to recognise without the help of stereoaerial photographs. All surface features recorded for British bog systems can be found on blanket bog. In particular, peat mounds are a feature unique to this bog type, and permanent pools are shared only with eccentric bog. Erosion features are often abundant in areas of blanket bog.

Features typical of blanket bog are:

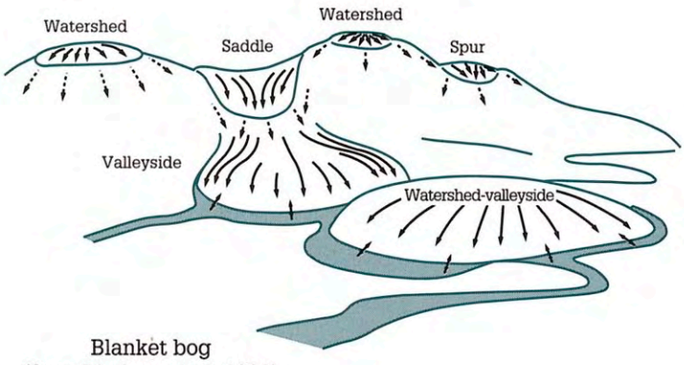
- the landscape is cloaked with peat, with non-peat areas representing isolated islands or corridors - particularly evident from soil maps;
- the peat thickness varies from only a few centimetres to 7-8 m;
- the peat is generally ombrotrophic;
- significant parts have clearly formed through paludification rather than terrestrialisation - particularly evident on slopes;
- the shape of the peat units in most cases is derived at least in part from the shape of the underlying terrain;
- separate hydrological units can be identified, but many are directly fused with others, rather than being invariably separated by lagg streams;
- marked surface patterning, particularly with A2/A3/A4 pools, is a feature found in Britain only on blanket and eccentric bogs (the presence of these features is a positive indicator, but their absence cannot be used as a negative indicator);
- widespread presence of erosion features.

Sub-categories of blanket bog

Blanket bog may initially appear to be a relatively uniform mantle of peat - 'a wet desert' as a local councillor once commented on being shown a particularly fine tract of bog. However, look more closely and, as with most supposedly featureless deserts, distinct elements can be distinguished within the peat mantle. The most readily distinguished units are those based on topography and hydromorphology. It then becomes possible to describe and sub-divide the whole of the general mantle using relatively few descriptive units which have been thus characterised. These descriptive sub-categories are outlined below and provide the basis for a broad sub-division of the resource. However, as always, these classes are not absolute, discrete entities - they lie on a continuum and thus gradients between types will be encountered.

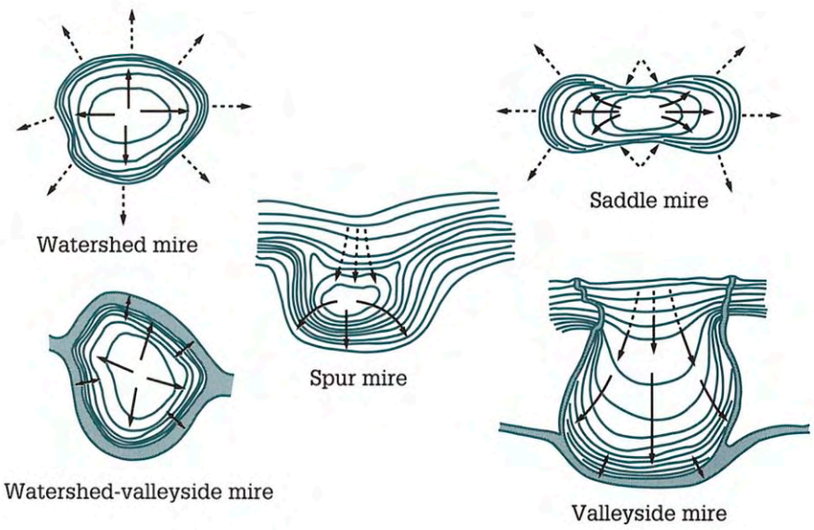
Nonetheless, with the aid of stereoaerial photographs to determine gradients (which can sometimes be so subtle or deceptive as to defy determination by eye in the field) the sub-categories can generally be readily determined from within the general matrix. The boundary between one unit and the next is inevitably somewhat arbitrary (without undertaking a multifactorial study which, even then, may leave too many questions unanswered) but will generally represent a relatively narrow zone lying between the two obvious units. Once all units within the blanket have been so identified, a few areas will probably still remain to be assigned. These are generally areas of extensive thin peat with few evident hydrological connections or broad topographical characteristics, or else are areas of deeper peat on exceptionally long slopes. Peat in the latter category will usually be assigned either to the lower parts of one unit or to the upper reaches of another unit downslope, but on the few occasions where the length of slope renders this unreasonable the ground

Fig 12.

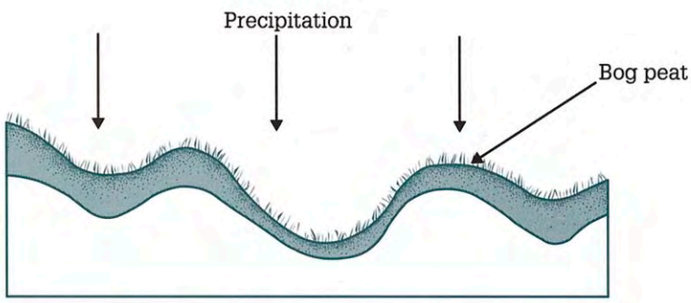


Blanket bog
(from Lindsay et al. 1988)

(a) Blanket bog landscape showing waterflow-lines. Solid flow-lines indicate the flow of water through deep peat; broken lines indicate the flow of water through shallow peat or mineral soil.



(b) Plan views of landscape features showing flow of water through deep peat (solid arrows) and shallow peat or mineral soil (broken lines).



(c) Sectional view of blanket mire (from Steiner 1992).

Figure 12.
The hydromorphological and topographical characteristics of blanket bog. Climate diagram typical of blanket bog regions taken from Walters & Lieth (1960) - for detailed description of climate diagram, in English, see Grünig (1994), p.56.

can be assigned to a general 'thin or sloping peat' category. For a general indication of the features visible on an aerial photograph of such a landscape, see for example, Goode and Lindsay (1979, Plate 1).

Watershed mire

This type occurs on watershed plateaux or broad ridges, where the surrounding land slopes away on all sides. The topographic situation varies from flat hilltops surrounded by steep slopes (e.g. Kinder Scout in the Peak District) to many of the vast flows on the gently contoured moorlands of Caithness and east Sutherland. This is the most clearly ombrotrophic type: there is no higher ground from which groundwater can drain. The only source of water is precipitation, direct or occult. Where patterns occur, they are mostly only small *Sphagnum* hollows or scattered pools in England and Wales, but in the north and west, watershed bogs show a wide range of surface patterning, and in the far north of Scotland they exhibit the extreme variant with the typical T3 and T4 deep, rounded, open-water pools (dubh lochain). Many watershed mires are massively eroded, and thus also contain extensive examples of T4 erosion hagg and TA2 erosion gullies (see Taylor 1983, Figure 1.11).

The characteristics are:

- within the bog unit itself, no ground, other than small rock outcrops, lies at an altitude greater than the bog;
- the margins fall away downslope on all sides;
- other than artesian upwellings, no water except direct precipitation can influence the bog and its margins; and
- if pools exist, they tend in central parts to be rounded or un-oriented, and may be very deep.

Valleyside mire

This type occurs on gently sloping or almost level ground lying between higher, steeper terrain and a watercourse or other water body which forms its lower margin. Slight enrichment may be apparent in the vegetation, for example increased *Molinia*, and, where there is frequent or strong water movement through a peat surface, these areas may grade into sloping fen. Valleyside mires are most clearly defined where there is surface patterning, typically with curved elongated pools following the contours. Hollows are usually A1-A3 (see Table 2 and Figure 8), and where A4 types occur they are typically near the upslope limit of the system. Whilst watershed and valleyside mires appear distinctively different when separated by a break in slope, there are many situations in which the one grades imperceptibly into the other, and drawing a distinction between them is then both arbitrary and pointless. Thus a single mound of mineral ground, bounded on all sides by streams, may be cloaked by a mound of peat which is both watershed and valleyside mire. Such systems are thus called watershed/valleyside, to distinguish them from hilltop watershed mires. The majority of the individual bogs of the Silver Flowe, Dumfries and Galloway, are of the valleyside or watershed/valleyside type, though the more isolated units of Craigeazle Bog and Snibe Bog towards the lower part of the valley have been assigned by some authors to raised bog. Taylor (1983) describes the whole system as a 'hybrid', but on balance it appears to be more logical to characterise the whole complex as a set of distinctive components within a much wider blanket bog landscape. Many valleyside and watershed/valleyside bogs are severely eroded (see Goode & Lindsay 1979, Plates 1, 6 and 7).

The characteristics are:

- the bog has an upslope margin and a downslope margin;
- the bog often has its crown close to the upslope margin, and thus the general body of the site has a single orientation of the gradient towards the downslope margin but a smaller proportion slopes towards the upslope margin;
- the downslope margin is bounded by a river or water body;
- the upslope margins may be influenced by seepage water running from the slope above;
- the downslope margins may be influenced by inundation from the river, or subject to erosive scouring; and
- if pool or hollow patterning exists it tends to be distinctly linear in character, though somewhat more rounded towards the crown.

Spur mire

Where the shoulder of a hill flattens into a broad spur, this small plateau often carries a patch of blanket bog with a distinctive form. Some of the bog will have the character of watershed mire, but ground closest to the slope above the spur may receive drainage water which provides a minerotrophic of soligenous influence. Occasionally, the spur topography has a basin-like form, and this may give rise to a peat lens resembling a more typical domed bog. The distinctive feature separating this from valleyside mire is that its lower edge is not associated with a river or lake but instead is delimited by a steepening slope. The bog at the head of the Silver Flowe, the Round Loch and Long Loch of the Dungeon, consists of three small spur mires.

The characteristics are:

- an upslope margin and a downslope margin;
- the bog often has its crown close to the upslope margin, and thus the general body of the site has a single orientation of the gradient towards the downslope margin but a smaller proportion slopes towards the upslope margin;
- the downslope margin is bounded by an increasingly steep slope;
- the upslope margins may be influenced by seepage water running from the slope above; and
- if pool or hollow patterning exists it tends to be distinctly linear in character, though more rounded towards the crown.

Saddle mire

This is similar in many respects to spur mire, but it lies in the depression between two higher slopes and so may receive a soligenous influence at each end. The mire may be largely ombrotrophic if the higher ground at each side slopes gradually upwards from the col. Depending on the angles of slope below the saddle, the mire extends downwards on either side, giving the appearance of a horse's saddle. If the ground at Dry Loch, right at the head of the Silver Flowe Valley, had not been planted, it would probably have supported saddle mire. Any peat such as there was has been lost beneath the trees, but the contours on the 1:50000 or particularly the 1:25000 (NX48) scale map are quite characteristic.

The features of a saddle mire are:

- the bog has two upslope and two downslope margins;
- the downslope margins are at right angles to the upslope margins (which face each other) - the bog thus curves in two directions like the seat of a saddle;
- the upslope margins may be influenced by water seepage from the slope above;
- the downslope margins are bounded by increasingly steep slopes; and
- if distinct patterning exists it tends to be linear except right in the very centre of the saddle, where it may have one or two rounded pools or non-oriented features.

Eccentric mire

Davis and Anderson (1991) provided a detailed account of a peat bog type which was not recorded for the North American continent prior to 1983. Termed *eccentric bog*, the type is identified as analogous to the eccentric bogs described from Fennoscandia by Ruuhijarvi (1960), Sjörs (1983), Eurola *et al.* (1984) and Moen (1985). Steiner (1992) described a similar type which he calls *Hanghochmoor* for Austria (see Figure 13).

Davis and Anderson (1991) stated that eccentric bogs slope mainly in one direction and that they occur on valleysides. They abut mineral upland at their upslope margin, whereas the downslope limit borders on an unpatterned fen which then itself borders a lake or stream in the valley bottom. The bog slope normally has a surface pattern of near-linear ridges and hollows aligned at right angles to the slope (Plate 13). The whole bog can be 'fan-shaped', with the narrow hinge of the fan at the upslope margin of the site. A concentric bog with its centre offset is not an eccentric bog because it slopes appreciably down on all sides from the highest point, and the highest point does not adjoin high ground.

The type has not been widely recognised for Britain, and Goode and Ratcliffe (1977) described the site as a raised mire complex. However, Moore and Bellamy (1974) and Moore (1977) described the site more neutrally as an eccentric mire complex. That site, plus Kentra Moss and possibly Blar na Caillich Buidhe, all occur within a limited region of Lochaber and Argyll. They clearly meet the criteria laid down by Davis and Anderson (1991) but lie within an overall complex of blanket peat. It is therefore proposed that these examples be termed 'eccentric bog', and are assigned to the blanket bog assemblage because all examples in Britain occur within blanket bog - none are recorded for the environment characterised by lowland raised bogs. Possible confusion may nevertheless still arise about these sites because their similarity with the form of blanket bog termed *valleyside flow* is evident. However, the patterns are very much more extreme than is typical for normal valleyside flow, and Taylor (1983) commented that the patterns of the Silver Flowe, though asymmetric, are not sufficiently so to 'merit the appellation "eccentric" raised bog (sic)'. In this case it thus seems reasonable to conclude that the widely recognised term eccentric bog can be applied to a few localised sites in Britain. The type is most strikingly recognised from stereo-aerial photographs (see Ratcliffe 1977).

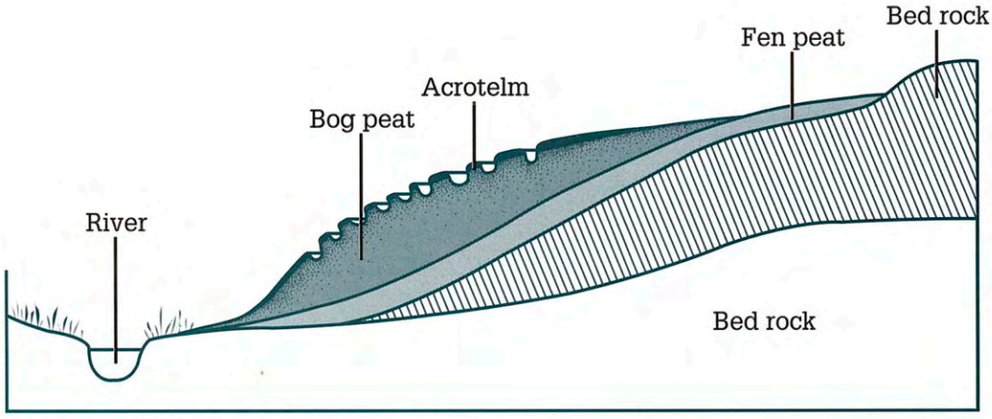
Surface features are characterised by hummocks, ridges, hollows and pools, all arranged in a distinctly arcuate microtope aligned at right angles to the direction of water seepage. Erosion hags and gullies may also be present. Peat mounds are not recorded for eccentric bogs.

Features characteristic of eccentric bog are:

- the bog is a dome of peat which along at least one axis slopes continuously from an upslope edge, corresponding to the highest part of the bog, to a downslope limit;
- the slope is caused by the shape of the underlying terrain;
- the surface of the bog is intensely patterned, and is dominated by very long but very narrow (0.5-1 m) ridges separated by equally long and narrow A2/A3 pools; and
- the downslope limit adjoins an unpatterned fen which feeds into a lake or stream in the valley bottom.

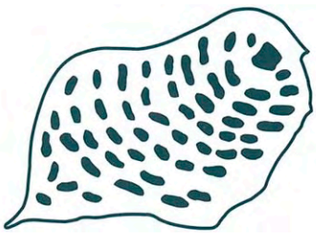
Unconfined raised bog units

Where profiles have been taken of the underlying terrain and surface contours, and a unit of peat within a blanket mire complex has been shown to have formed a dome



(a) Sectional view of an eccentric bog

(i)



(ii)

(b) Plan views showing the characteristic shapes adopted by eccentric bogs as indicated by (i) Moore and Bellamy (1974) and (ii) Moen (1985)

(c) Distribution of eccentric bog in Britain

Figure 13.
The hydromorphological and topographical characteristics of eccentric bog.

largely through peat accumulation rather than because of the underlying terrain, these can be identified as *unconfined* raised bog units. Such units are characterised by:

- a relatively simple dome possessing no overall orientation of slope;
- evidence which demonstrates that the dome is derived purely from peat growth;
- significant depths of peat connecting the dome with other components of the blanket mire complex;
- a hydrology which is also intimately linked to adjoining peat areas.

Section 7 Ridge-Raised/Intermediate Bog or Semi-confined Raised Bog

Where climate and terrain characterise the transition between 'upland' and 'lowland' environments, often around the low foothills and outliers of more extensive upland massifs, it is possible to find isolated areas of peat which have the characteristics of both raised bog and blanket bog (Plate 14). Moore and Bellamy (1974) observe that this is one of the most difficult of Europe's mire types to delimit in terms of its geographical distribution.

The type undoubtedly represents part of the continuum from lowland raised bog to blanket bog, but is not sufficiently distinct in its own right to merit a separate category of bog. In most cases it is possible to say that the site has a greater preponderance of features typical of raised bog, or of blanket bog, and thus the site should be regarded as one or other of these two main types. It is important to record in such cases, however, that the site is an example of the transition between raised and blanket bog and that features of both can therefore be found on the site.

It is worth spending a little time to consider the features which characterise these sites because it appears increasingly possible that their biotic complement may be relatively rich compared with either raised or blanket bog.

Ridge-raised mires were first described by Kulczynski (1949) for the Pripet Marshes in the former USSR, and Masing (1982) gives an account from Estonia of what he terms 'single' mires and 'compound' mires, illustrating the way in which these are related. The bog type is identified by Hulme (1980) for Scotland as 'semi-confined mire', while Goodwillie (1980) describes a broad type for Europe which he terms 'oceanic raised bogs'.

It should be emphasised that in Britain the type is extremely restricted in total extent, barely occurring at all in England and Wales, and showing only a localised distribution in Scotland (see Section 13). In profile such sites are generally shown as consisting of two lenses of domed bog which have fused across an intervening mineral ridge. However, Hulme's (1980) description allows for a broader definition, and Steiner (1992) provides another example, which he terms *Sattelhochmoor*, having a profile in which the domed shape of the bog is provided in part by the domed nature of the underlying mineral base - in other words the site occupies a watershed ridge. In fact, most examples in Britain are a combination of these two forms.

Perhaps the most distinctive feature of such sites is that they have regularly been classified first as raised bog by one authority, then blanket bog by another, and perhaps back to raised bog by a third. The type is recognised in the first case because:

- the site is not a smooth simple dome but clearly consists of two or more distinct lenses which fuse together into a continuous expanse without intervening lagg streams; and
- the overall convexity, or general shape, of the bog is evidently determined to a significant degree by the shape of the underlying mineral terrain, with altitudinal differences between parts often as much as 20-30 m or more.

The other characteristic feature is that such sites lie within the transition zone between the harsh environment of the uplands and the gentler conditions of the lowlands. As a result, they usually possess a mixture of features, fauna and flora from both environments, and thus may display an unusual diversity of plant and animal life. Dunlin and golden plover do not breed on raised bogs in Britain but they can be found on these intermediate sites. Entomological

mixtures are likely to be even more striking. Areas of thin peat or even exposed mineral ground can be found within the site. A very characteristic feature is that at least some of the bog margin is defined by a steep slope in the underlying mineral soil, where the peat becomes gradually thinner, eventually fading downslope into steep acid grassland.

That semi-confined raised bog is intermediate in character between confined raised bog and blanket mire is most evidently identifiable by its plan shape from soil maps, which show the characteristics of interlinked, but limited, bodies of peat. More often than not in practice the individual unit is best considered as a sub-class of blanket bog, because when it occurs it is almost invariably associated with the geographical or altitudinal limits of blanket bog distribution. It also generally occupies the same place in the landscape typical of blanket bog - namely the high watershed ridges and saddles - rather than the low-lying terrain characteristic of raised bog.

Being formed in a climate which is somewhat less extreme than is typical for blanket bog, the peat matrix of this intermediate bog is often barely more flushed or oxidised than raised bog peat. Peat depths are thus often considerable, though rarely as deep as typical raised bog deposits.

The surface features of this type of bog are generally limited to hummocks, ridges and hollows, together with erosion hags and gullies. No examples have been recorded with peat mounds, and open-water hollows (A2-A4) are virtually unknown for this habitat in Britain although examples can be found in both the Republic of Ireland and, to a lesser extent, Northern Ireland.

Features characteristic of this 'intermediate' semi-confined mire are that:

- it occurs as several fused lenses of peat;
- it does not cover whole landscapes, instead occurs as isolated examples surrounded by non-bog peat habitat - evident from soil maps;
- it lies over watersheds, saddles and spurs, rather than in low-lying valleys and basins;
- much of the bog shape is derived from the underlying terrain;
- some or all of the margin is formed by mineral slopes falling away at too steep an angle for peat formation;
- peat depths are typically close to those found in raised bog; and
- it possesses features, fauna and flora characteristic of both upland and lowland environments.

Sub-categories of semi-confined raised mire

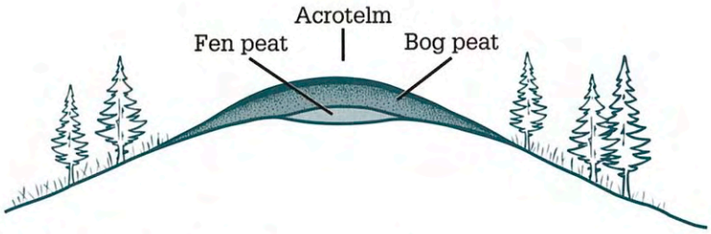
Two main forms of semi-confined raised mire can be identified on the basis of topography and hydro-morphology, although many states of transition can be found between these two (figure 14).

Typical ridge-raised bog

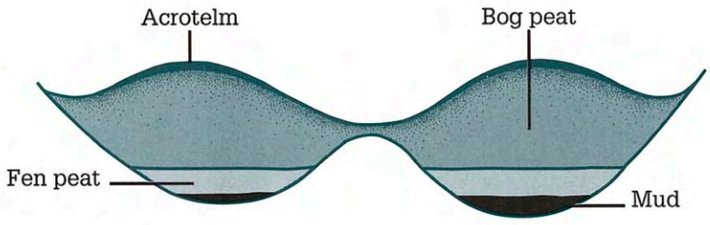
This form corresponds to the description of the type given by Moore and Bellamy (1974) as two lenses of peat which have fused across an intervening mineral ridge. It also equates to Moen's Atlantic raised bog type (Moen 1985). The profile is similar to that of a raised bog, except with two or more terrestrialised basins between which the peat has subsequently fused. Much of the shape of the bog is derived from peat growth, rather than from the underlying terrain.

Saddle/watershed intermediate bog

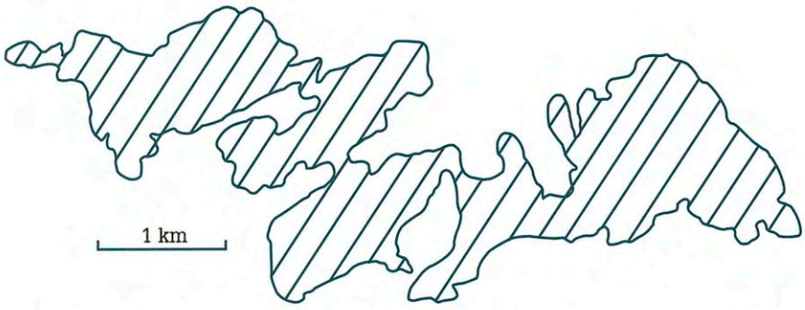
This type fits within Hulme's concept of a semi-confined mire, and corresponds to Steiner's *Sattelhochmoor*, which lies across a



(a) Sattelhochmoor (Saddle ridge bog)



(b) Ridge raised bog



(c) Plan view showing the characteristic shape of both intermediate bog types (Sattelhochmoor and ridge raised bog)

(d) Distribution of intermediate bog in Britain

Figure 14.
The hydromorphological and topographical characteristics of ridge-raised/intermediate bog.

saddle or watershed summit, and derives much of its shape from the underlying terrain. There may have been a small amount of terrestrialisation within small depressions across the plateau or saddle, but the majority of the site is derived from direct paludification.

Part III: Value, Condition and Conservation of Bog Systems

Part III: Value, Condition and Conservation of Bog Systems

Section 8 Natural Heritage Value of Peat Bog Systems

It can undoubtedly be difficult to persuade people that a peat bog is a biotope which is as worthy of conservation as, for example, a flower-rich meadow or an ancient woodland. Those who have not spent time looking at a bog for its own features and values can easily be swayed by the 'wet desert' view. It is probably therefore worthwhile reviewing some of the very real benefits to be gained by conserving these very distinctive parts of our landscape for present and future generations.

Ancient climax habitat

Peat bogs are among some of the most ancient of Britain's natural or near-natural ecosystems, with some of the oldest examples dating back more than 10000 years. Raised bogs are certainly natural climax habitats, with a demonstrable record of development to a biotope which has been stable for many thousands of years. The record for blanket bog is less clear, with considerable evidence for human activity at the time of extensive blanket mire formation, even in the far north (Moore 1973, Bennett *et al.* 1992). Nevertheless, blanket bog is considerably more ancient than many other habitats in Britain, and represents a habitat and landscape type which is rare in global terms (see below).

The gene pool

Although every habitat can make its own contribution to the overall gene pool, peat bogs are such highly specialised and hostile environments that they contain a number of quite remarkable species adaptations which significantly enhance the richness of Britain's natural gene pool. The most obvious are the carnivorous plants such as *Drosera*, which rely on bog and poor fen habitats for the major part of their distribution, and the remarkable *Sphagnum* bog mosses, but many other species show particular adaptations or may synthesise potentially important products.

Particular species values

Some species typical of bogs are quite simply rare, regionally, nationally or even globally. Thus the rare Greenland race of the white-fronted goose (*Anser albifrons flavirostris*) relies on wet peat bogs with pools for feeding and roosting. *Sphagnum imbricatum* is a bog moss which is almost entirely restricted to bogs and makes up much of the national peat soil deposit yet is now nationally scarce in Britain. The invertebrate assemblage of bog systems contains many nationally and internationally rare species.

Edge of range

Being something of a lower latitude version of northern tundra ecosystems, peat bogs represent important oceanic outliers of the tundra and thus possess a large number of species which approach the southern edge of their distribution. Dunlin and golden plover, for example, rely very much on such habitats for this southern extension of their breeding range, and similar patterns are seen with plant and, particularly, invertebrate populations.

Wetland values

One of the important aspects of peat bogs is that they contribute significantly to the overall benefits which society derives from wetland systems as a whole. Such *wetland values* are rarely quantified and costed, but are becoming increasingly recognised as a valid and important component in any assessment of environmental impact (see particularly Maltby 1986 and Williams 1990). These values arise from at least six different functions.

Biological indicators

Being supplied with water and nutrients entirely from the atmosphere, peat bogs are particularly sensitive indicators of change, either of climate or of pollution loadings.

Peat chemistry

The complex chemical nature of peat soils means that the structure and function of many organic molecules have yet to be determined. Some health treatments currently use peat as a source of considerable relief for certain conditions, but if the chemistry can be understood it may be possible to identify active ingredients.

Hydrological cycle

Being almost entirely water by weight, peat bogs play an important part in the local and regional hydrological cycle. Although there is conflicting evidence about the part bogs play in controlling flows and supplying areas downstream in dry periods, it is clear that in high rainfall areas the blanket peat mantle plays a vital part in preventing sub-soil scouring and erosion.

Local climate

Another feature of their composition is that peat bogs release considerable quantities of water vapour into the local atmosphere, thereby tending to encourage cooler, more even temperatures, with relatively high humidity throughout the year.

Water quality

Water derived from peat catchments is renowned for its quality. Advertisements for certain commercial products make particular reference to this fact. The cation exchange ability of undisturbed peat soils ensures that water outputs are of a remarkably consistent chemical composition whatever the input waters. Disturbance of such soils can have a dramatic effect on downstream quality.

Atmospheric carbon cycle

Peat soils are almost entirely organic, and thus have high proportions of carbon compared with most soils. The process of peat formation effectively locks up atmospheric carbon as fossil carbon, with timescales of many thousands of years. Recent research has indicated that the quantity of carbon locked up in the world's peat soils is 3.5 times the quantity of carbon held in the world's tropical rainforests (Immirzi *et al.* 1992). Drainage of peat soils releases this fossil carbon back to the atmosphere - a 1 m depth of peat soil contains 1000 tonnes of carbon per hectare, all of which will be released if the soil continues to be oxidised. This must be balanced against the release of methane by undisturbed bogs. One molecule of methane has much more impact on the atmospheric 'greenhouse' process than a molecule of carbon dioxide, and thus debate continues as to whether the total carbon balance of undisturbed bogs is 'greenhouse' positive, negative or neutral. Nevertheless, it is quite clear that if the existing carbon store, which has accumulated over a period of many millennia, were to be destroyed and oxidised the resulting volumes of carbon which would be released into the atmosphere would be very considerable and have a profound impact on the 'greenhouse' process. Indeed, some new ideas proposed by Brown and others suggest that undisturbed bogs contain a closed methane cycle - that the methane stored in a bog is locked within the peat as part of a methane producer-methane feeder cycle. Under normal circumstances, the bulk of the methane in a bog is thus effectively 'fossil' gas, fixed in place and merelycontributing to the low hydraulic conductivity of peat soils. Only when the bog is disturbed is this methane released. If this is true, drainage of bog peat releases both carbon dioxide when the peat matrix is oxidised and the fossil methane which may escape as methane, or which may be oxidised to carbon dioxide on contact with the atmosphere.

The peat archive

As well as carbon, peat bog soils contain almost all of the material which has contributed to their formation over the millennia. This archive has always been valued but is increasingly coming to be recognised as a sophisticated means of understanding many modern problems such as climate change. In former times it was thought adequate to take a number of samples from key sites, and then store these samples for use by other workers in the future. In practice this approach has come to be recognised as impractical. That selected sampling and long-term storage is not the answer has been emphasised by Charman (in press). There are the problems of archiving and long-term storage; the range of sites required changes with different studies; finally, and perhaps most significantly, sampling techniques are constantly changing, often becoming more sophisticated and demanding - for example, a soil chemist such as Dr Bill Shotyk, at the University of Berne, currently looking at metal pollution loads in the peat archive, cannot use cores taken with a normal metal corer.

Palaeoecology

The record stored in the peat gives a picture of the bog's own development, which thus makes it possible to reconstruct the site from its earliest beginnings. However, also preserved with the peat is the record of pollen rain from both local and distant sources, which has enabled palynologists to reconstruct the vegetation history of Britain. For this, a wide geographical spread of sites is important. A particular feature of blanket bog is that it has been shown to have smothered and preserved human landscapes, such as field patterns, which existed prior to blanket peat development (Caulfield 1989).

Climate change

A growing understanding of the relationship between peat archives and climate patterns of the past means that an increasingly significant proportion of research into recent climate change is being centred on peat bog systems.

Atmospheric pollution

As well as being natural filters which can trap and record current pollutants, peat bogs contain a record of atmospheric pollution throughout their profile and can thus be used to provide an archive of the background levels of deposition. A few sites in Britain are already being used in this way as part of a global pollution study organised by the University of Bern (W. Shotyk, personal communication).

Natural chronometer

The peat record also acts as a chronometer for other events. For example volcanic dust trapped in the dated layers of peat bogs enables geographers and geologists to establish precise dates for volcanic eruptions many thousands of years ago and many thousands of miles away (e.g. Dugmore 1989). This also works the other way around; when the date of a volcanic event is known, peat stratigraphers can chemically characterise the tephra layers preserved within the peat and thus determine the source, and date, of a layer. This gives a fixed chronological datum within the peat column.

Archaeological record

Perhaps the most dramatic aspect of the archive is the archaeological record. Artefacts, mammals, insects, even human remains, have been found. Some of this has provided important insights into the natural environment of the time, but of course it is also a dramatic means of interesting the general public in the many special features of such habitats. There is clearly a potential conflict between the desire to excavate

archaeological features and the wish to conserve the habitat. However, the general philosophy now being promoted throughout the archaeological world is that it is better to maintain artefacts preserved in the peat and await the development of non-destructive techniques such as ground-penetrating radar (e.g. Welsby 1988), or the probing technique of Caulfield (1989), than to remove peat in order to find artefacts.

Traditional and modern uses of species

Many bog plants have a long history of use, either as medicines or as food. Some of these are still important locally, and new uses are emerging. Thus in places the berries of *Empetrum nigrum, Vaccinium oxycoccos* and *V. myrtillus* are still collected for pie fillings or for jam, and *Myrica gale* is a common component of modern pot-pourris.

Sporting and agricultural land use

By far the most common use for peat bogs today is as part of rough grazing land for sheep and, to a lesser extent, cattle and horses, which is then usually combined with the activities of a sporting estate for grouse shooting, deer stalking and fishing. Grouse and deer both rely on many of the species found on typical undisturbed bogs, whereas salmon, sea trout and brown trout depend on the quality of waters produced by peatland catchments.

Biotope and landscape value

Lowland bogs are remarkable in being able to provide the experience of a truly primaeval landscape, an ancient natural biotope. Blanket bogs, on the other hand, exist as landscape units and thus by their definition provide a very particular kind of biotope with a very high 'wilderness' factor. A very large proportion of the global landscape within the boreal zone is densely wooded. Anyone who has travelled any distance in Finland, Sweden, Russia or Canada will know the feeling of only being able to see as far as the next wall of trees. The open landscapes of Britain and Ireland are a particularly distinctive and unusual feature of these islands, shared with only a few other places around the globe.

International value

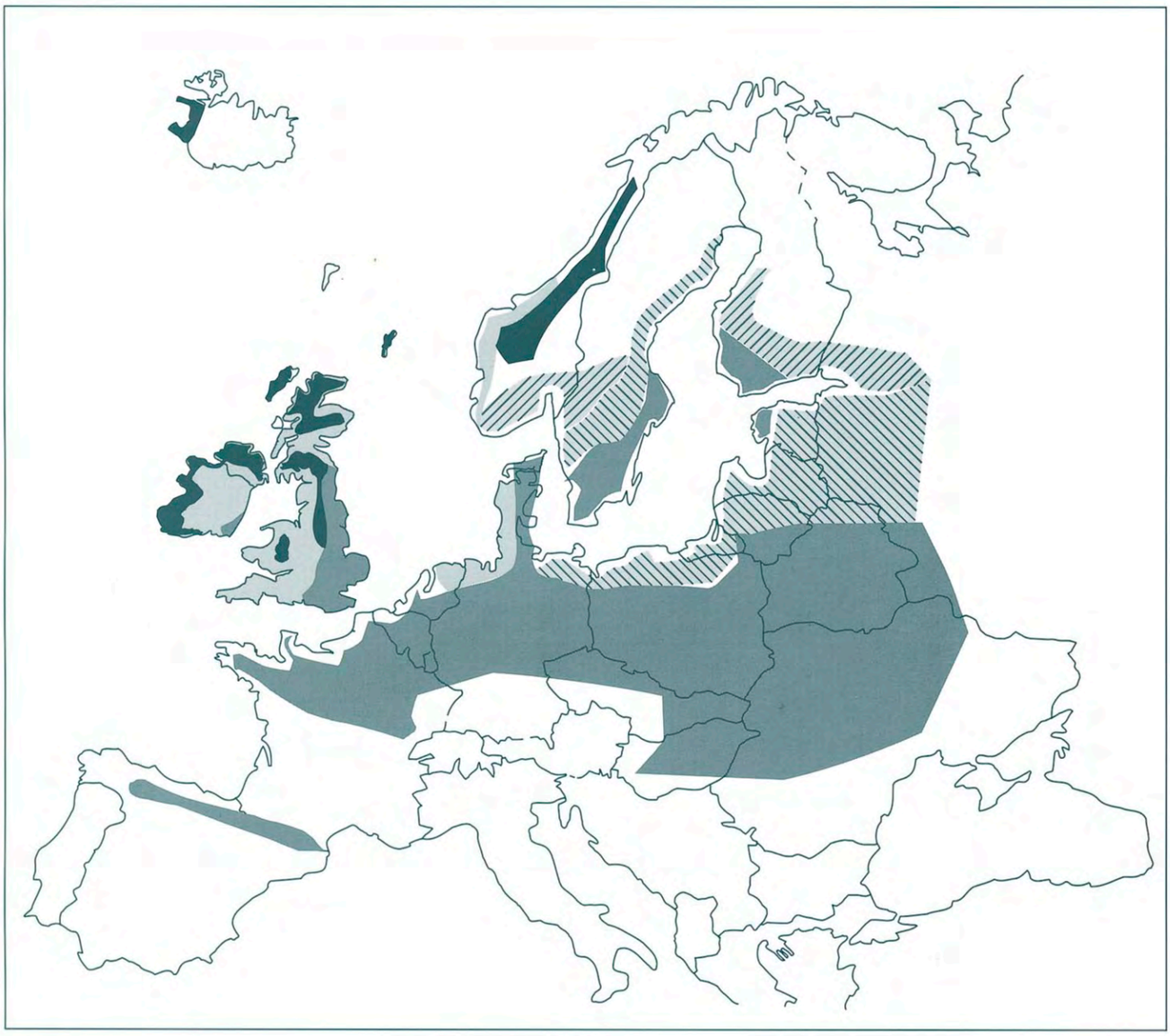
Raised bogs

Raised bogs are a relatively widespread peatland type in the northern hemisphere, but the British examples are structurally and florisitically at the extreme oceanic end of the spectrum. The overlap in Britain and Ireland between continental types of mire and oceanic types of bog vegetation is well illustrated by Goodwillie (1980) (see Figures 15 and 16), although because of widespread habitat damage some of this is necessarily speculative. It seems that raised bogs displaying this overlap in Ireland were once widespread, but many have been totally destroyed, and most of the remainder modified by human activities.

Blanket bog

Blanket bog is a tundra type of ecosystem occurring in Britain in a southern and insular context, as a response to oceanic conditions as distinct from the permafrost waterlogging which creates true tundra. Blanket bog depends on a very particular climatic range, which restricts its distribution to Norway, Newfoundland, Alaska, Kamchatka and Japan in the northern hemisphere, together with a southern hemisphere variant in Tierra del Fuego, the Falkland Islands, Tasmania and New Zealand, where they are dominated by 'cushion bog' rather than *Sphagnum* bog (see Figure 17). Britain and Ireland are generally accepted as the 'type' localities for the habitat in the northern hemisphere, and

on the basis of current global inventories Britain is thought to contain 10-15% of the total global area of this peatland formation (Lindsay *et al.* 1988).



blanket mire

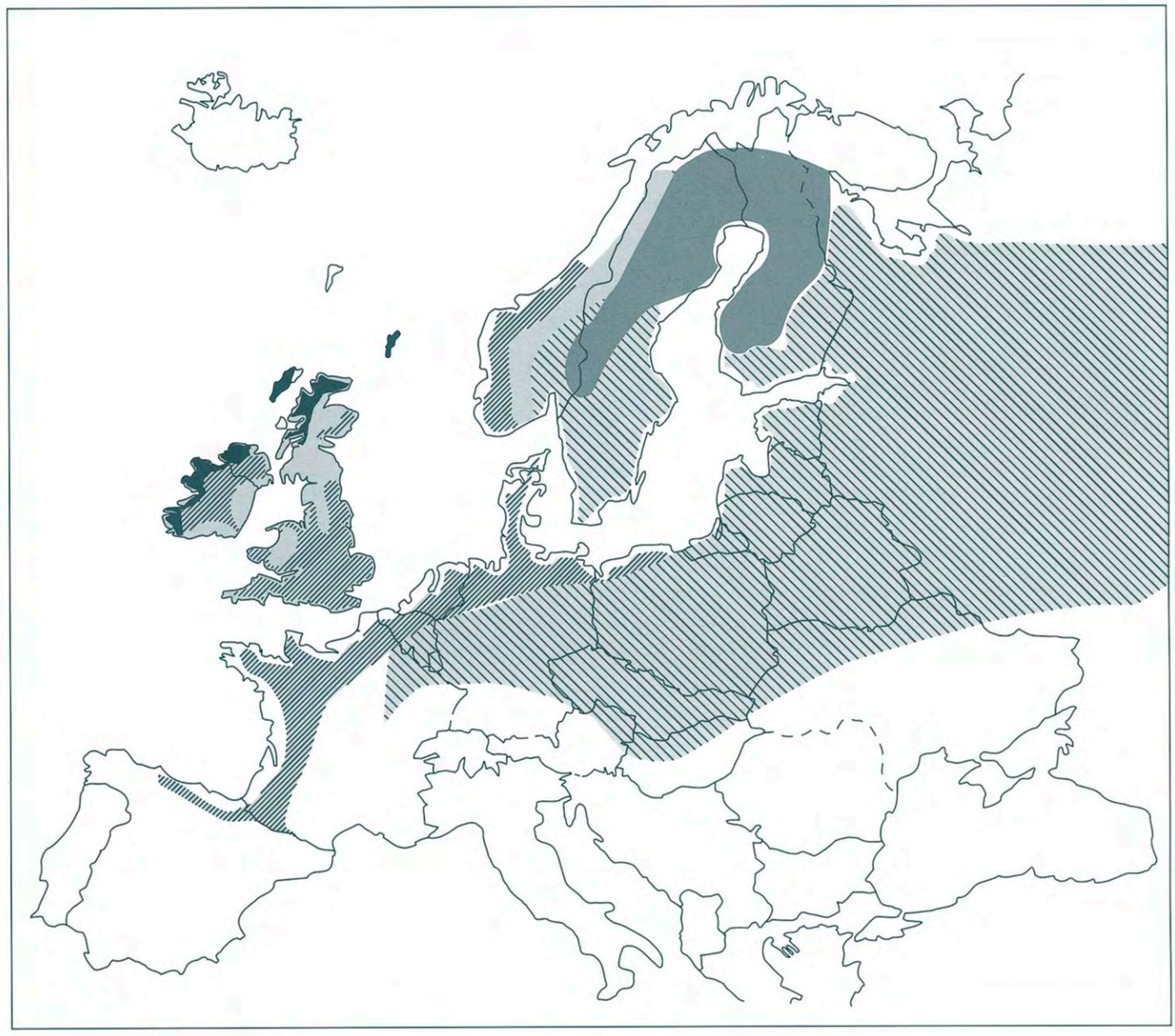
oceanic raised mire

flat (plateau) raised mire

eccentric raised mire

concentric raised mire

Figure 15.
Predominant bog types in western Europe, excluding minerotrophic mires (fens) and mountain-mire complexes (adapted from Goodwillie 1980). All shading represents the region within which bog types characteristically occur; it gives no indication of extent. Thus in Norway the extent of blanket mire is very small, but is distributed throughout a wide area of the country.



Pleurozia purpurea

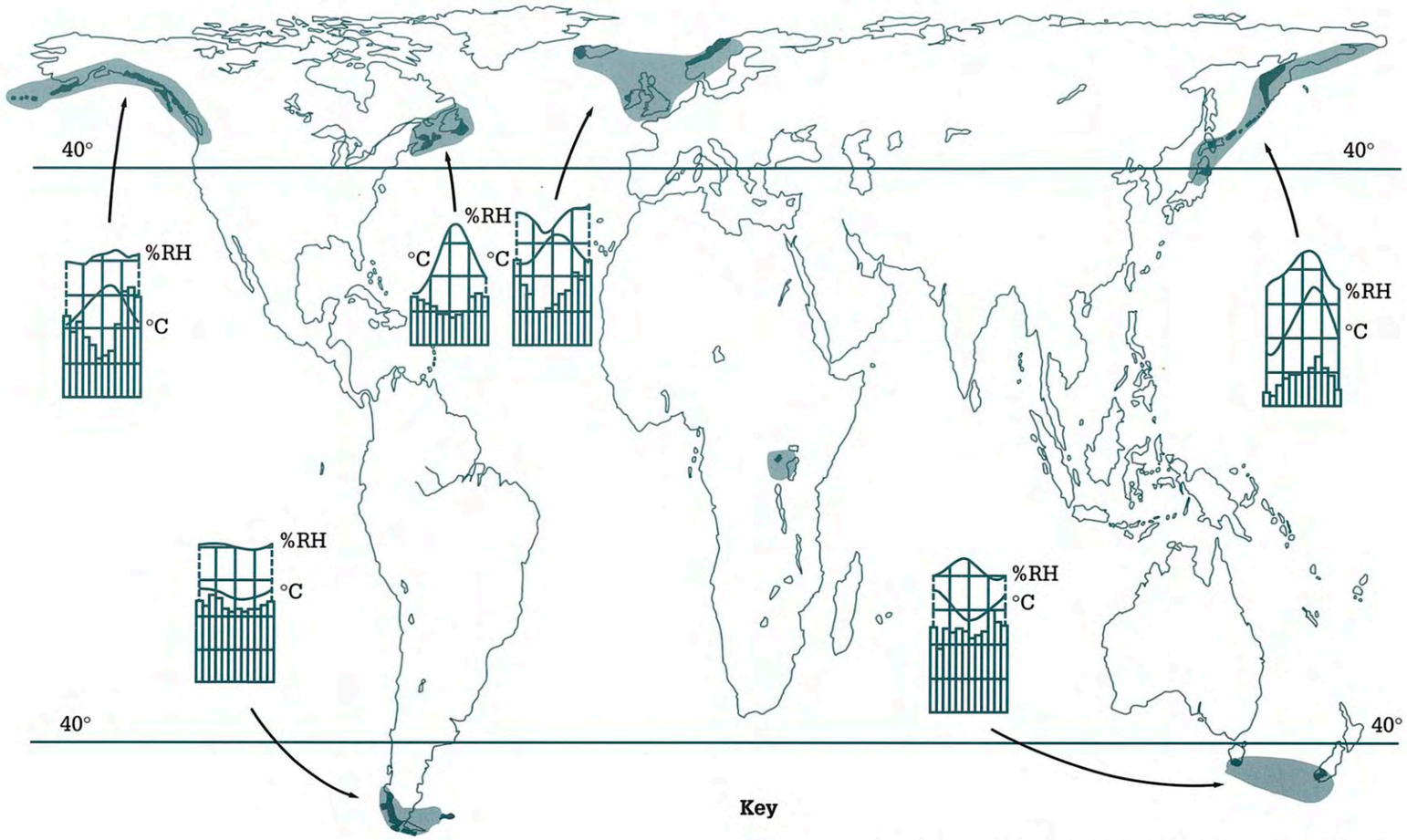
Scirpus cespitosus

Erica tetralix/ Sphagnum magellanicum

Vaccinium spp./ Erica tetralix

Sphagnum fuscum

Figure 16.
Characteristic species in the vegetation communities of ombrotrophic peat bogs in western Europe. (Adapted from Goodwillie 1980)



Key

Areas with climate suitable for the formation of blanket bog

Areas where blanket bog is recorded

%RH Average monthly percentage relative humidity

°C Average monthly temperature (°C)

Average monthly preciptation

Figure 17.
World distribution of blanket bog. Shaded areas indicate areas of the globe with climate suitable for blanket bog formation, based on climate diagrams from Physico-geographical *Atlas of the World* (1964). Dark shading indicates regions from where blanket bog is recorded, rather than the actual extent of the resource. (From Lindsay *et al.* 1988).

Section 9 International Legislation, Conventions and Designations of Relevance to Peat Bog Systems

The UK government is signatory to a number of international conventions and agreements concerning various aspects of nature conservation and environmental protection. Many of these have considerable relevance to the conservation of peat bogs.

The Ramsar Convention on Wetlands of International Importance especially as waterfowl habitat

This was ratified by the UK government in 1976. It requires contracting parties to promote the conservation of 'listed' wetlands and exhorts the 'wise use' of wetlands in all areas of policy planning and formulation. Damaging development on listed sites can proceed only in the 'urgent national interest'.

The Convention on the Conservation of European Wildlife and Natural Habitats - The Bern Convention

The Berne Convention is a Council of Europe initiative, and is designed to conserve wild flora and fauna and their natural habitats, particularly those which are endangered. The Convention imposes clear legal obligations on Parties to meet these objectives. The key elements for the protection of habitats are laid out in Articles 4 and 6. These can be summarised as follows:

- contracting parties shall ensure the conservation of the habitats of wild flora and fauna, particularly those listed in annexes (and these list a number of species found on bogs, including, for example, dunlin), as well as conserving endangered natural habitats;
- contracting parties shall avoid as far as possible any deterioration of those areas described in para.1 through planning and development policies;
- special attention should be given to areas of importance for migratory species listed in the annexes, particularly those areas used as wintering, staging, feeding, breeding or moulting areas;
- parties shall ensure special protection of the fauna listed in Annex II (including many peatland birds), prohibiting deliberate damage to or destruction of breeding or resting sites.

The EC Directive on the Conservation of Wild Birds (Directive 79/409/EEC)

This requires member states to take measures to protect wild birds and to preserve sufficient diversity of habitats for all species naturally occurring within the national territories so as to maintain these populations at a level which meets ecological, scientific and cultural requirements. Species whose status is a cause for concern are identified in Annex 1 of the Directive as requiring special conservation measures. The UK government is obliged to designate some suitable areas for these species as Special Protection Areas (SPAs). The same measures apply to migratory species. Significant deterioration of important habitats must be avoided. The Directive thus affords protection both to birds and to the habitats on which they depend.

The EC Directive on the Conservation of Natural and Semi-Natural Habitats and of Wild Fauna and Flora (Directive 92/43/EEC)

This requires member states to take particular measures to protect the natural range and diversity of habitats and non-bird species within the European Union. Habitats whose status is a cause for concern are

identified in Annex 1 of the Directive, and those causing particular concern are marked as requiring priority action. Two such types are 'active' examples of both raised and blanket bog. Although much of the value placed on these by the Directive relates to the widespread damage which has occurred to both types, for blanket bog there is also recognition that the total European extent of this habitat has always been small and localised. The UK government is obliged to designate some suitable areas for these habitats as Special Areas for Conservation (SACs). Member states are obliged to ensure that such areas are afforded 'favourable conservation status', namely that 'the specific structure and functions which are necessary for [their] long-term maintenance exist and are likely to continue to exist for the foreseeable future'.

The United Nations Conference on Environment and Development Convention on Biological Diversity was ratified by the UK government on 1 September 1994.

The UK Biodiversity Action Plan was published in 1994 by the UK government. The former expresses a shared belief that action must be taken to halt the world-wide loss of animal and plant species and genetic resources. Signatory states recognised that each country has the primary responsibility to save and enhance biodiversity within its jurisdiction. By signing the Convention, states also committed themselves to drawing up national plans and programmes designed to meet these objectives.

Article 8 of the Biodiversity Convention is concerned with *in situ* conservation, making it clear that contracting parties shall, as far as possible and as appropriate:

- *establish* a system of protected areas or areas where special measures need to be taken to conserve biological diversity;
- *develop*, where necessary, guidelines for the selection, establishment and management of protected areas or areas where special measures need to be taken to conserve biological diversity;
- *regulate* or manage biological resources important for the conservation of biological diversity whether within or outside protected areas, with a view to ensuring their conservation and sustainable use;
- *promote* the protection of ecosystems, natural habitats and the maintenance of viable populations of species in natural surroundings;
- *promote* environmentally sound and sustainable development in areas adjacent to protected areas with a view to furthering protection of these areas;
- *rehabilitate* and restore degraded ecosystems and promote the recovery of threatened species, *inter alia*, through the development and implementation of plans or other management strategies;
- *prevent* the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species;
- *endeavour* to provide the conditions needed for compatibility between present uses and the conservation of biological diversity and the sustainable use of its components;
- *subject* to its national legislation, respect, preserve and maintain knowledge innovations and practices of indigenous and local communities embodying traditional life-styles relevant for the conservation and sustainable use of biological diversity and promote their wider application with the approval and involvement of the holders of such knowledge, innovations and practices and encourage the equitable sharing of the benefits arising from the utilisation of such knowledge, innovations and practices;

- *develop* or maintain necessary legislation and/or other regulatory provisions for the protection of threatened species and populations;
- *where* a significant adverse effect on biological diversity has been determined pursuant to Article 7 (monitoring of biodiversity), regulate or manage the relevant processes and categories of activities;
- *cooperate* in providing financial and other support for *in situ* conservation outlined in the above paragraphs, particularly to developing countries.

The Biodiversity Action Plan has as its goal the conservation and enhancement of biological diversity within the UK, as well as contributing to the conservation of global biodiversity through appropriate mechanisms. The UK Plan identifies six underlying principles and four objectives to which the UK government is committed, of which the following are particularly relevant.

The underlying principles are:

- *where* biological resources are used, such use should be sustainable;
- *wise use* should be ensured for non-renewable resources;
- *conservation* of biodiversity requires the care and involvement of individuals and communities as well as Governmental processes;
- *conservation* of biodiversity should be an integral part of Government programmes, policy and action;
- *conservation policy* and practice should be based upon a sound knowledge base; and
- *the precautionary principle* should guide decisions.

The *objectives* for conserving biodiversity are to conserve and where practicable enhance:

- the overall populations and natural ranges of native species and the quality and range of wildlife habitats and ecosystems;
- internationally important and threatened species, habitats and ecosystems;
- species, habitats and natural and managed ecosystems that are characteristic of local areas; and
- the biodiversity of natural and semi-natural habitats where this has been diminished over recent past decades.

The Action Plan identifies 59 specific tasks to which the UK government is committed. Task No. 2 states that the UK government will 'continue to designate additional protected areas to deal with acknowledged gaps in the existing coverage, for example in relation to freshwater habitats, peatlands and intertidal wildlife habitats and species'. The peat bogs section of the *Guidelines for Selection of Biological SSSIs* have recently been revised (Joint Nature Conservation Committee in press). These Guidelines provide the basis for the ongoing programme of site designation acknowledged in the Action Plan.

Section 10 The Nature Conservation Condition of Peat Bog Systems

Much of the peat bog resource is now considerably modified or reduced. Peatlands have been widely used as a source of fuel peat, and many have been exploited commercially for horticultural peat or moss litter. Large areas of the upland bogs in northern England have been seriously affected by atmospheric pollution, whereas the majority of upland bogs have suffered substantial damage from excessive burning and overgrazing. Many blanket bogs are also heavily eroded. With modern techniques, large areas of blanket bog landscape can be drained and afforested with conifers - a widespread practice first begun in the 1920s, following the need for a strategic reserve of timber demonstrated during the First World War.

Primary (1°) and secondary (2°) bogs

All forms of peat bogs, or parts of bogs, which still retain their full complement of Quaternary archive and a surface formed only through an uninterrupted history of natural growth are termed *primary bog (1°)*, though growth may now have ceased as a result of drainage or erosion. Where part of the original expanse has been removed by agricultural land claim or peat cutting, the cut surface which results (if it retains any kind of peat surface at all) is termed a *secondary (2°) bog surface*. Thus, areas of commercial peat extraction, domestic cutting and agricultural land claimed from the bog by peat removal, can generally all be classed as *secondary* bog. Secondary bog has lost part of its value irretrievably - the original historical record in the peat archive cannot be recovered.

Both these major conditions can then be further sub-divided into surface conditions which describe more accurately their current land-use and conservation value. The concepts of primary and secondary bog are of less significance when considering blanket bog because a very considerable proportion of the resource remains in a primary condition. Of more importance, given the long history of land use in blanket mire areas, is the second level of interest, namely the extent to which the bog remains in a natural rather than a moribund and degraded state. Nonetheless, the widespread extent of erosion within blanket bog provides a significant area of ground which can indeed be classed as a secondary surface, especially where revegetation is now occurring within erosion gullies.

It is important to understand that most sites will display a mixture of the various condition states described in Section 11.

It is worth noting that, although the diagrams presented here show the condition classes on a raised bog profile, all the states described can also be found on blanket bog.

Primary bog types

Where a bog surface has reached its present state through a sequence of growth interrupted only by natural processes and having a largely complete stratigraphy and pollen archive, that surface can be classed as primary bog. It is a natural climax formation with characteristics which cannot be replaced if lost, because any replacement would have a different development sequence, stratigraphy, pollen record and resulting wildlife complement. The destruction or disturbance of primary peat is thus an irrevocable step.

Primary natural bog
(Plates 15, 16, figure 18a)

This land class represents the most natural examples of remaining bog, possessing an intact archive of the Holocene, a naturally formed surface, *together with* a typical bog vegetation and surface pattern. If *Sphagnum* in particular is widespread across the site, even in small amounts, this indicates that the water table is still close to the surface over much of the bog and that conditions continue to be suitable, more or less, for the accumulation of fresh *Sphagnum* peat. Such areas are laying down fresh peat, though the net accumulation of peat within the bog as a whole may be zero, or even negative, depending on other factors such as marginal drainage or peat removal influencing the bog as a whole. It is possible for only parts of a site to be primary natural bog. Indeed even a completely undisturbed site will have a mire margin where *Sphagnum*-rich, peat-forming vegetation may be scarce or absent (Sjörs 1948, Nature Conservancy Council 1989).

Active bog is a term which has attracted some debate. The definition of 'active' bog currently accepted in relation to the EC Habitats and Species Directive states that it should be taken to mean 'still supporting a significant area of vegetation that is normally peat forming, but bogs where active formation is temporarily at a standstill, such as after a fire or during a natural climatic cycle, are included'.

Primary moribund bog
(Plates 17-20, figure 18b)

Where the bog surface has been affected by, for example, a serious fire and the peat-forming species have been lost, the surface is termed *primary moribund*. Fire damage may have removed almost all the vegetation but the moribund state often proves to be only a temporary phase; the vegetation at Glasson Moss NNR, Cumbria, has shown significant recovery to a primary natural state 15 years after its last significant fire in 1976 (R. A. Lindsay, Nature Conservancy Council, unpublished).

In other cases the surface may be fully vegetated but with species which are not significantly peat forming. Such examples tend to occur on sites which have suffered significant drainage at their margins and now have lowered water tables. These conditions may persist for a much greater length of time than the moribund state resulting from fire.

Primary micro-erosion
(Plates 21, 22, figure 18c)

In some instances, often under the influence of either drainage or burning, microforms break down into moribund hummocks or tussocks while the low ridges and hollows combine to form a very shallow (no more than 50 cm) network of bare peat channels.

This very particular surface is termed *micro-erosion*. There are none of the classic signs of erosion such as gullies, haggs or slabs described by, for example, Bower (1962), but the entire surface is clearly entering the early stages of erosive breakdown. The type is very distinctive on aerial photographs as a surface dominated by densely packed small papillae.

The type is not found on raised bogs but may be found on intermediate bog and is very common on blanket bog, particularly in the north and west. With sympathetic management, as seen for example within the Kielder Forest mires, it is possible to reduce the likelihood of developing into full-scale erosion and encourage the redevelopment of an active surface.

Primary drained bog (Plates 23, 24, figure 18d)

Where the overall shape of a bog remains largely undisturbed but the surface has been drained by a regular or irregular pattern of ditches, the ground between the drains can still be regarded as primary bog. However, the overall character of the bog surface hydrology has clearly been changed. If the surface is now moribund and dominated by non-peat-forming vegetation, such areas are termed primary drained bog.

If the drains are maintained rather than allowed to collapse, the upper layers of peat are likely to undergo significant slumping and oxidative wastage, with the result that the Quaternary archive can no longer be described as completely undisturbed. However, the relative resistance to decomposition of items in the archive such as pollen grains means that in general the material is compressed rather than lost.

Depending on the intensity and age of drainage, the vegetation may still retain many features of natural bog, or may have lost almost all trace of the original vegetation (microbroken: Lindsay *et al.* 1988) type. The most intense or long-established drainage effects will certainly also have a profound effect on the surface features of the bog. Hummocks and hollows tend to be lost and the surface is simplified to a single microtope layer, as illustrated by Woike and Schmatzler (1980) (see also Section 12).

Primary gully/slab erosion (Plate 25, figure 18e)

Largely restricted to blanket bog, the deeper forms of erosion are widespread and generally most intense on plateaux and valleyside flows. In some cases much of the bog surface between gullies may remain largely intact, but in deeply and intensely gullied examples primary surfaces may be represented only by moribund hag tops.

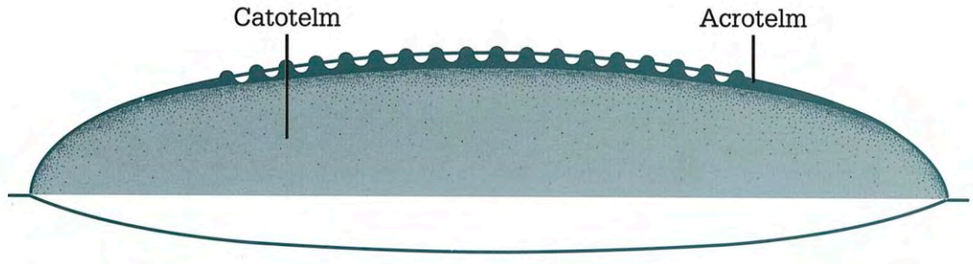
It is not yet known whether all examples of erosion are the result of human interference, or whether blanket bog also has a natural erosion cycle. The evidence obtained so far is conflicting. Tallis (1964, 1981) among others has provided much information about, and considered many aspects of, erosion as a phenomenon found widely in blanket mire areas. Though often thought to be highly degraded and unsightly, the type should be considered a part of the natural range of variation until such time as the origins and status of this phenomenon have been more clearly established.

Primary wooded bog (Plates 26-29, figure 18f)

Wooded bogs may be densely covered with self-sown scrub, be dominated by self-sown mature woodland, or may have been afforested. In the last case, planting is preceded by intensive drainage, and thus the surface layers will have undergone more dramatic changes than in the case of self-sown woodland.

Figure 18.
A summary of the general conditions in which bogs may be found in Great Britain. It should be noted that all areas which still retain peat, even archaic deposits, potentially possess significant scientific value. The archaeological artefacts alone, from an area of arable peatland, can prove to be of considerable scientific importance. The order used here cannot therefore be used as a simplistic means of ranking scientific quality, especially as most sites display. combinations of these classes.

Figure 18(a).
Natural (1°) primary bog
'Natural' primary bog consists of a primary dome dominated by an actively-growing and *Sphagnum*-rich surface pattern with an undisturbed actrotelm. The peat lens contains a complete archaeological and palynological record.



Natural (1°) primary bog - modified
'Near-Natural' primary bog has been somewhat modified by the effects of marginal drainage and peat removal. The surface is still actively-growing and *Sphagnum*-rich with a largely intact acrotelm. However, the surface pattern has been simplified, having, in this case for example, lost all *Sphagnum* hollows. The peat archive remains largely intact, if somewhat compressed.

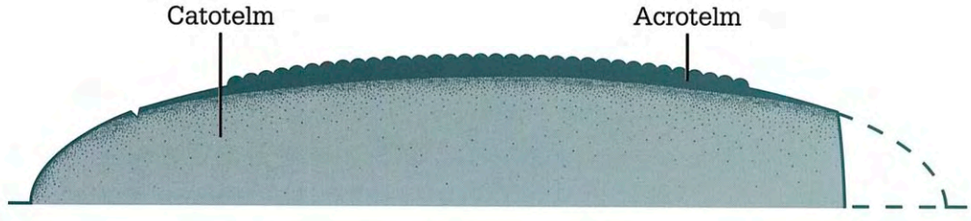
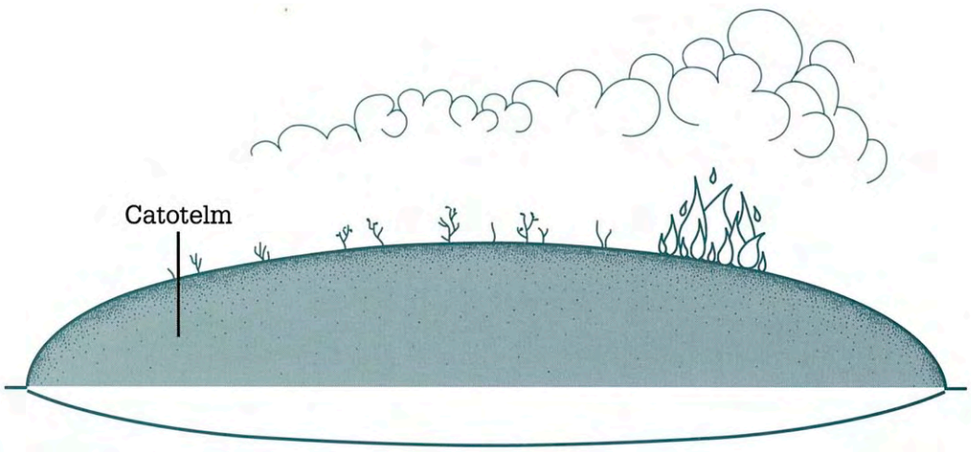


Figure 18(b).
Moribund (1°) primary bog. A bog stripped of its living vegetation and much of its acrotelm by fire. The bog nonetheless retains a complete primary dome and a complete archive. This 'stillstand' phase occurs in natural conditions due to lightning strikes. The site can be expected to recover completely within 20-25 years, provided no other damage occurs.



Moribund (1°) primary bog. A primary natural dome which has been reduced by peat removal at the periphery. The whole dome has therefore suffered some shrinkage, and the vegetation is dominated by dwarf shrubs rather than *Sphagnum*. The surface is therefore not natural in the strict sense and the acrotelm is somewhat degraded, but will become increasingly natural again as the dome sinks to a new stable shape. The peat archive remains largely intact, if somewhat condensed.

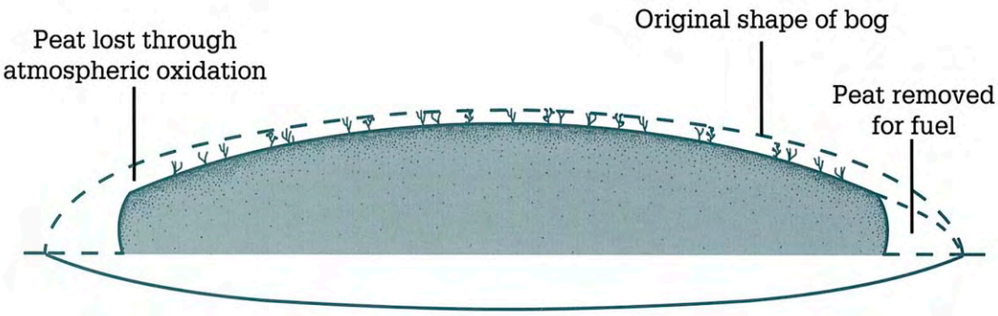


Figure 18(c).
Primary (1°) micro-erosion
Where a patterned surface has become somewhat degraded but extensive erosion has not yet become established, the break-down of a ridge-hollow or ridge-pool microtope often leads to the loss of much acrotelm but the catotelm remains largely intact, together with its archive. Many of the ridges or hummocks retain a vegetation cover. Positive conservation management of such areas to stabilise the process and prevent true erosion is possible in many cases.

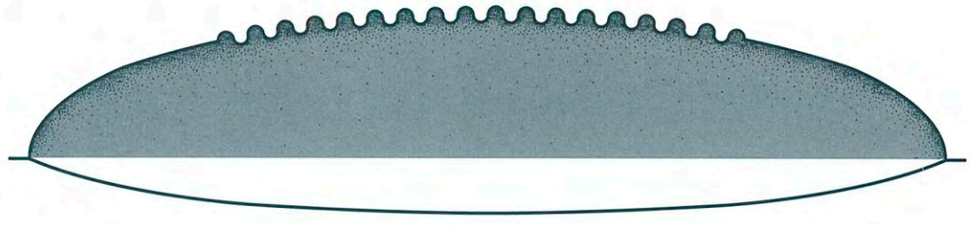


Figure 18(d).
Drained (1°) primary bog.
A primary dome which has been affected by drainage to the extent that much of the surface is no longer natural, though limited parts may retain a *Sphagnum* cover. The acrotelm is considerably degraded. The drains, if not regularly cleaned out, or if blocked with dams, will, however, rapidly choke with vegetation and the water table re-stabilise. The peat archive remains largely intact but is significantly condensed.

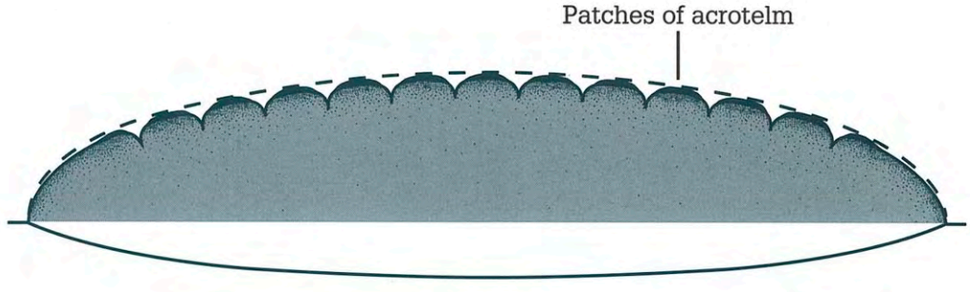
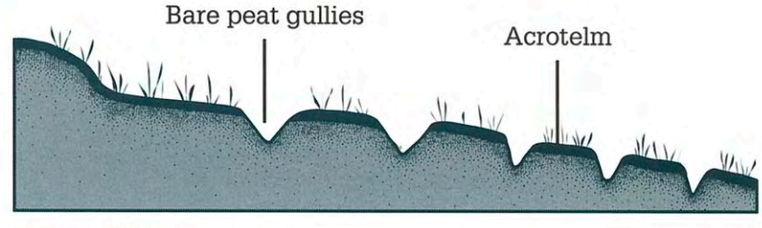
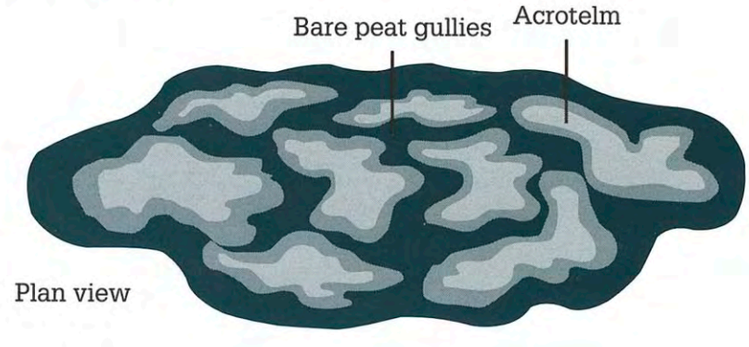


Figure 18(e).
Primary (1°) gully/slab erosion.
Much of the peat remains intact as primary bog, even with natural acrotelm in many instances, but significant areas of the acrotelm and catotelm have been lost in the formation of deep erosion gullies. The peat archive is also lost from these areas, although it is retained in condensed form in the primary hags and slabs. (Please note: the shading used in the plan view has been reversed to show the bare peat gullies more realistically.)

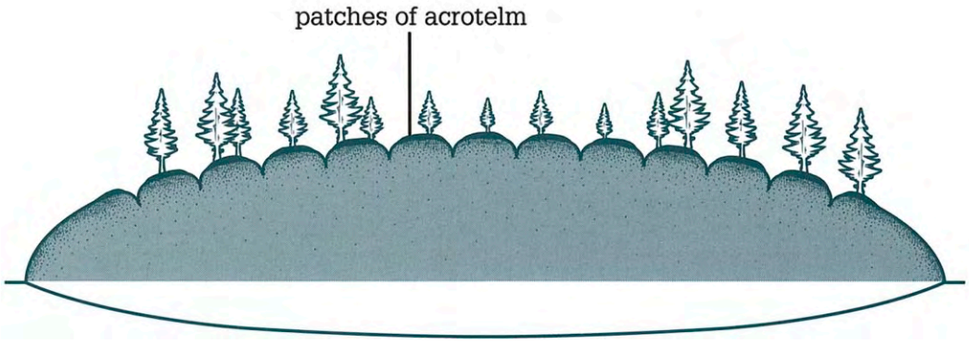


Sectional view



Plan view

Figure 18(f).
Wooded (1°) primary bog - active.
The surface has not lost its natural *Sphagnum* cover despite the spread of self-sown (or planted) woodland across the bog. This bog still retains a primary dome, a form of acrotelm, and almost all of its peat archive. It may, however, degenerate gradually to a moribund condition unless the trees are removed and any drains blocked. If such management is possible, recovery to an active state is usually rapid.



Primary (1°) bog with closed-canopy forest - moribund.
Although a primary dome remains, together with much of its peat archive, the acrotelm is now completely destroyed and the surface is moribund. The catotelm therefore begins a long-term sequence of shrinkage and wastage. If conservation management can remove the trees and block the drains, a return to an active bog vegetation can be rapid, though the species composition will be relatively limited, similar to that found in secondary peat cuttings.

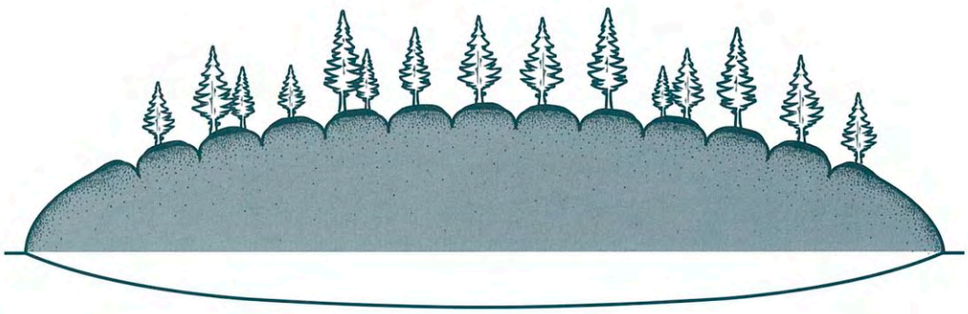


Figure 18(g).
Active (2°) secondary bog.
A bog which has been cut-over, either by domestic or commercial peat cutting but where the water table has stabilised because the drainage pattern has become blocked, and the surface vegetation is now dominated by secondary *Sphagnum* growth. A new acrotelm has developed, and peat is being laid down to replace the missing parts of the catotelm. Sufficient peat depth remains for the living vegetation still to be rooted in acid peat. A partial peat archive remains.

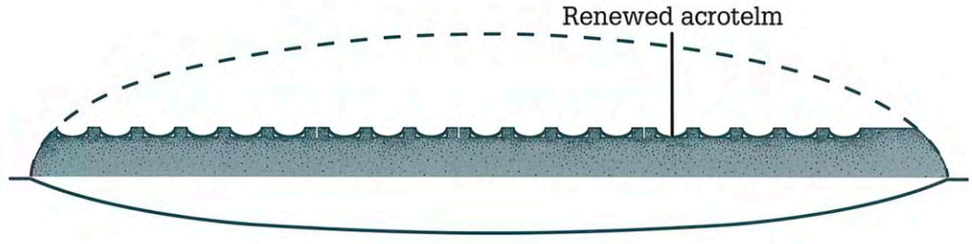
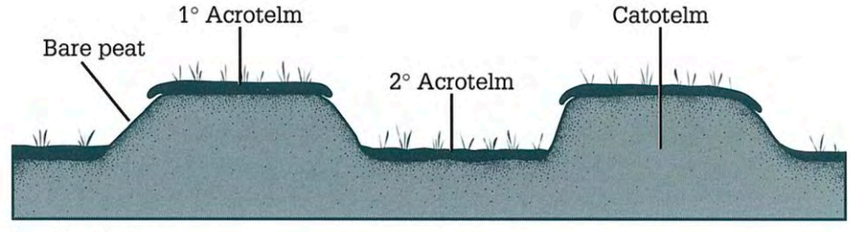
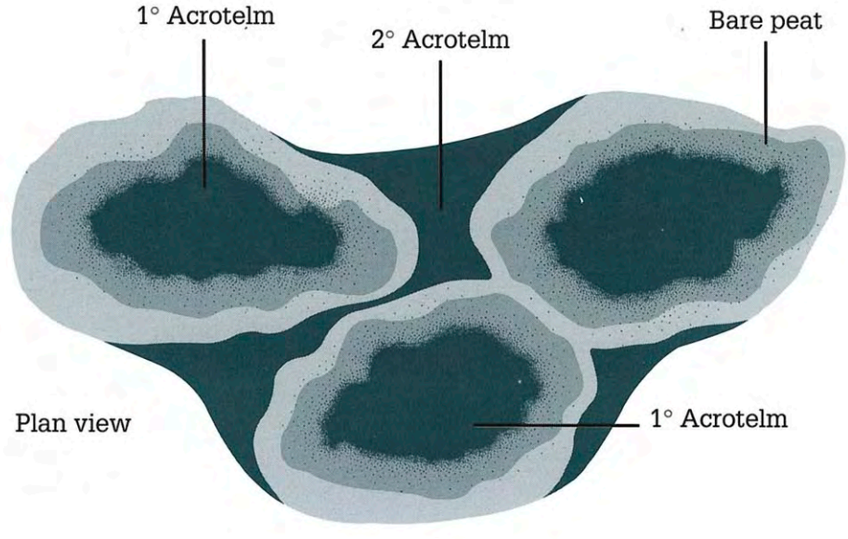


Figure 18(h).
Active (2°) secondary erosion complex.
The major part of the area is covered with an active, peat-forming vegetation and has a well-formed, albeit secondary acrotelm. Areas of bare catotelm peat may exist, corresponding to the still-exposed sides of erosion hags, but much bare peat has now been covered beneath fresh secondary growth in the original erosion gullies. The original peat archive, though condensed, is still present in the hags. A new archive is present in the secondary peat.

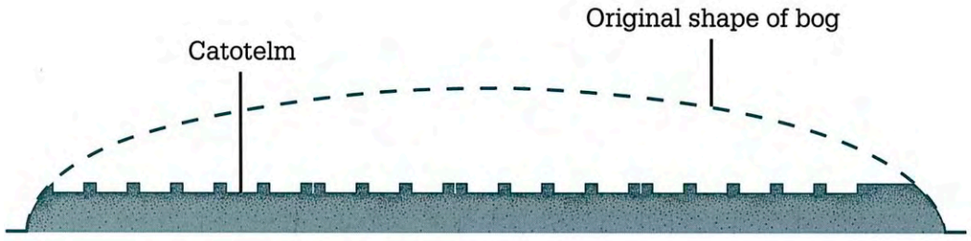


Sectional view



Plan view

Figure 18(i).
Moribund (2°) secondary bog - block cutting.
Block-cut commercial peat workings with an efficient drainage system. The surface may have scattered vegetation, but no active peat formation and no acrotelm. It retains a partial peat archive in the remaining catotelm. Given conservation management, the site retains sufficient peat depth to return to active secondary bog vegetation if the drainage system were blocked to retain rainwater.



Moribund (2°) secondary bog - milling.
Milled-peat commercial workings devoid of vegetation. The area has no acrotelm but retains a partial peat archive in the remaining catotelm. Given conservation management, the site retains sufficient peat depth to return to active secondary bog vegetation if the drainage system were blocked to retain rainwater.

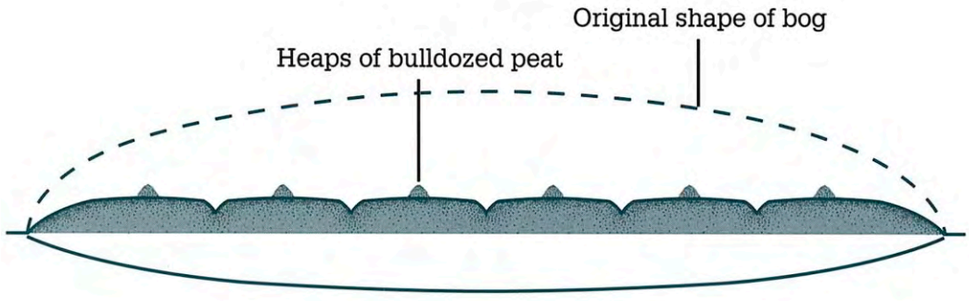


Figure 18(j).
Secondary (2°) sheet erosion.
The majority of this surface is moribund, often with only thin peat deposits remaining. Occasional remnant hags contain a condensed peat archive and support a degraded acrotelm or a moribund primary surface.

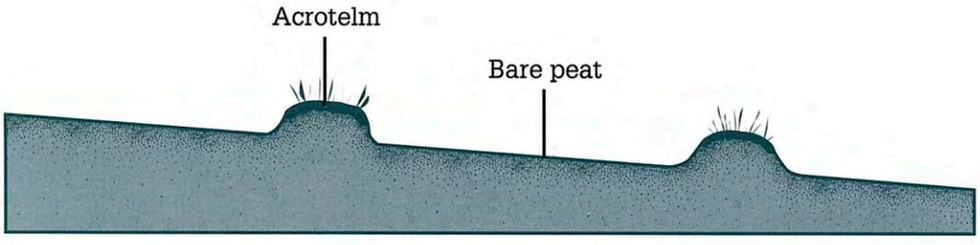
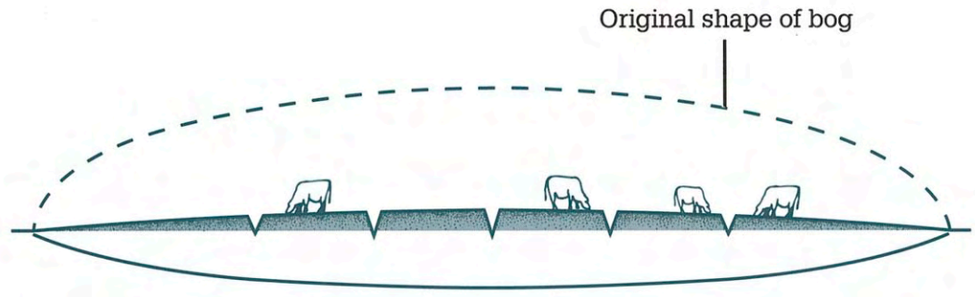


Figure 18(k).
Archaic peat deposit.
The peat has been removed down to the level of the ground water table and the surface no longer reflects its origins as a bog environment but instead supports, for example, an agricultural ecosystem. Some peat archive remains, but conservation management is unlikely to return the vegetation to active bog growth within any meaningful timescale. The main potential is for fenland development.



The factor having most influence over the eventual state of the woodland cover, and the peat surface beneath, is the balance between water loss and tree growth. Where tree growth is sufficiently vigorous for canopy closure to occur, interception and evapotranspiration will tend to cause a steady drying out of the bog surface layers to a much greater degree than is possible with drainage alone. Where, however, any drainage system collapses before canopy closure, growth in plantations may become sufficiently checked to prevent canopy closure, and the water table of the bog rises steadily back to the surface. Under these conditions *Sphagnum* growth may become re-established and commercial forest come to resemble examples of *Sphagnum*-rich self-sown woodland.

Self-sown woodland is often surprisingly rich in peat-forming ground vegetation. The commonest tree species is birch *(Betula pubescens)*, which has a light foliage even in high summer, and a branch structure which offers much less resistance to rainfall than conifers during the winter months. The density of trees also tends to be less than is typical for a commercial plantation. The effects of water loss and leaf litter have an effect on the species composition of the ground layer, simplifying it to only five or so species with perhaps only two or three *Sphagnum* species. None of these species is typical of open bog conditions in Britain (*S. recurvum, S. palustre and S. fimbriatum*), but the community is undoubtedly still actively growing and peat-forming, though because of increased decomposition the net rate of peat accumulation may be zero or even negative. *Sphagnum*-rich woodland on a primary surface can be considered to be a form of primary natural bog. Much wooded bog, particularly commercial plantations, however, tend to have moribund bog as an understorey.

Nevertheless, research evidence from Switzerland and experiments in Britain have demonstrated that even bogs with closed-canopy forest and completely moribund surfaces can be encouraged to re-establish *Sphagnum* growth simply by removing the tree cover and blocking drains. The bog water table rises rapidly to the surface and provides suitable conditions for a range, albeit attenuated to begin with, of typical bog species and *Sphagna* to re-establish.

The effects of oxidation and wastage may have been considerable in all these cases, and a great many bog species are lost, possibly forever, from the site. Nonetheless, clear evidence exists for the importance of such sites in terms of their potential contribution to the conservation of the resource because they at least still retain their primary dome and thus a relatively intact overall bog shape and hydrology.

Secondary bog surface

For raised bogs the importance of secondary sites lies in the fact that only through the positive conservation management of these damaged areas is it possible to consider expanding the extent of active bog vegetation in Britain beyond its present total of some 3000-5000 ha (see Section 14), which is acknowledged by the Department of Environment to be below the 'critical natural capital', as defined by English Nature, for the habitat. Once the peat has been dug to a depth where the mineral groundwater table influences the surface vegetation and the area is no longer secondary bog but a geotrophic fen, the potential for restoration to truly ombrotrophic bog vegetation within timescales of less than 200 or 300 years has been largely lost, although the precursors can be re-established much more rapidly. In other morphological types the role of secondary bog is of less consequence for nature conservation, although still important when

forming part of a site which contains primary bog. Secondary bog surfaces have become much commoner on blanket bog in Northern Ireland and western Scotland with the introduction of the 'Difco' peat extrusion system.

Secondary active regeneration
(Plates 30-32, figure 18g)

The vast majority of raised and many blanket bogs in Britain have at least some history of domestic peat cutting. Indeed sites are recorded from both Britain and Ireland where the entire primary dome has been removed in this way.

One of the clearest indications of regenerating peat cuttings is the presence of a cut peat face or, in older cuttings, a distinct if overgrown step up from the regenerating cuttings onto what is usually somewhat drier primary raised bog. Domestic peat cuttings which are still actively worked may qualify as 'regenerating' because the living turves from above the fresh cut are placed at the foot of the new face. They rapidly knit together into a secondary vegetated surface. Areas of regenerating domestic cutting tend to display particularly characteristic curving or irregular pale swathes on aerial photographs, in contrast to the smooth, even tones of a primary bog surface.

The most common feature of regenerating cuttings is the simplicity of the species complement with, typically, no more than seven or eight species in total. Often a single species of *Sphagnum* dominates the ground layer - usually *S. recurvum*, or sometimes *S. papillosum* or *S. magellanicum*. The rarer *Sphagna* such as *S. imbricatum* or *S. fuscum* are never found in such cuttings, nor generally are certain higher plants such as the great sundew (*Drosera anglica*), round-leaved sundew (*Drosera rotundifolia*), deer-hair grass (*Scirpus cespitosus*) and *Cladonia* lichens.

Secondary active erosion complex
(Plate 33, figure 18h)

Regeneration within erosion complexes is not unusual within blanket bog areas. Sometimes this involves the infilling of relatively narrow erosion gullies and subsequent knitting of this secondary vegetation with the remnant primary vegetation of the hag tops. In other cases, sheet erosion (see below) may have removed all but a scattered series of erosion hags to expose a thin peat layer over a mineral soil. Wet heath vegetation with *Juncus squarrosus* and/or *Nardus stricta* often regenerates over this layer, but sometimes *Sphagnum* forms a major component of the vegetation and may be well advanced in the process of re-establishing significant peat deposits over the eroded surfaces.

Secondary moribund surfaces
(Plates 34-37, figure 18i)

A commercially worked site is most efficient when it has the minimum vegetation, either because the method of working requires large expanses of bare peat (e.g. surface milling) or because vegetation represents a fire risk and also tends to establish root systems which make subsequent industrial extraction more difficult.

Methods of working up to the early 1980s meant that, on large sites, the whole area could not efficiently be worked all at once. This tended to lead to a mobile mosaic of bare ground and secondary bog vegetation whereby areas not currently being worked were left to re-establish a secondary vegetation until such time as they were to be brought into production again. On such sites the definition of what, exactly, qualifies as secondary active and secondary moribund presents some difficulties. The move increasingly to milled peat extraction means that this difficulty is disappearing, but so too are the old mobile mosaic communities.

Crown Copyright

Plate 13.
Eccentric mire. This is an aerial view of an eccentric mire (Claish Moss in Argyll) taken from an altitude of some 15,000 feet. The distance from the top of the main bog to the dark loch shore in at the bottom of the photograph is about 1.5 km. The pale dots and snaking lines are hummocks and ridges, the dark lines are [A2] mud-bottom hollows and [A3] pools. These lines are all arranged at right angles to the direction of surface slope, that is, the lines of pools and ridges act rather as a spirit level, indicating areas of constant height.

L. Gill

Plate 14.
Intermediate or semi-confined bog. This illustrates an area of bog which has formed on the foothills of the Pentland Hills, south of Edinburgh. It consists of several lenses resembling raised bogs, but some of which have escaped their natal sites and fused over quite high mineral ridges. The altitudinal differences between the various parts of bog, and even within individual units, greatly exceeds the depth of peat in any one unit. In other words the topography of the bog in many places is determined more by the topography of the underlying deposits than by peat accumulation. The site therefore has characteristics of both raised and blanket bog.

L. Gill

Plate 15.
Primary natural bog - aerial view. As there are no sites in Britain which are still entirely primary natural, the condition can only be found as parts of larger sites. In this case the remainder of the site has been planted with conifers and some long-term effects are already evident, but for the moment, at least, the surface retains a relatively natural appearance over much of the area. Dark patches are stands of either heather (*Calluna vulgaris*) or sweet gale (*Myrica gale*).

R.A. Lindsay

Plate 16.
Primary natural bog - ground view. In the foreground, within areas of [T1] low ridge, the white-beaked sedge (*Rhynchospora alba*) forms a sward over a carpet of *Sphagnum tenellum*. Denser stands of cross-leaved heath (*Erica tetralix*) can be seen beyond that, and then clumps of heather (*Calluna vulgaris*) in the middle distance. For a more detailed view of a typical vegetation, see Plate 10.

R.A. Lindsay

Plate 17.
Primary moribund bog (burning). After a severe fire most of the sward of vegetation can be lost, leaving only a layer of peat ash. Where the fire has burnt into the peat there may be deeper hollows or channels of ash, as can be seen here. Pale patches in the distance are hummocks of *Sphagnum* which have been burnt on the surface but not reduced entirely to charcoal.

R.A. Lindsay

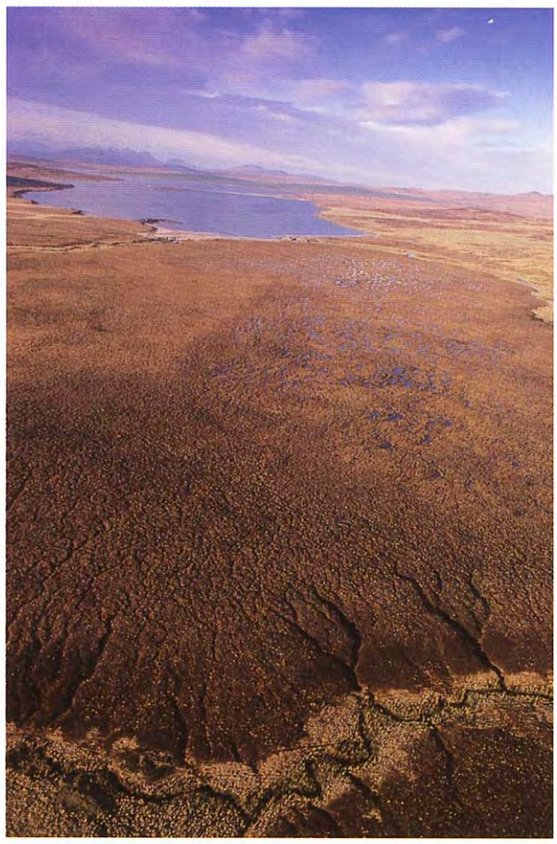
Plate 18.
Primary moribund bog (burning - detail). One of the most characteristic species to recover quickly from burning is the hare's-tail cotton grass (*Eriophorum vaginatum*). Its tight arrangement of leaf sheaths and root mass protects the living tissue inside from the heat, and recovery of aerial parts can occur within a couple of months. The same response is shown by deer-hair grass (*Trichophorum cespitosum* = *Scirpus cespitosus*) in north-western Scotland.

L. Gill

Plate 19.
Primary moribund bog (drying). Some bogs are dominated by heather (*Calluna vulgaris*) and have little *Sphagnum*, the bryophyte layer being either entirely absent or dominated by *Hypnum*-type mosses. The raised remnant of a dome has a vegetation which is a dark brown, indicating an abundance of heather. The crown is also being invaded by birch, which is another sign of the falling water-tables caused by the very evident agricultural land-claim which now delimits the bog.

D.A. Ratcliffe

Plate 20.
Primary moribund bog (drying - detail). The foreground is dominated by heather (*Calluna vulgaris*) and hare's-tail cotton grass (*Eriophorum vaginatum*), while the steady encroachment of birch across the site is evident.



S.G. Moore

Plate 21.
Primary micro-erosion - aerial view. In the middle distance the bog surface has a rather dimpled appearance which, towards the bottom of the picture, gradually combines to form the headwaters of the very evident erosion gullies. These run off the bog into the streamcourse bounded by pale purple-moor grass (*Molinia caerulea*) at the bottom of the photograph. This dimpled effect is very characteristic of micro-erosion, though care must be taken in identifying it because even undamaged bog has a faintly dimpled appearance when seen from the air.

R.A. Lindsay

Plate 22.
Primary micro-erosion - ground view. This photograph clearly shows the lack of deep erosion gullies. Instead the bog surface is broken into small bare patches, with, typically, clumps of deer-hair grass (*Trichophorum cespitsoum* = *Scirpus cespitosus*).

L. Gill

Plate 23.
Primary drained bog - aerial view.
Drains come in all shapes and sizes but a characteristic feature is that they leave untouched the ground between the drains, ignoring for a moment the indirect effects of de-watering and oxidative wastage. This picture shows a typical example of drainage attempts on a raised bog. These drains will probably be left for several years to do their work, then another set will be dug to take the drying process even further.

R.A. Lindsay

Plate 24.
Primary drained bog - ground view.
These are drains (or more accurately ploughing furrows) dug for forestry on blanket bog. Their primary purpose is to remove excess surface water and provide a raised turf in which to plant the tree seedlings. The effect of these furrows is much the same as 'deep' drainage: the more rapid removal of surface water prevents its retention in the acrotelm.

R.A. Lindsay

Plate 25.
Primary eroding bog - deep gullies. The scale of the erosion process can be judged from this photograph. Erosion has removed all the peat from the central gully-channel down to the underlying glacial deposits. There is limited evidence of revegetation on the gully floor, but the system still appears to be actively eroding. Great thicknesses of material can be lost from the bare peat faces in single events: when heavy rain follows a dry spell and the peat has cracked into 'plates' these can be easily lifted and washed away by the rainwater.

L. Gill

Plate 26.
Primary wooded/active bog - aerial view. The bog is dryer than it would naturally be because of various drainage activities. Since the 1940s the site has become rapidly covered by birch and pine scrub. The cover remains fairly thin, at present, and much of the site continues to support a primary bog vegetation, albeit modified.

Nature Conservancy Council

Plate 27.
Primary wooded/active bog - ground view. The scatter of trees is sufficient to give the place a woodland feel. However, the density of trees is such that significant areas retain a bog vegetation. This vegetation is modified by a combination of enrichment from leaf-litter and drying by evapotranspiration and interception by the tree cover.

L. Gill

Plate 28.
Primary wooded/moribund bog - aerial view. The typical pattern of commercial afforestation gives rise to dense forest canopies which hide the presence of a peat soil. Without recourse to soil maps, it would be difficult to know that this forest has been planted entirely on deep peat.

R. A. Lindsay

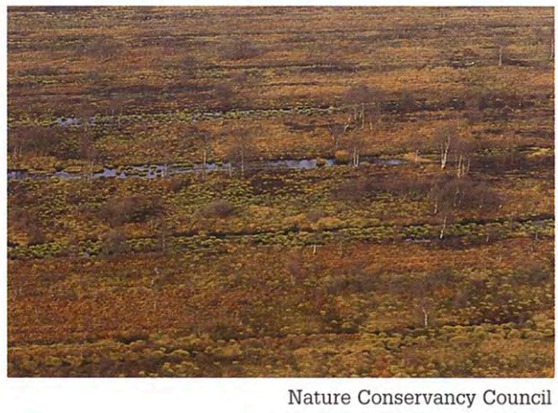
Plate 29.
Primary wooded/moribund bog - ground view. The combination of leaf-litter and interception has removed all trace of bog vegetation; the ground surface is entirely covered by pine needles. However, the water table is still often close to the surface on such sites, causing problems for tree growth. It can then show a dramatic response on removal of the trees, when such surfaces have been shown to return to very wet conditions capable of supporting a limited range of *Sphagnum* species within a year or so.

L. Gill

Plate 30.
Secondary re-vegetating bog - aerial view of domestic peat cuttings. The dark remnant of primary dome in the centre of the picture is a typical example of the condition described in Plates 19 and 20. Around it is a colourful mosaic of light and dark bands indicating where peat has been cut for domestic fuel and within which revegetation is occuring.

Plate 31.
Secondary re-vegetating bog - ground view of domestic peat cuttings. The cut peats are placed on the uncut vegetation above the face to dry over the summer. The skin of vegetation which lay above this fresh-cut peat was sliced off (flayed) prior to the peats being cut and laid down at the foot of the face. In time this knits back into a somewhat modified bog vegetation.

R.A. Lindsay



Nature Conservancy Council

Plate 32.
Secondary re-vegetating bog - aerial view of commercial peat cuttings. The more regular pattern of commercial working, compared to the somewhat haphazard patterns of Plate 30, is evident in this picture. The straight cutting hollows have become infilled with water and *Sphagnum*-dominated vegetation, while the raised baulks are drier and in places have been colonised by birch trees.

R.A. Lindsay

Plate 33.
Secondary re-vegetating erosion. On occasion, and for reasons which are not yet understood, erosion gullies can re-vegetate, healing the deep, dark gashes in the peat landscape. Here the former erosion complex is still very evident, but also evident is the degree to which the bottom of the former erosion gullies has become overgrown with bog vegetation. If the re-growth continues, the bare peat faces can be completely smothered by fresh growth. The resulting bog surface - a few can be seen in the hills of Mid-Wales - has a generally flat but strangely undulating character.

L. Gill

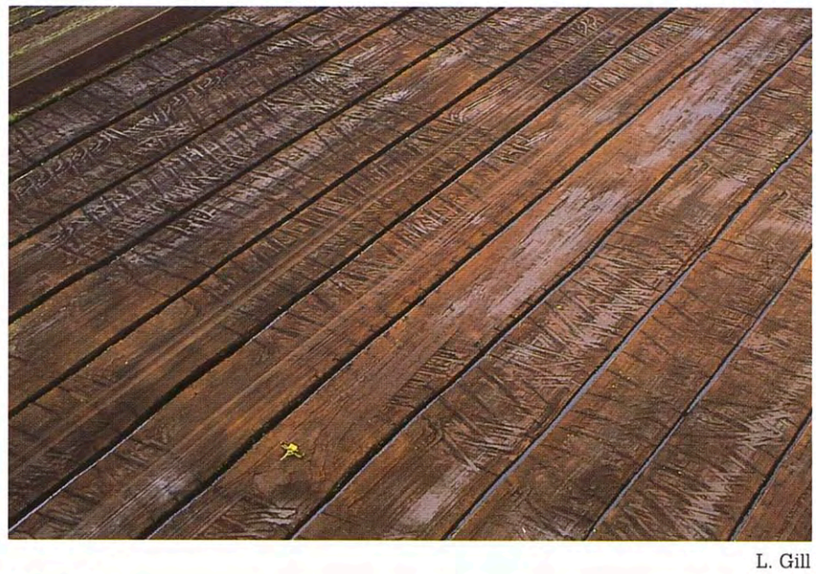
Plate 34.
Secondary moribund bog - block-cutting - aerial view. The traditional method of commercial peat extraction involves little more than a large-scale and partly mechanised adaptation of the domestic method. Peats are cut from long trenches, and laid on the higher uncut face to dry. The trenches and raised baulks can be seen laid out in a regular pattern to the right and bottom of the photograph. This is an area which has recently been taken into conservation management; the water visible in the hollows has been retained by the construction of dams across the main drainage system. Re-establishment of secondary bog vegetation has already begun.

P. Rowarth

Plate 35.
Secondary moribund bog - block cutting - ground view. This is an actively worked area of commercial cuttings. The bog surface is entirely devoid of vegetation.

P. Rowarth

Plate 36.
Secondary moribund bog - surface milling - ground view. Surface milling of a bog requires the entire surface to be stripped of its vegetation and drains to be installed at regular intervals. The photograph shows a bog completely stripped of its vegetation and a system of drains being dug by the machine in the middle distance.



L. Gill

Plate 37.
Secondary moribund bog - surface milling - aerial view. The series of drains delimiting each of the milling 'fields' can be clearly seen, as can the completely bare nature of the ground. To give a sense of scale, the small yellow object at the bottom centre of the photograph is a large piece of machinery of a similar size to the one in plate 36.

R.A. Lindsay

Plate 38.
Secondary moribund bog - sheet erosion. In some circumstances, erosion becomes so intense and extensive that it produces a surface not so different from commercial peat milling. Large tracts of the ground have nothing but bare peat and, in extreme cases, peat loss can be so severe that large areas of underlying mineral soils may be exposed. Few bog species can tolerate such conditions, but this picture emphasises that the deer-hair grass (*Trichophorum cespitosum* = *Scirpus cespitosus*) can survive and is often accompanied by the moss *Racomitrium lanuginosum*.

D.A. Goode

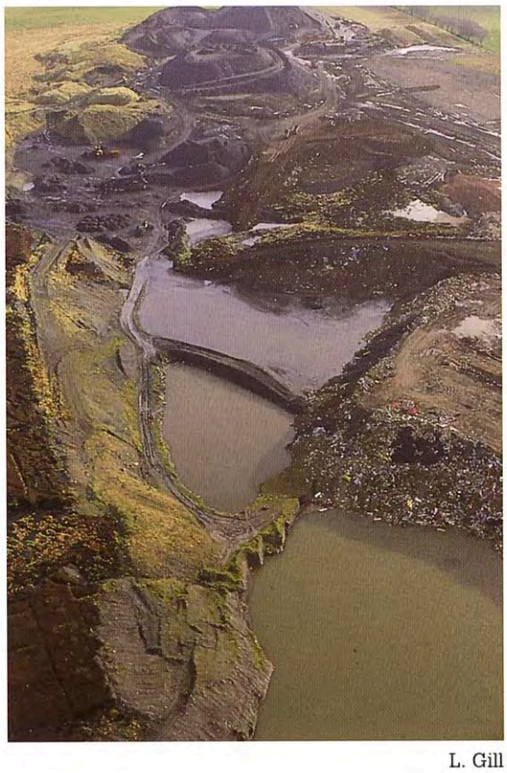
Plate 39.
Archaic agricultural deposits. Where the bog has been turned over to intensive agricultural usage, there may be no trace of bog vegetation. The only sign of the area having once been bog is the dark peaty soil, as can be seen in this photograph.

J.B. Ratcliffe

Plate 40.
Drainage - a fresh drain. The picture shows a single agricultural drain - a 'moor-grip'. The unoxidised nature of the raised turf indicates that this drain has only recently been dug. The drain is narrow, and appears to be having little immediate effect on the surrounding vegetation.

R.A. Lindsay

Plate 41.
Drainage - an old drain. This photograph shows a similar drain to the one in Plate 40, but one which has been operating for a very much longer period. It has been deepened by bottom-scouring, and has led to the general slumping of the ditch sides. The dry nature of the vegetation extending either side of the drain can be seen from the abundance of *Racomitrium lanuginosum*, heather (*Calluna vulgaris*) and various pale lichens. The surface of the bog in this general vicinity is now dominated by micro-erosion.



L. Gill

Plate 42.
Opencast mining - complete loss of peatland environment. Where the peat is removed to gain access to minerals beneath, the entire peatland system of vegetation, hydrology and archive is lost. 'Restoration' of any form of bog environment has yet to be demonstrated, despite many attempts.

Secondary moribund areas are important because sometimes they represent the only example of a peat bog environment in the area, they are still ombrotrophic and they often have a drainage system which can be readily blocked to encourage resoaking of the peat surface.

Secondary sheet erosion
(Plate 38, figure 18j)

Some parts of blanket bogs are subject to such extreme erosion that large expanses of the original bog surface have been lost, thus exposing considerable areas of bare peat. This is particularly true of high-level watershed plateaux such as the summit ridge of the Monadhliaths, or Kinder Scout. The reasons for such erosion are not yet understood, but the phenomenon may yet prove to be in part at least a natural process. A clear understanding of the origins of erosion is vital in any consideration of the long-term stability of blanket bog systems. A distinction should perhaps be made between primary gully erosion, for which the origins are in general not clear, and secondary sheet erosion, which in some cases at least is the result of fire damage, and in other areas may be the result of wind erosion. The conservation caveat given for primary gully erosion should, however, still be borne in mind even with sheet erosion.

Archaic peat bog soils
(Plate 39, figure 18k)

Where bogs have been converted to agricultural use there is generally no evidence today from the vegetation that the ground was ever a peat bog, apart from the dark nature of the soil. All trace of the original bog vegetation has been removed, and is replaced by an agricultural crop. Often the peat has become geotrophic once more, having been stripped away to the extent that it is subject to the mineral groundwater table. In some cases the archaic deposit has been entirely covered by some cultural activity such as building or rubbish tipping. It is thus possible to distinguish exposed archaic peat from covered archaic peat.

The type is recognised more as a soil series than a habitat because distinctions between areas which were once fen or bog rely entirely on the soil type. However, the importance of the type extends beyond the concerns of soil conservation. Such areas still retain a partial Quaternary archive, often in geographical regions where no other forms of bog peat survive. Archaic deposits also often retain sufficient of the features unique to bog conditions for them to represent the best, probably the only, possibility of rehabilitation to any form of secondary bog habitat within the area. Without at least an acid peat base on which to start, bog vegetation is unlikely to establish rapidly - a fen phase or *Sphagnum* monoculture of indeterminate duration is usually required first.

The identification of condition classes

More often than not a site consists of many differing condition classes. Figure 19 shows a typical example of a raised bog in Britain today. The distinction between primary and secondary areas is usually fairly evident, other than on heavily wooded bogs. Stereoaerial photographs between 1:10000 and 1:25000 scale are particularly helpful in this. The subsequent recognition of individual parts which correspond to particular conditions is generally a step which requires the use of stereoaerial photographs, supplemented by field survey.

Having identified the areas of primary and secondary bog it will generally be possible to recognise within the primary bog a zone evidently influenced by marginal effects - the

mire margin - and the central area of the mire expanse. Within these expanse, margin and secondary regions a number of sub-compartments can usually be distinguished from the aerial photographs. These may result from fire damage, drainage, grazing, hand cutting as opposed to commercial cutting or a variety of other factors, but they can be noted simply as distinctive 'parts' on a 1:10000 outline map. Field survey can then be used to identify the nature of these various compartments, each of which ought to be assessed separately and then assigned to one of the condition classes described above.

Adjoining compartments which, following field survey, prove to belong to the same condition class should be merged to make a larger compartment. Compartments which prove to be based on vegetation differences but which nevertheless fall into the same condition class should also be merged into a single condition class, although their differing natures ought to be noted. Species/quadrat field data will continue to characterise their different vegetation types.

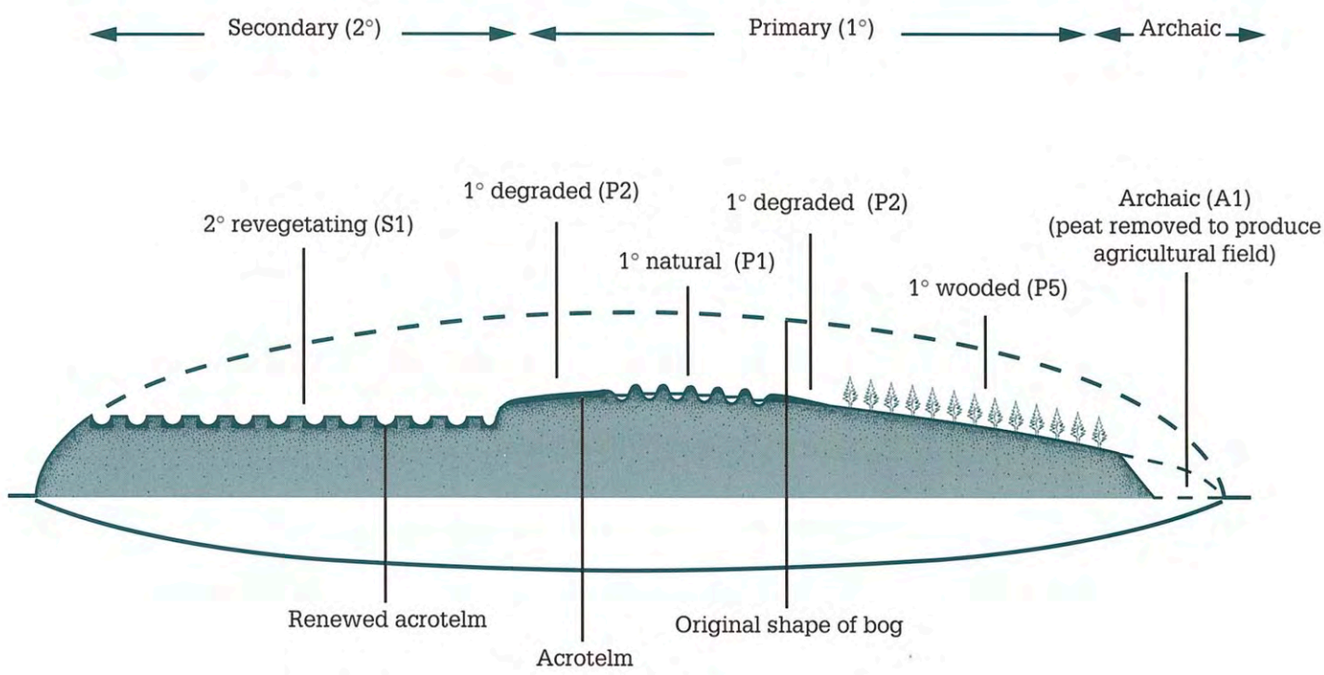


Figure 19.
The typical pattern of land-use conditions on a raised bog. Most bogs have been altered in some way by a variety of human activities. Shown schematically is a raised bog peat dome which has been significantly reduced in diameter by domestic peat cutting (secondary revegetating) and agricultural land-claim (archaic peat). The peat dome is typically lowered somewhat by shrinkage and oxidative wastage, although no direct extraction or other removal of peat has taken place within this part (primary bog). Various conditions can be found on this primary surface, including scrub, coniferous plantation (primary wooded), an impoverished bog vegetation as a result of water table draw down (primary degraded) and islands of near-natural bog vegetation towards the centre (primary natural).

Section 12 Hydrological Implications of Habitat Change

Bogs are first and foremost hydrological units, often consisting of up to 98% water by weight, and in terms of site protection their boundary requirements should therefore be regarded as similar to those of aquatic systems. The fundamental objective of conservation management is to maintain or, where necessary, stabilise and enhance the hydrological integrity of an ombrotrophic system.

A steady accumulation of knowledge about the hydrological processes which govern bog systems means that an increasingly clear idea exists of what may be necessary to fulfil this fundamental objective (e.g. Ivanov 1981, Bragg *et al.* 1991, Ingram 1992, Heathwaite & Göttlich 1993). Despite this progress, much still remains to be investigated, and many aspects can only be approached at present on the basis of experience, anecdotal evidence or informed speculation rather than any rigorous scientific analysis.

Nevertheless, adoption of the Precautionary Principle, as identified in the UK Biodiversity Action Plan, necessitates the adoption of certain maxims, namely:

- where doubts exist about the limits of a hydrological unit, assume that the larger, rather than the smaller, boundary is appropriate;
- if experience and anecdotal information are the only forms of guidance available, use them but do so with caution; and
- major, irrevocable actions which may themselves close off other options in the future should only be undertaken when the result is virtually certain and future requirements are known.

Practical conservation action

The logical first step involves delimiting the individual hydrological units which contain the identified interest. Where individual bogs fuse with other bogs the complete unit of each must first be defined. The hydrological links between these units should then be identified and the whole interlinked complex, or macrotope, ought then to be treated as a single conservation unit in order to be sure that all significant hydrological components have been incorporated.

Conservation of the entire unit both emphasises the hydrological continuity of the peat body and also may enable negotiations to be opened with the relevant land users eventually to minimise the impact of their operations either on the site or adjacent to it. In the case of past afforestation, for example, this may involve seeking to fell the timber at the earliest opportunity with an agreement that there will be no further forest rotations within the hydrological unit.

Such an approach is in accord with the provisions of the EC Habitats Directive, which states that the conservation of a site will be considered 'favourable' only when '*the specific structure and functions which are necessary for its long-term maintenance exist and are likely to exist for the foreseeable future*'.

The groundwater mound theory (Ingram 1982, Bragg *et al.* 1991) indicates the reasons for defining the complete hydrological unit in each case. In mineral soils, as described above, the water table adopts a half-ellipse between two sub-surface drains. If these drains are placed closer together the entire half-ellipse changes to a smaller ellipse of the same shape (see Figure 20a). The same principles are thought to apply, through the groundwater mound theory, to bogs; if the diameter of the bog is reduced by physical removal, the bog water table will become unstable because one edge of the ellipse has been forced to adopt an unnaturally steep hydraulic gradient.

Over a period of decades, it is suggested that the water table will tend to re-establish a new lower ellipse (see Figure 20b). Figure 21 illustrates this overall process in the form of a generalised model for a circular bog which has increasingly large 'bites' removed. It can be seen that the whole pattern of water table contours is predicted to change, and that the highest point of the mound changes its location, as well as sinking by some 25%.

Figure 20 and the groundwater mound theory predict the behaviour of the water table alone, not the peat body. However, it should be clear from Section 2.6 that changes in the water table will also have an effect on the peat body itself. A fall of the water table into the catotelm, no matter how small, will certainly lead to some fall in the actual peat surface through slumping, shrinkage and oxidative wastage. The peat surface thus follows the water table downwards. Hobbs (1986) presented a detailed and illuminating analysis of the processes occurring in the peat from an engineering geologist's perspective, while Heathwaite and Göttlich (1993) did the same from a mire ecologist's viewpoint. Lindsay *et al.* (1988) also summarised the sequence of events and presented an example from a raised bog in Cumbria.

It is important to recognise that no dramatic overall lowering of the water table into the peat will be observed. The process will occur as a series of small incremental losses, with a slight fall in the water table, then an incremental loss of catotelm peat. The focus of interest should thus be the behaviour of the water table in relation to the extremes of its behaviour, particularly the summer minimum levels and the length of effective drought periods.

During the period of restabilisation for both water table and peat, which is thought to take many decades or even centuries, the water content of the acrotelm, or surface layer, is thus likely to be lowered compared with the site in its formerly undisturbed state. This may involve a fall of only a few centimetres in the average water table, but Ivanov (1981) states that '*the maximum difference in mean long-term [water] levels which does not lead to a change in the quantity or floristic composition of mire plant communities is very small. For several varieties of moss cover it is less than 4-5 cm.*' The gradual shift in vegetation and surface pattern resulting from a gradual fall in the bog water table has been illustrated by Woike and Schmatzler (1980) - see Figure 22 and Plates 40 and 41.

The changed behaviour of the water table within the acrotelm, both schematically and based on actual data, can be seen in Figure 23, from which it is evident that the water table falls into lower parts of the acrotelm more regularly than before, and that drought periods are extended because the water table falls more rapidly into the drought zone.

In the case of a bog where part of the peat body remains as upstanding primary bog and part is primary wooded or active secondary, the area of open primary bog can generally be assumed to be *sinking, even though active*, because its overall rate of accumulation will be less than its rate of decomposition at least until the whole dome sinks to a new stable ellipse. In contrast, the secondary bog, if active, can be assumed to be *rising* as it accumulates peat, although the rate of accumulation will depend on the *Sphagnum* species involved.

The overall effect of these two processes is that the primary bog dome may well continue to sink until it finally meets the upward growth of secondary bog. The two should then fuse to form a unified growing bog. If the secondary area is abandoned to

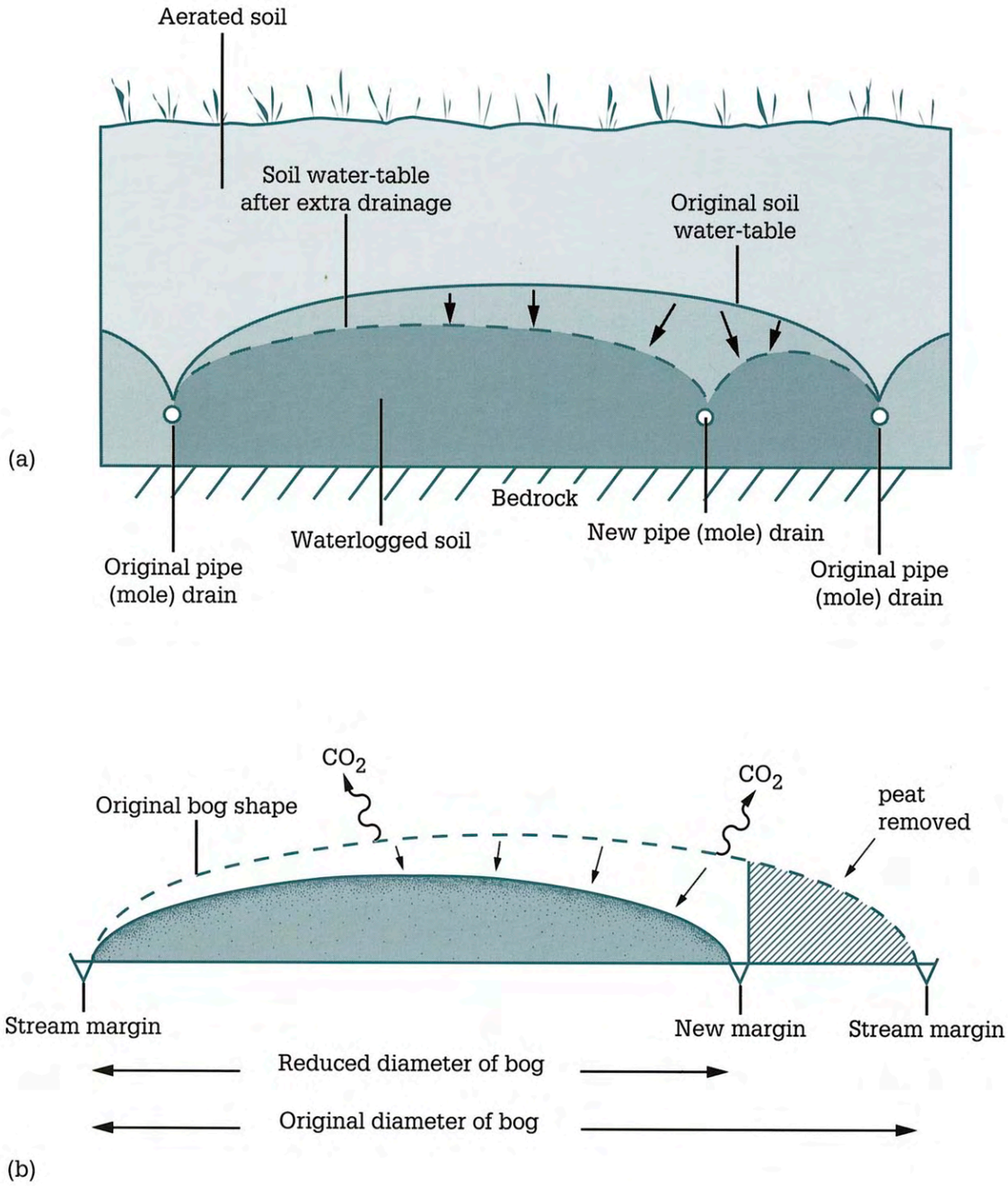


Figure 20.
Changes in the groundwater mound of mineral and peat soils as a result of drainage or peat removal. Figure 20(a) shows the effect of adding extra sub-surface drains in a mineral soil. Figure 20(b) shows the longer-term effect, as a result of slumping and oxidative wastage, of removing part of a bog dome.

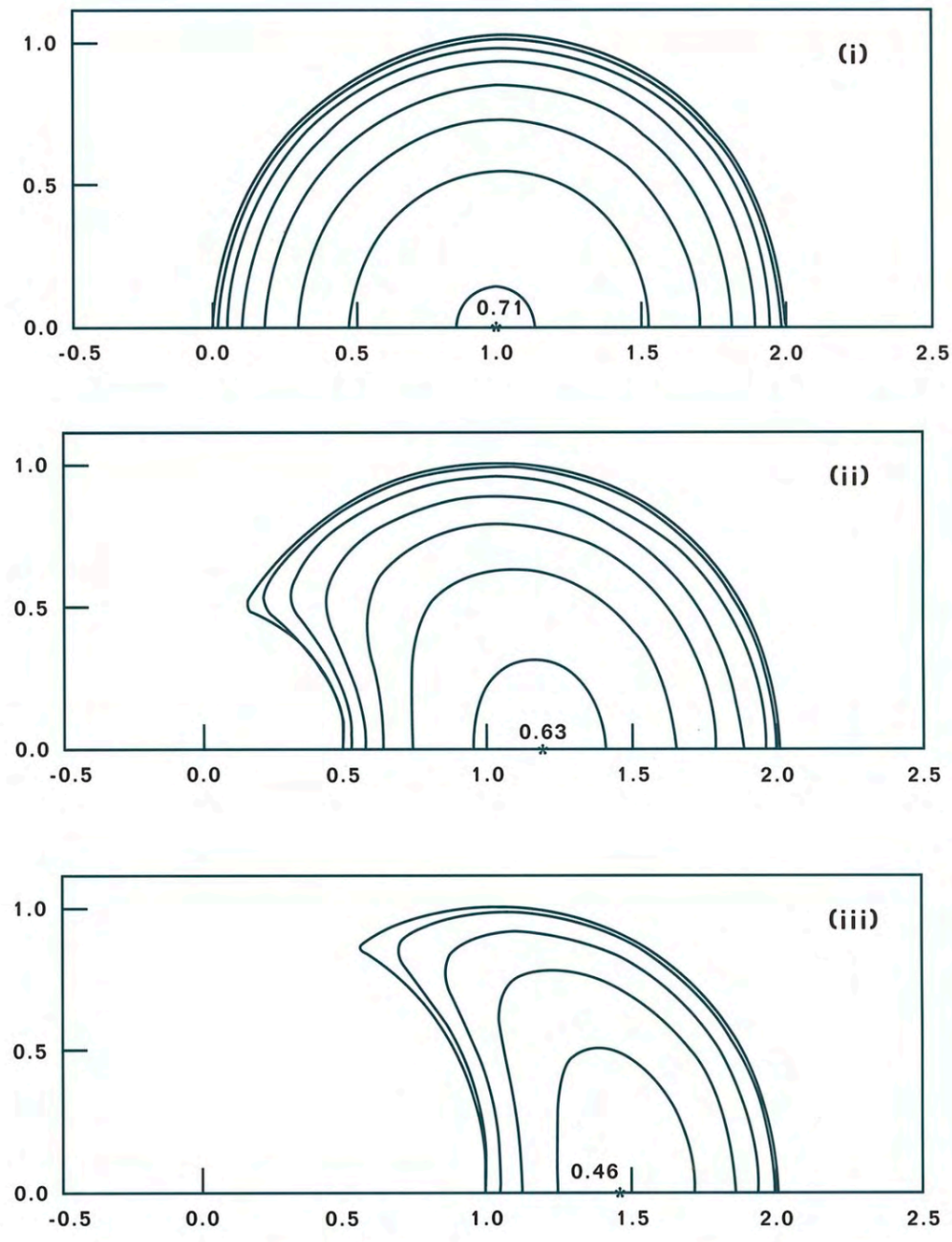


Figure 21.
Three-dimensional groundwater mounds computed using the steady state Forchheimer equation for a circular mire of unit radius on a horizontal substratum: (i) intact, (ii) after removing peat from the edge for a distance equal to half the radius of the bog, (iii) the same but for a distance equal to the radius. Contour lines indicate the relative height of the water table across the groundwater mound. Note particularly the way in which the height at the summit (*) decreases as a larger area of the groundwater mound is removed. The units, including height, are dimensionless, but show the relative % change on a bog of radius 1.0. Actual examples can be scaled-up from this dimensionless model. (Taken from Ingram 1982.)

some other land use and is not permitted to accumulate peat, the primary bog would probably then sink for a much greater period of time and to a greater extent, increasing the likelihood that significant species will be lost before a new stable shape can be attained.

Even archaic peat soils under pasture can be encouraged to redevelop a secondary active vegetation, whereas these same soils, if allowed to be continually underdrained, will continue to waste away and possibly undermine the hydrological stability of the remainder.

Site boundaries can be drawn up on the basis of soil maps and stereoaerial photographs. Subsequent consideration of the special conditions which affect individual sites, particularly after field survey, will often enable any provisional site boundary drawn up on the basis of the Precautionary Principle to be subsequently modified, thus excluding land which can be shown to be no longer part of the hydrological or ecological components of the site. For example, motorway construction may remove part of a bog leaving two widely separated peat units. Alternatively, the original extent of bog may once have been so much larger than the area of remaining ombrotrophic peat (as in the case of Winmarleigh Moss SSSI on the Lancashire coastal plain) that now a very much smaller area of peat soil may be sufficient to encompass the existing hydrological functions of the surviving remnant.

Bunding of cut peat edges using impermeable materials such as clay, butyl sheeting, steel shuttering, even bulldozed peat, is a technique which has been proposed and indeed carried out, on a number of sites. It is discussed in *The Peatland Management Handbook* (Rowell 1988) as both a management practice and also a method of providing a site boundary where the site has been damaged or truncated, but it should perhaps be emphasised that, in general, it is difficult to apply the Precautionary Principle when adopting such a method. The techniques involved are still largely experimental and tend to be irrevocable. Indeed, any such major engineering works, whether it be bunding or 'recontouring' of a bog, involve operations which are based on only a few examples. The initial results from these examples are inconclusive. If problems do occur, as they have with clay bunds for example, where cracking and water leakage have been a constant problem (e.g. Shapwick Heath, Somerset), the reversal or modification of these operations is likely to be very disruptive or even impossible - once peat has been removed it cannot simply be put back. Considerable thought should thus go into a review of all available options before embarking on such irrevocable actions.

A particular form of bunding, termed 'pressure bunding', has been adopted in Wales, at Cors Caron NNR, and represents the type of major engineering operation which is non-irrevocable. The bund is constructed at the outer limit of the peat soil, i.e. on the edge of the former hydrological unit of the raised bog. Thus the bund encourages a high water table to develop in the area of secondary peat cuttings and archaic peat under (abandoned) agricultural land, thus forming a secondary lagg fen. This in turn helps to raise and stabilise the water table in the remaining primary dome. However, if problems are observed to occur in the future, these bunds can be removed with no physical disruption to the primary peat body.

More conventional bunding, on the other hand, may tend to perpetuate an unstable situation. Indeed, in many cases it may make the situation less stable, as for example:

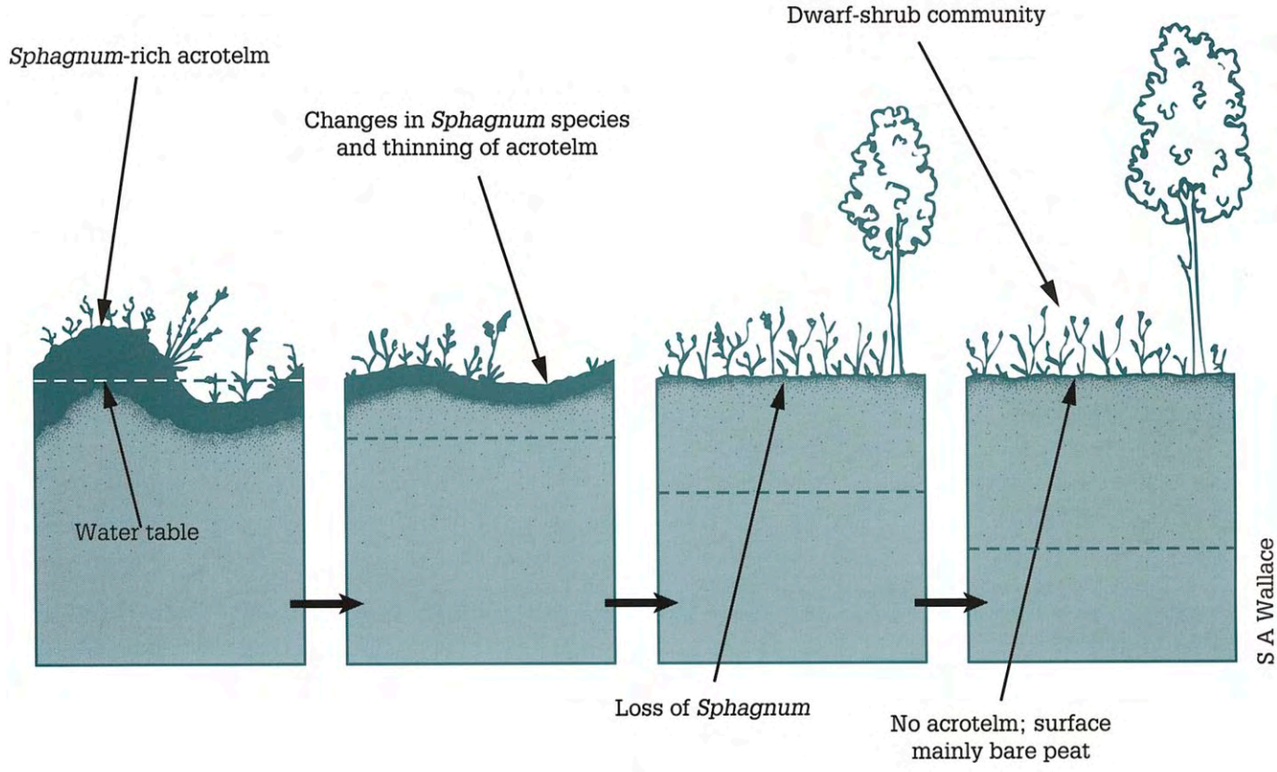


Figure 22.
Changes in the surface and vegetation of an ombrotrophic bog with lowering of the water table (after Woike & Schmatzler 1980).

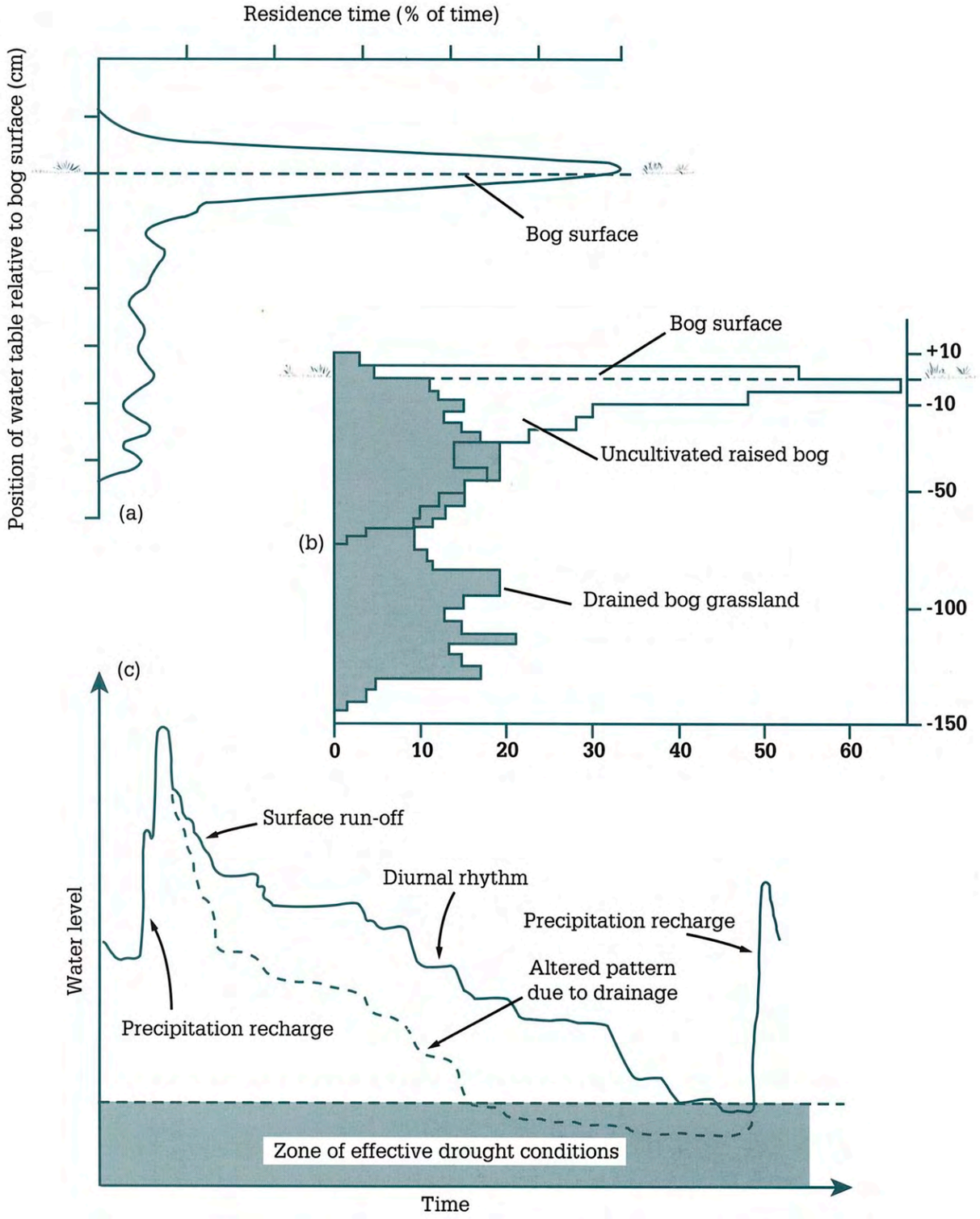


Figure 23.
The effect of drainage on the water table in the acrotelm. (a) Location of the water table in relation to the bog surface, expressed as proportion of time spent at particular depths ('residence time'). (Taken from Bragg 1982.) (b) Pattern of residence times for bog water tables in both a natural and a drained bog in western Germany. (Taken from Ingram 1983.) (c) Continuous recording of the water table, showing run-off and diurnal rhythm, from an undrained bog in Argyll (SNH unpublished data) and a generalised indication of the effect of increasing the surface run-off by, for example, drainage.

- a successful bund will encourage increased growth of the bog, which may thus involve an increase in bog surface height. The bund will also thus need to be raised to keep pace, thereby creating an even more extreme hydraulic gradient across the bund matrix;
- the natural tendency for the outer surface of a bund to dry and crack, thereby encouraging pipe flow from the bog, is likely to increase as the hydraulic gradient across the bund becomes steeper;
- the natural flow lines of the bog water table are abruptly intersected by a bund, potentially causing erosion at the peat-bund interface during storm events as water is channelled in unnatural volume along the bund face;
- even sympathetically constructed bunds using semipermeable materials can only approximate the natural hydrological conductivity of peat. Evidence that a peat bund fails to meet the design requirements would generally become evident only during extreme conditions (e.g. heavy rainstorms), and emergency remedial works may well not be possible under such conditions;
- indeed, because bunds tend to involve extensive engineering works, they are also very difficult to modify or remove if they prove to be unsuitable or harmful. Once in place, a bund tends to be a permanent feature.

On a site which is hydrologically unstable because peat has been removed from the margins, leaving a cut face, the least resource-demanding and probably safest strategy is also the simplest. It is one which leaves a wide range of management options open for the future. In practice, this means accepting a certain degree of oxidative wastage and consequent 'recontouring' by such natural processes. The site is defined according to its hydrological unit, including both primary and secondary peat. Gradual slumping is then accepted as the least disruptive measure for areas of upstanding primary bog, but positive conservation measures should be employed to limit water loss from the primary dome as far as possible, as well as encouraging rapid regrowth of secondary bog around the primary remnant. Thus drains would be blocked in both primary and secondary areas of bog, encroaching woodland removed and fires prevented. If there is particular concern about the loss of some of the wetter parts of the bog surface during the settlement phase, consideration could be given to the use of a 'pressure bund' at the outer margins of the hydrological unit.

Many of these suggestions are more directly applicable to raised bog than to blanket bog. This is because much more work has been carried out on the former than on the latter. Hydrological processes also tend to be more complex in blanket bog because of the additional influence of topography. Nevertheless, some experiments are currently under way on blanket bog systems. Most notably these are in the Peak District and the Pennines in relation to peat erosion and its mitigation, and on the Border Mires in and around Kielder Forest. In the case of the Border Mires the impacts of forest drainage and rehabilitation management of previously afforested peatlands are under investigation and are beginning to produce some promising results.

Section 13 Original Extent and Distribution of Bog Types

The National Peatland Resource Inventory (NPRI) (SNH, unpublished) indicates that the total extent of bog peat in Britain is just over 1.5 million hectares. The distribution of deep peat soils (including fen), as opposed to the present remaining habitat, can be seen in Figure 24. This illustrates the former extent of the peatland habitat, much of which now lies under agricultural fields or forestry plantations. The distribution of this between peatland types and countries, as digitised into the NPRI, can be seen in Table 4 and Figure 25.

Raised bog

The distribution of soils derived originally from raised bog habitat - i.e. the original extent of the habitat, not the present day resource - can be seen in Figures 26 and 27. These maps highlight the fact that certain parts of Britain, particularly north-west England, central Strathclyde and the Grampian coastal plain, were at least in former times particularly important regions for the raised bog habitat. Conversely, the distribution in certain other localities is so thinly scattered that whole regions have only a few sites. (See also Lindsay *et al.* in press)

Blanket bog

In England and Wales, blanket bog is exclusively associated with upland environments. In the south-west it is thus found on Dartmoor and Exmoor, though not, strictly, on Bodmin Moor. It is also abundant throughout the upland massifs of Wales. Northwards from the Peak District, which lies at the southern extremity of the Pennine chain, blanket bog is relatively widespread on high ground and continues to be so through the Scottish Southern Uplands. From Arran northwards the west coast of Scotland is dominated by blanket bog, with only a few scattered examples of raised bog or eccentric bog. North of the Highland Boundary Fault blanket bog becomes steadily less dependent upon altitude with the result that, in northern and western districts of Scotland, blanket bog is common down to sea level.

Blanket bog soils cover at least 1.4 million hectares of Britain, but this figure is based on peat with a minimum depth of 1 m. Very much more extensive areas of thinner blanket peat occur, particularly in Scotland, and thus the total coverage may be approximately 2 million hectares.

Ridge raised/intermediate mires

These are limited in total extent, with very few examples in England and Wales. The transition stages between raised and blanket bog show a more widespread but localised distribution in Scotland, particularly associated with the Southern Uplands. Where such sites occur they are usually to be found along the fringes either of upland massifs or of significant expanses of blanket mire. The NPRI estimates the total extent of the resource as a little over 9000 ha. Although this figure is by no means definitive, it seems clear that the type is of limited overall extent.

Eccentric bogs

These are restricted entirely to the far west coast of Scotland, and almost exclusively to the Ardnamurchan peninsula. Their total area is thus extremely small.

Figure 24.
Total area of deep peat soils for Great Britain. The areas shown were digitised by the NPRI from the British Geological Survey Drift Edition 1:50,000-scale sheets, plus additional sources where necessary, which indicate peat deposits greater than 1 m deep.

Summary areas (in hectares) of peat soils greater than 1 metre in depth by genetic type and country.					
Country	**Fen**	**Raised bog**	**Blanket bog**	**Intermediate bog**	**Total area**
England	131672	37413	214138	981	384204
Scotland	(*) 1215	27892	1056198	10653	1095958
Wales	(*) 2867	4086	158770	85	165808
Total measured peat	135754	69391	1429106	11719	1645970
Total bog peat				1510216	

Notes
Scottish fen peat is underestimated
(*) data incomplete
Totals include some peat which is only 0.3-0.5m deep

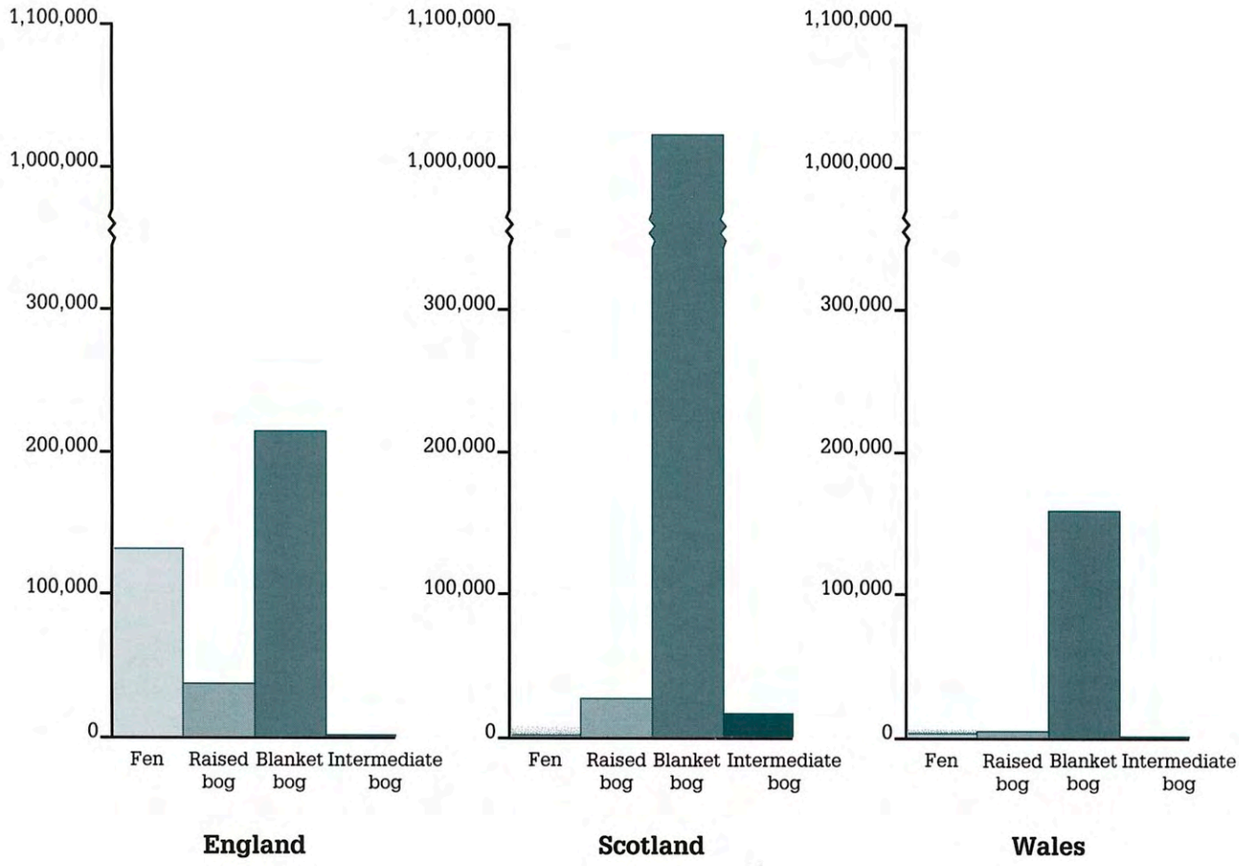


Figure 25.
The distribution of soils derived from the two major peat bog types recorded by the NPRI for Britain - raised and blanket bog. Intermediate bog, which shows characteristics of both main types, is also recorded. Fenland soils are presented for England, but the data for Wales and Scotland substantially under-estimate the extent of fen soils.

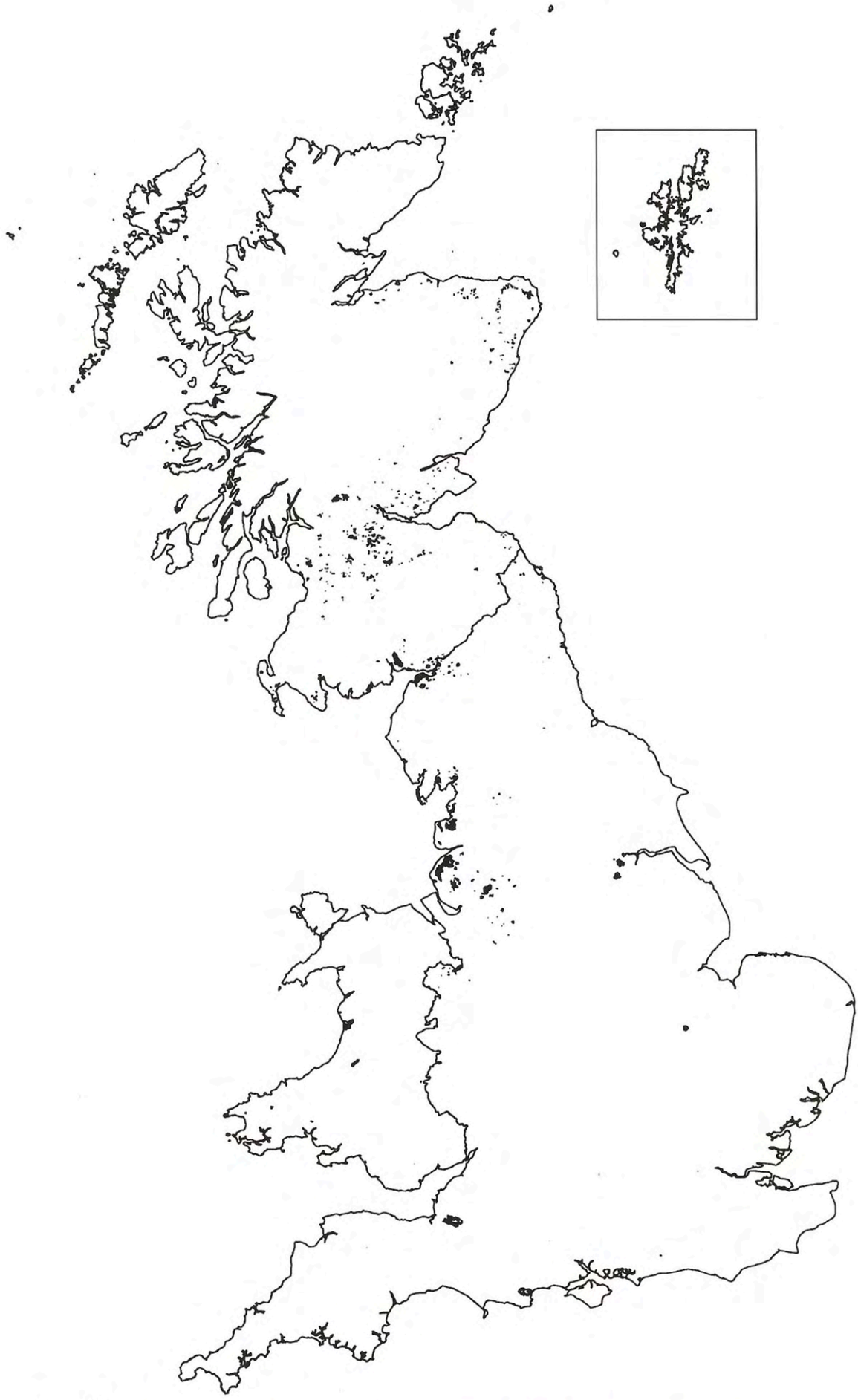


Figure 26.
The distribution of soils derived from former or existing raised bog habitat in Great Britain.
Lowland raised bogs comprise only a small proportion of the peatland resource in Great Britain with very few individual sites covering more than 100 ha.

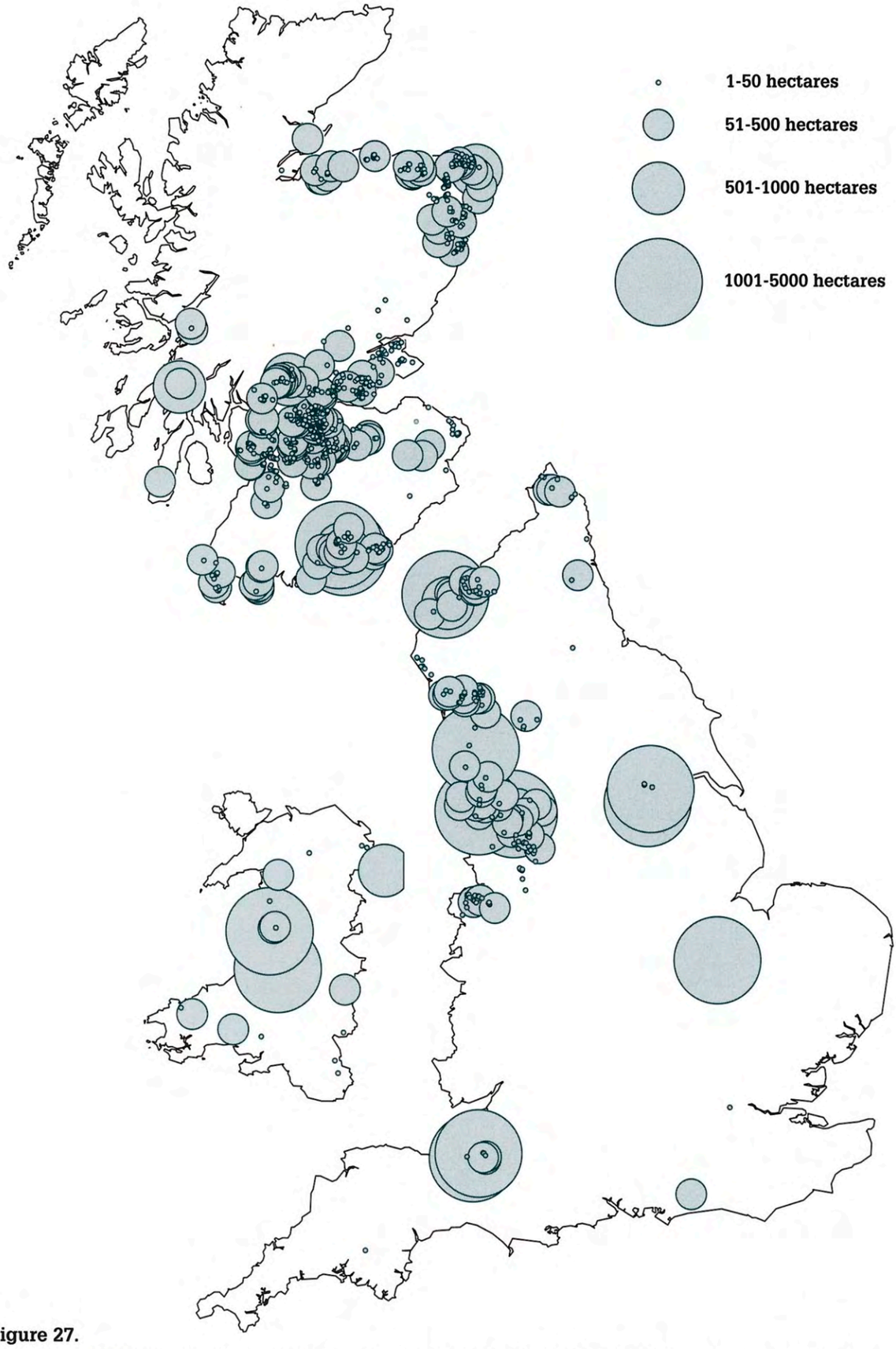


Figure 27.
The distribution of soils derived from former or existing raised bog habitat (expressed as sized circles). Individual bogs are displayed as area circles allocated to four size-classes (see key). The map shows the former distribution of raised bog sites (using soil and geomorphological criteria rather than current vegetation), rather than the extent of surviving habitat today.

Section 14 The Pattern of Land-Use Change and Habitat Loss in Britain and Europe

Conservation measures necessary to protect an adequate representation of the peat bog resource in Britain cannot be identified without also considering the present state and distribution of that resource. The original extent of peat bog habitat in Britain may give an overall context for conservation measures, but priorities are also identified in the light of current distributions and pressures.

Raised bog

In the case of raised bogs, the NPRI has identified that, of the 67000 ha of raised bog in Britain, only some 5.5% can still be classed as natural primary bog (Lindsay *et al.* in press). If, rather than measuring the actual extent of natural primary bog, each raised bog is classed according to its predominant land use - in other words identifying the major hydrological impact on the site - a number of significant land use pressures can be identified (see Figures 28 and 29).

Although England once possessed the largest proportion of raised bog in Britain, it now does not have a single site (except Tor Royal Bog, Devon, which is probably more of a valley mire) which is predominantly natural primary bog. Almost half the sites have undergone land claim for agriculture and are now effectively geotrophic. A total of 16 sites, mostly large sites, are subject to commercial peat extraction, and a proportion of this is so worked out that it is now also geotrophic. Only 11% of sites in England now support some form of open bog habitat on a primary peat dome.

In Scotland the land-use changes are rather more evenly spread, but even here only 55 of the original 851 sites (6.5%) are still predominantly natural primary bog. The most significant land use changes have been due to afforestation and agricultural land claim, accounting for 53% of all sites. A large proportion of the original resource in Wales is still in a natural state, but this is derived largely from two large NNRs, Cors Caron and Cors Fochno. The remaining sites consist mainly of secondary peat cuttings which are actively regenerating.

For Britain as a whole, almost 32% of all original raised bog sites are now geotrophic agricultural peat. The total remaining number of sites, which are still predominantly natural primary bog, represents 5.6% of the original number of raised bogs in Britain.

The land use figures presented here are based on *numbers* of sites, rather than *area* of the resource. Thus commercial peat cutting is recorded as the major land use on 30 sites, but the total area represents a significant proportion of the resource, particularly in England. Agriculture, though widespread as a cause of land-use change, is given added emphasis because a few very large sites in Lancashire and Cambridgeshire have been subject to almost complete agricultural land claim.

Blanket bog

Detailed data for land use changes on blanket bog are not readily available for Britain, although the NPRI has provided data for parts of Scotland and England (e.g. Caithness and Sutherland, Shetland, the Outer Hebrides and the Pennines), and a comprehensive mapping programme is currently under way. However, one of the most dramatic changes to occur to this habitat during the twentieth century has been the expansion of forestry. Taylor (1983) shows that, for NW England and the majority of Scotland, more than half of all forestry planting up to 1978 had been carried out on peat soils. During the 1980s this proportion undoubtedly rose because the Forestry Grant Scheme available during this period encouraged private planting on such ground.

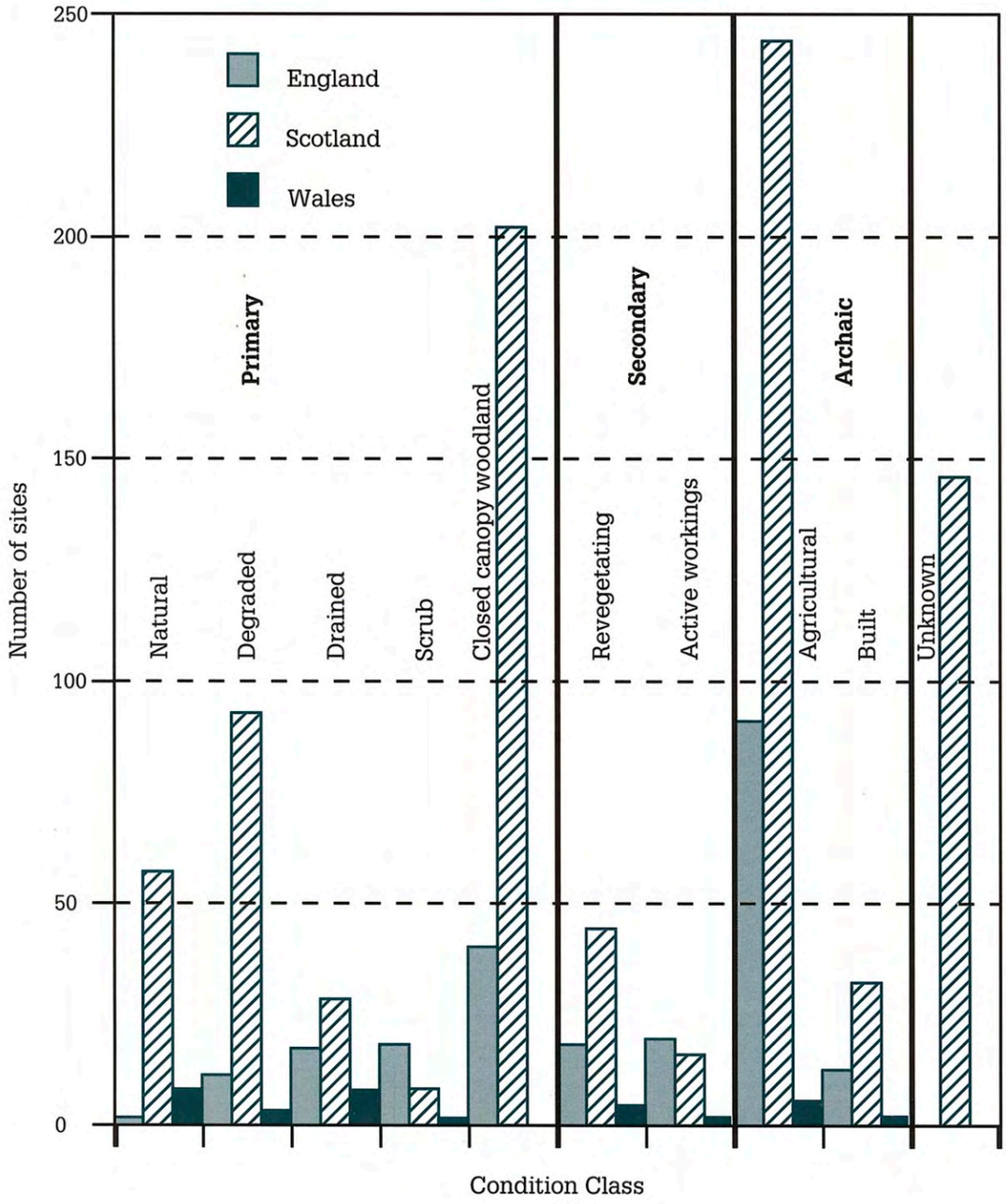


Figure 28.
Number of raised bog sites classified according to their major land use. The largest proportion of habitat change has been as a result of agricultural land-claim leaving archaic peat soils. An appreciable number of sites have been cut-over, and a substantial number have closed canopy woodland. Sites with natural or degraded areas are commonest in Scotland.

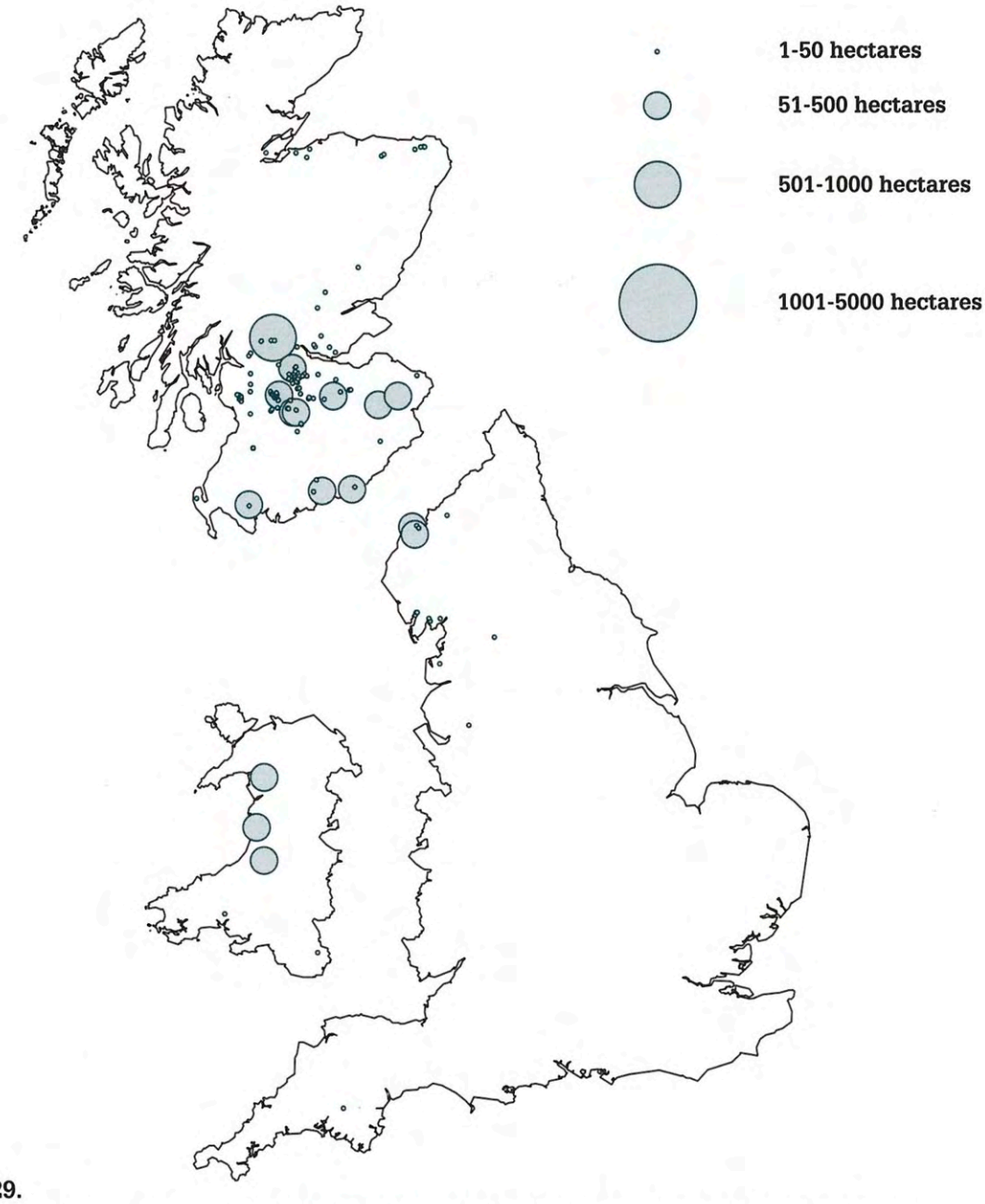
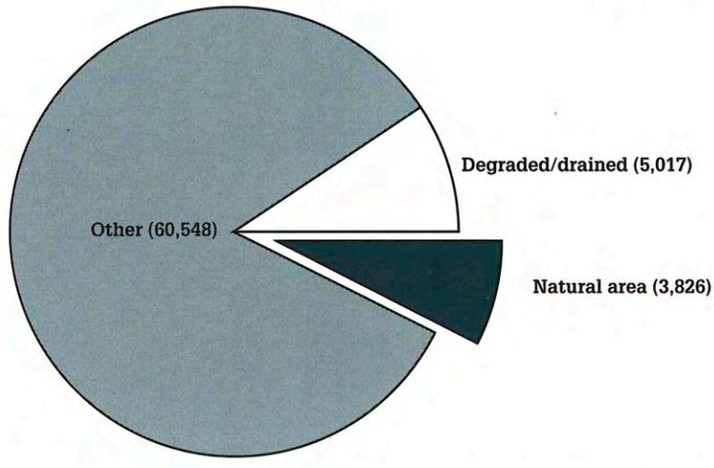


Figure 29.

(a) Estimated present area of natural primary raised bog, expressed as sized circles.



(b) Proportion of the original extent of raised bog habitat which remains either in a natural or a degraded condition.

Less dramatic in immediate effect are three facets of land use which have been the subject of much historical debate but which, in the light of recent research, are now coming to be recognised as significant sources of blanket bog degradation. Overgrazing, burning and moorland drainage (moor gripping) are all widespread features associated with the stocking of blanket bog hill ground with high densities of sheep, deer or even, on occasion, cattle. Such is the extent of these, and also the more recently recognised impacts of acid precipitation on both raised and blanket bog (Skeffington *et al.* in press), that current estimates for the area of natural primary blanket bog suggest that no more than 10% survives in this state.

Ridge-raised/intermediate bogs

The British resource is relatively limited, but is relatively accessible and occurs in a somewhat more benign climate than that typical of blanket bog or eccentric bog. As a result many sites have undergone afforestation, moor gripping, burning, overgrazing or land claim for agriculture. Furthermore, because the peat is formed in a more lowland climate and is thus more suitable for horticultural purposes, at least one large site has had commercial peat extraction. Others have been destroyed by opencast coal mining. From an original extent of only 9000 ha, the resource is now reduced to only a few examples.

Eccentric bogs

As there are very few examples of this type in Britain, and all occur in one of the less accessible parts of the country, it is perhaps not surprising that most such sites are relatively undamaged. However, Blar na Caillich Buidhe has a major drain bisecting it, causing extensive slumping and erosion, and there have been problems with domestic refuse disposal adjacent to Kentra Moss.

European Union

Goodwillie's (1980) review of European peatlands revealed that few areas of extensive natural peatland remain within the European Union. However, a more recent update of Goodwillie's study, carried out this time by the International Mire Conservation Group for the whole of Europe including Iceland (International Mire Conservation Groups unpublished data) presents a rather more detailed picture of the current situation, particularly in relation to raised bogs. Using only data for the European Union from that report, the picture is as follows.

In **Belgium** no more than 150 ha of *active raised* bog is known, the remainder being degraded *Molinia* bogs or bogs which are afforested. **Denmark** retains some 2500 ha of *active raised bog* spread between 30 sites, although the majority of this total is derived from only two sites - Store Vildmose and Lille Wildmose. In **France** the total *mire* area is somewhere between 60000 and 90000 ha, but the proportion which is raised bog is not known. What is known is that almost all raised bogs in the lowlands have been destroyed, leaving only those within the Jura, Massif Central and the Vosges in any form of relatively natural state. In **Germany** the eastern region of Mecklenburg has only 600 ha of near-natural bog, all have been destroyed in the Baden region, and then opinions differ as to the extent of near-natural bogs in Bavaria, Schleswig-Holstein and Lower Saxony. From an original total of 434500 ha, mainly from Lower Saxony, the maximum near-natural area is some 58000 ha while the minimum is considered by German and Austrian mire specialists to be considerably less than that - in Lower Saxony and Bremen 'only about 75 ha are actively growing bog'. *In* **Ireland** the total former area of raised bog amounted to 311300 ha, of which 'only 3.9% (12141 ha) remains sufficiently intact to be conserved without considerable restoration being

necessary'. The lowland raised bogs of **Northern Ireland** formerly covered at least 25,196 ha, but today no more than 2,270 ha (9%) is 'intact'. The **Netherlands** originally possessed some 180000 ha of ombrotrophic peatland but no natural areas of the habitat now remain. **Spain** possessed a few very small raised bogs in the Cantabrian mountains but most, and certainly the largest, of these have been destroyed for horticultural peat since World War II. No records for raised bogs in **Italy** or **Portugal** exist, although it is thought that a few small sites may occur.

References

Academy of Sciences of the USSR, and Chief Directorate of Geodesy and Cartography 1964. *Fiziko-geograficheskii Atlas Mira.* (*Physico-geographical Atlas of the World*). Moscow, State Geological Committee of the USSR.

Backéus, I. 1988. Weather variables as predictors of *Sphagnum* growth on a bog. *Holarctic Ecology*, 11, 146-150.

Bakker, T.W.M. 1992. The shape of bogs from a hydrological point of view. *International Peat Journal*, 4, 47-54.

Barber, K.E. 1981. *Peat Stratigraphy and Climatic Change.* Rotterdam, Balkema.

Bennett, K.D., Boreham, S., Sharp, M.J. & Switzur, V.R. 1992. Holocene history of environment, vegetation and human settlement on Catta Ness, Lunnasting, Shetland. *Journal of Ecology*, 80, 241-273.

Birks, H.J.B. 1973. *Past and Present Vegetation of the Isle of Skye - a Palaeoecological Study.* Cambridge, Cambridge University Press.

Birse, E.L. 1971. *Assessment of Climatic Conditions in Scotland. 3. The Bioclimatic Sub-regions.* Aberdeen, Macaulay Institute for Soil Research.

Birse, E.L. 1980. *Plant Communities of Scotland. A Preliminary Phytocoenonia.* Aberdeen, Macaulay Institute for Soil Research (Soil Survey of Scotland Bulletin No. 4).

Birse, E.L. 1984. *The Phytocoenonia of Scotland. Additions and Revision.* Aberdeen, Macaulay Institute for Soil Research (Soil Survey of Scotland Bulletin No. 5).

Bower, M.M. 1962. The cause of erosion in blanket peat bogs: a review of recent work in the southern Pennines. *Scottish Geographical Magazine*, 78, 33-43.

Bragg, O.M. 1982. *The acrotelm of Dun Moss.* PhD thesis, University of Dundee.

Bragg, O.M., Brown, J.M.B. & Ingram, H.A.P. 1991. Modelling the ecohydrological consequences of peat extraction from a Scottish raised mire. *Hydrological Basis of Ecologically Sound Management of Soil and Groundwater* (*Proceedings of the Vienna Symposium, August 1991*). IAHS Publication No. 202, Wallingford, 13-22.

Bragg, O.M. & Brown, J.M.B. 1992. *A Manual of Mire Models.* Unpublished Report to Scottish Natural Heritage, Edinburgh.

Brown, A. 1989. An ombrotrophic bog as a methane reservoir. *Global Biogeochemical Cycles*, 3, 3, 205-213.

Caulfield, S. 1989. *Céide Fields and Belderrig: A Guide to two Prehistoric Farms in North Mayo.* Killala, Mayo, Morrigan Book Company.

Charman, D.J. in press. Holocene ombrotrophic peats : conservation and value in Quaternary research. In: *Conserving our landscape : evolving landforms and ice-age heritage.* ed. by C. Stevens, C.P. Green, J.E. Gordon and M.G. Macklin. Peterborough, English Nature.

Clymo, R.S. 1978. A model of peat growth. In: *Production Ecology of British Moors and Montane Grasslands*, ed. by O.W. Heal & D.F. Perkins, with W.M. Brown, pp. 187-223. Berlin, Springer-Verlag.

Clymo, R.S. 1984. The limits to peat bog growth. *Royal Society Philosophical Transactions, B*, 303, 605-654.

Clymo, R.S. & Hayward, P.M. 1982. The ecology of Sphagnum. In: *Bryophyte Ecology*, ed. by A.J.E. Smith, pp. 229-291. Newton Abbot, David & Charles.

Clymo, R.S. & Reddaway, E.J.F. 1971. Productivity of *Sphagnum* (bog-moss) and peat accumulation. *Hidrobiologia*, 12, 181-192.

Cowardin, L.M., Carter, V., Golet, F.C. & LaRoe, E.T. 1979. *Classification of Wetlands and Deepwater Habitats of the United States.* US Fish and Wildlife Service.

Cross, J. In press. *The Raised Bogs of Ireland.* Dublin, Office of Public Works.

Daniels, R.E. 1978. Floristic analyses of British mires and mire communities. *Journal of Ecology*, 66, 773-802.

Daniels, R.E. 1985. Major lines of variation in the vegetation of British peatlands. *Aquilo, Seria Botanica*, 21, 61-67.

Davis, R.B. & Anderson, D.S. 1991. *The Eccentric Bogs of Maine: A Rare Wetland Type in the United States.* Maine State Planning Office, Critical Areas Programme, Planning Report 93, University of Maine.

Dierssen, K. 1982. *Die wichtigsten Pflanzengesellschaften der Moore NW-Europas.* (The Major Plant Communities of North-west European Mires). Geneva, Conservatoire et Jardin Botaniques.

Dierssen, K.& Dierssen, B. 1985. Suggestions for a common approach in phytosociology for Scandinavian and Central European mire ecologists. *Aquilo, Seria Botanica*, 21, 33-44.

Doyle, G.J. and Moore, J.J. 1980. Western blanket bog (*Pleurozio purpureae-Ericetum tetralicis*) in Ireland and Great Britain. *Colloquues Phytosociologiques*, 7, 213-223.

Dugmore, A. 1989. Icelandic volcanic ash in Scotland. *Scottish Geographical Magazine*, 105, 168-172.

Du Rietz, G.E. 1954. Die Mineralbodenwasserzeigergrenze als Grundlage einer natürlichen Zweigliederung der nord- und mitteleuropäischen Moore. *Vegetatio*, 5-6, 571-585.

Eurola, S. 1975. Snow and ground frost conditions of some Finnish mire types. *Annales Botanici Fennici*, 12, 1-16.

Eurola, S., Hicks, S. & Kaakinen, E. 1984. Key to Finnish mire types. In: *European Mires*, ed. by P.D. Moore, pp. 11-118. London, Academic Press.

Geiger, R. 1965. *The Climate Near the Ground.* University of Harvard Press, Cambridge, Massachusetts.

Godwin, H. 1981. *The Archive of the Peat Bogs.* Cambridge, Cambridge University Press.

Goode, D.A. & Lindsay, R.A. 1979. The peatland vegetation of Lewis. *Royal Society of Edinburgh Proceedings*, 77B, 279-293

Goode, D.A. & Ratcliffe, D.A. 1977. Peatlands. In: *A Nature Conservation Review*, ed. by D.A. Ratcliffe, Vol. 1, pp. 249-287; Vol. 2, pp. 206-244. Cambridge, Cambridge University Press.

Goodwillie, R. 1980. *European Peatlands.* Strasbourg, Council of Europe (Nature and Environment Series, No. 19).

Gore, A.J.P. 1983. Introduction. In: *Mires: Swamp, Bog, Fen and Moor. General Studies*, ed. by A.J.P. Gore, pp. 1-34. Amsterdam, Elsevier Scientific (Ecosystems of the World 4A).

Grünig, A. (ed.) 1994. *Mires and Man. Mire Conservation in a Densely Populated Country - the Swiss Experience.* Excursion Guide and Symposium Proceedings of the 5th Field Symposium of the International Mire Conservation Group (IMCG) to Switzerland 1992. Birmensdorf, Swiss Federal Institute for Forest, Snow and Landscape Research. 415 p.

Grünig, A., Vetterli, L. & Wildi, O. 1986. *Die Hoch- und Ubergangsmoore der Schweiz - eine Inventarauswertung* [The Raised and Transition Bogs of Switzerland - Findings from a National Inventory]. Birmensdorf, Swiss Federal Institute of Forestry Research, Berichte 281.

Heathwaite, A.L. & Göttlich, K. 1993. *Mires: Process, Exploitation and Conservation.* Chichester, John Wiley & Sons Ltd.

Hillel, D. 1971. *Soil and Water: Physical Principles and Processes.* New York, Academic Press.

Hobbs, N.B. 1986. Mire morphology and the properties and behaviour of some British and foreign peats. *Quarterly Journal of Engineering Geology*, 19, 7-80.

Hornung, M. & Newson, M.D. 1986. Upland afforestation influences on stream hydrology and chemistry. *Soil Use Management*, 2, 61-65.

Hulme, P.D. 1980. The classification of Scottish peatlands. *Scottish Geographical Magazine*, 96, 46-50.

Hutchinson, J.N. 1980. The record of peat wastage in the East Anglian Fenlands at Holme Post, 1848-1978. AD. *Journal of Ecology*, 68, 229-249.

Immirzi, C.P. & Maltby, E. with Clymo, R.S. 1992. *The Global Status of Peatlands and their Role in Carbon Cycling.* A Report for Friends of the Earth by the Wetland Ecosystems Research Group, Department of Geography, University of Exeter. London, Friends of the Earth.

Ingram, H.A.P. 1982. Size and shape in raised mire ecosystems: a geophysical model. *Nature*, 297, 300-303.

Ingram, H.A.P. 1983. Hydrology. In: *Mires: Swamp, Bog, Fen and Moor. General Studies*, ed. by A.J.P. Gore, pp. 67-158. Amsterdam, Elsevier Scientific (Ecosystems of the World 4A).

Ingram, H.A.P. 1992. Peatland hydrology - keynote address. *Proceedings of the British Ecological Society/International Peat Society Conference "Peatland Ecosystems and Man: an Impact Assessment."* Ed. by O.M. Bragg, P.D. Hulme, H.A.P. Ingram & R.A. Robertson. pp. 67-93. University of Dundee. International Peat Society.

Ingram, H.A.P. & Bragg, O.M. 1984. The diplotelmic mire: some hydrological consequences reviewed. In: *Proceedings of the Seventh International Peat Congress, Dublin, 1984*, 1, 220—234.

Ivanov, K.E. 1981. *Water Movement in Mirelands.* London, Academic Press.

Joint Nature Conservation Committee. In press. *Guidelines for Selection of SSSIs: Bogs.* Peterborough, JNCC.

Kirkby, M., Kneale, P. & Smith, R. In press. Modelling the form and distribution of peat mires. In: *Hydrology and Hydrochemistry of British Wetlands: Proceedings of the Institute of British Geographers Annual Conference 1993*, University of London.

Kulczynski, S. 1949. Peat Bogs of Polesie. *Mem. Acad. Pol. Sci. Lett., Cl. Sci. Math. Nat., Ser. B*, 15, 356 pp.

Lindsay, R.A., Riggall, J. & Bignal, E.M. 1983. Ombrogenous mires in Islay and Mull. *Royal Society of Edinburgh, Proceedings*, 83B, 341-371.

Lindsay, R.A., Riggall, J. & Burd, F. 1985. The use of small-scale surface patterns in the classification of British peatlands. *Aquilo, Seria Botanica*, 21, 69-79.

Lindsay, R.A., Charman, D.J., Everingham, F., O'Reilly, R.M., Palmer, M.A., Rowell, T.A. & Stroud, D.A. 1988. *The Flow Country: The Peatlands of Caithness and Sutherland.* Peterborough, Nature Conservancy Council.

Lindsay, R.A., Andrews, J.H., Gordon, J.E. & Immirzi, C.P. In press. *Lowland Raised Bogs in Great Britain*: Battleby, Scottish Natural Heritage.

MacDonald, J., Wood, R.F., Edwards, M.V. & Aldhous, J.R., (eds.) 1957. *Exotic Forest Trees in Great Britain.* London, HMSO (Forestry Commission Bulletin No. 30).

McVean, D.N. & Ratcliffe, D.A. 1962. *Plant Communities of the Scottish Highlands.* London, HMSO (Monographs of the Nature Conservancy No. 1).

Maltby, E. 1986. *Waterlogged Wealth: Why Waste the World's Wet Places?* London: International Institute for Environment and Development.

Masing, V. 1982. The plant cover of Estonian bogs: a structural analysis. In: *Peatland Ecosystems* ed. by T. Frey *et al.* Estonian Contributions to the International Biological Programme, No. 9, Tallinn, Academy of Sciences of the Estonian SSR.

Moen, A. 1985. Classification of mires for conservation purposes in Norway. *Aquilo, Seria Botanica*, 21, 95-100.

Moore, J.J. 1968. A classification of the bogs and wet heaths of Northern Europe. In: *Pflanzensoziologische Systematik*, ed. by R. Tüxen, pp. 306-320. The Hague, Junk.

Moore, P.D. 1973. The influence of prehistoric cultures upon the initiation and spread of blanket bog in upland Wales. *Nature*, 241, 350-353.

Moore, P.D. 1977. Stratigraphy and pollen analysis of Claish Moss, north-west Scotland: significance for the origin of surface pools and forest history. *Journal of Ecology*, 65, 375-397.

Moore, P.D. 1984. The classification of mires: an introduction. In: *European Mires*, ed. by P.D. Moore, pp. 1-10, London, Academic Press.

Moore, P.D. 1990. Soils and ecology: temperate wetlands. In: *Wetlands - A Threatened Landscape*, ed. by M. Williams. Oxford, Basil Blackwell (Special publications Series/Institute of British Geographers; No. 25), 95-114.

Moore, P.D. & Bellamy, D.J. 1974. *Peatlands*. London, Elek Science.

Nature Conservancy Council. 1989. *Guidelines for the Selection of Biological SSSIs*. Peterborough, Nature Conservancy Council.

Osvald, H. 1923. Die Vegetation des Hochmoores Komosse, Kap. 5. [The vegetation of the raised bogs of Komosse, Chapter 5]. *Svenska Växtsociologiska Sällskapets Handlingar*, 1, 265-310.

Osvald, H. 1925. Zur Vegetation der ozeanischen Hochmoore in Norvegen. [On the vegetation of oceanic raised bogs in Norway.] *Svenska Växtsociologiska Sällskapets Handlingar*, VII, 1-106.

Osvald, H. 1933. Vegetation of the Pacific Bogs of North America. *Acta Phytogeographica Suecica*, V, 1-33.

Osvald, H. 1949. Notes on the vegetation of British and Irish mosses. *Acta Phytogeographica Suecica*, 26, 1-62.

Ratcliffe, D.A. 1964. Mires and bogs. In: *The Vegetation of Scotland*, ed. by J.H. Burnett, pp. 426-478. Edinburgh, Oliver & Boyd.

Ratcliffe, D.A. 1968. An ecological account of Atlantic bryophytes in the British Isles. *New Phytologist*, 67, 365-439.

Rodwell, J.S. (ed.), 1991. *British Plant Communities*, -Vol. 2: *Mires and Heaths*. Cambridge University Press, Cambridge.

Rowell, T A (1988). *The Peatland Management Handbook*. Research and Survey in Nature Conservation No. 14., (Peterborough), Nature Conservancy Council.

Ruuhijarvi, R. 1960. über die regionale Einteilung der nordfinnischen Moore. *Annales Botanici Societatis Zoologicae Botanicae Fennicae Vanamo*, 31, 1-360.

Ruuhijarvi, R.E. 1983. The Finnish mire types and their regional distribution. In: *Mires: Swamps, Bog, Fen and Moor. Regional Studies*, ed. by A.J.P. Gore, pp. 47-67. Amsterdam, Elsevier Scientific (Ecosystems of the World 4B).

Shotyk, W. 1988. Review of the Inorganic Geochemistry of Peats and Peatland Waters. *Earth Science Review*, 25, 95-176.

Sjörs, H. 1948. Myrvegetation i Bergslagen. [Mire Vegetation in Bergslagen, Sweden]. *Acta Phytogeographica Suecica*, 21, 1-299. [English summary: 277-299].

Sjörs, H. 1983. Mires of Sweden. In: *Mires: Swamp, Bog, Fen and Moor. Regional Studies*, ed. by A.J.P. Gore, pp. 69-94. Amsterdam, Elsevier Scientific (Ecosystems of the World 4B).

Skeffington, R.A., Wilson, E.J., Hogan, D., Immirzi, P. and Maltby, E. In Press. In: *Hydrology and Hydrochemistry of British Wetlands : Proceedings of the Institute of British Geographers Annual Conference* 1993, University of London.

Smith, L.T. ed. 1910. *The Itinerary of John Leland in or about the Years 1535-1543*, Vol. 5 (Part IX). London, G.Bell & Sons.

Steiner, G.M. 1984. *Österreichischer Moorschutzkatalog. (Austrian Mire Conservation Catalogue).* Vienna, Verlag BMGU.

Steiner, G.M. 1992. *Österreichischer Moorschutzkatalog. (Austrian Mire Conservation Catalogue).* Grüne Reihe des, Bundesministeriums für Umwelt, Jungend und Familie, Band 1. Graz, Verlag Ulrich Moser.

Stremme, H. 1908. über Kaolinbildung. *Z. Prakt. Geol.*, 16, 122-128.

Succow, M. 1980. Die Moortypen der DDR und ihre Bewertung für die Humuswirtschaft. *Zeitschrift für Angewandte Geologie*, 26, 193-203.

Succow, M. 1981. *Landschaftsökologische Kennzeichnung und Typisieriung der Moore der DDR. Habilitationsschrift.* Forschungzentrum f. Bodenfruchtbarkeit, Müncheberg.

Taylor, J.A. 1983. The peatlands of Great Britain and Ireland. In: *Mires: Swamp, Bog, Fen and Moor. Regional Studies*, ed. by A.J.P. Gore, pp. 1-46. Amsterdam, Elsevier Scientific (Ecosystems of the World 4B).

Tallis, J.H. 1964. Studies on southern Pennine peats. II. The pattern of erosion. *Journal of Ecology*, 52, 333-344.

Tallis, J.H. 1981. Causes of erosion, a working hypothesis. In: *Peak District Moorland Erosion Study. Phase 1 Report*, ed. by J. Phillips, D. Yalden and J. Tallis, 224-234. Bakewell, Peak Park Joint Planning Board.

Tolonen, K., Davis, R.B. & Widoff, L. 1988. *Peat Accumulation Rates in Selected Maine Peat Deposits.* Augusta, Maine Geological Society.

Tout, D. 1976. Temperature. In: *The Climate of the British Isles,* ed. by Cahndler, T.J. & Gregory, S. pp. 96-128. London.

Tubridy, M. 1984. Creation and Management of a Heritage Zone at Clonmachnoise, Co. Offaly, Ireland. *Final Report (EEC Contract No. 6611/12).* Dublin, Trinity College.

Walters, H. & Lieth, H. 1967. *Klimadiagramm-Weltatlas. (World Atlas of Climate Diagrams).* Jena, Fischer.

Wells, D.E. & Zoltai, S. 1985. Canadian system of wetland classification and its application to circumboreal wetlands. *Aquilo, Seria Botanica,* 21, 45-52.

Welsby, J. 1988. The utilisation of geo-radar in monitoring cut-over peatlands. In: *Proceedings of the 8th International Peat Congress, Leningrad,* 99-107. Helsinki, International Peat Society.

Wheeler, B.D. 1984. British fens - a review. In: *European Mires,* ed. by P.D. Moore, pp. 237-282. London, Academic Press.

Wickman, F.E. 1951. The maximum height of raised bogs and a note on the motion of water in soligenous mires. *Geologiska Föreningens i Stockholm Förhandlingar,* 73, 413-422.

Williams, B.L. 1992. Microbial nitrogen transformations in peatland disturbed by drainage and fertilisers. In: *Peatland Ecosystems and Man : An Impact Assessment,* ed. by Bragg, O.M., Hulme, P.D., Ingram, H.A.P. & Roberston, R.A. Finland, International Peat Society.

Williams, M., (ed.) 1990. *Wetlands - A Threatened Landscape.* Oxford, Basil Blackwell (Special publications Series/Institute of British Geographers; No. 25).

Woike, M. & Schmatzler, E. 1980. *Moore. Bedeutung - Schutz - Regeneration.* Bonn, Deutscher Naturschutzring.

Zoltai, S.C. & Pollett, F.C. 1983. Wetlands in Canada: their classification, distribution and use. In: *Mires: Swamp, Bog, Fen and Moor. Regional Studies,* ed. by A.J.P. Gore, pp. 245-268. Amsterdam, Elsevier Scientific (Ecosystems of the World 4B).

Scottish Natural Heritage is a government body established by Parliament in 1992, responsible to the Secretary of State for Scotland. Our task is to secure the conservation and enhancement of Scotland's unique and precious natural heritage - the wildlife, habitats and landscapes which have evolved in Scotland through the long partnership between people and nature.

We advise on policies and promote projects that aim to improve the natural heritage and support its sustainable use.

Our aim is to help people enjoy Scotland's natural heritage responsibly, understand it more fully and use it wisely so that it can be sustained for future generations.

Scottish Natural Heritage publications and publication catalogue are available from: Publications Section, Scottish Natural Heritage, Battleby, Redgorton, Perth PH1 3EW. Tel: 01738 627921

Price: £10.00

Cover photography: R.A. Lindsay, L. Campbell
Designed and produced by Morton Ward Associates, Scotland

ISBN 1 85397 100 6

HS4K0294
February 1995

Printed on environmentally friendly paper