Frontispiece. Storamyren in 1997, a relatively undisturbed Baltic raised mire south of Umeå, Västerbotten, Sweden. Upper, the pine-forested ground, and lower, pools on the surface. Photographs by Paul Buckland.

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EQUIFINALITY, CONSERVATION AND THE ORIGINS OF LOWLAND RAISED MIRES. THE CASE OF THORNE AND HATFIELD MOORS

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The origins and development of raised mires have been the subject of much discussion. The extensive suite of radiocarbon dates for Thorne and Hatfield Moors, lying either side of the old course of the River Don in south Yorkshire, allows several models to be tested. The oldest dates lie towards the northern edge of what was once a complex of several mires, margined by lagg fens towards the bounding rivers, and origins can be seen in rising water tables ultimately controlled by sea-level and increased freshwater runoff as a result of forest clearance. The palaeoecological record, both plant and animal, shows no evidence of estuarine influence or of any extent of open freshwater, and a polyfocal origin from wetland development around small pools, followed by coalescence of the incipient mires, is prefered.

Introduction

The origins of the once extensive lowland raised mires of eastern England have been the subject of much less attention than their western and upland equivalents. In the west, in Ireland, Wales and northern Britain, raised mires and the related, if biologically less diverse, blanket mires co-exist down to sea-level. Eastwards, the latter become restricted to uplands, where rainfall exceeds 1200mm *p.a.* (Moore 1992), and areas of potential raised mire are confined to flat, poorly drained regions close to sea-level and broad floodplains of the major rivers. Commercial peat extraction and intensive drainage have left only a remnant of what was once an extensive habitat in eastern England. By the beginning of the nineteenth century there was little remaining in the Fens to suggest the former existence of raised mires (Godwin 1978), and the Humberhead Levels (Figure 1) provides the only remaining refuge for the unique floral and faunal associations of the eastern raised mires.

On the Humberhead Levels, large-scale drainage began in the seventeenth century (Korthals-Altes 1925), and the wetlands have been progressively reduced in size until only two core areas, Thorne Moors and Hatfield Moors, remain. Large-scale peat extraction has further reduced the bulk of these to either bare peat or regenerative poor-fen (Smart, Wheeler & Willis 1986, Eversham 1991), subject to further invasion by birch *Betula*-willow *Salix* scrub and oak *Quercus* and rhododendron *Rhododendron*, as the water-table has been progressively pumped down. The long-term future for lowland raised mires is bleak, but, with the effective exhaustion of economically viable peat from both Thorne and Hatfield Moors, conservation is presented with a virtual *tabula rasa* to begin re-creation. This may be approached from two, not necessarily exclusive, philosophic standpoints: either by the encouragement of any survivors in the refugia of old peat cuttings and balks by effective management techniques, or by the re-introduction of species from other localities. Both methods require a knowledge of autecology and synecology which we perhaps do not yet possess. There is more to the complex ecosystem of a mire than the few reasonably easily identifiable plants, yet most restoration schemes take little note of anything more (*cf.* Wheeler & Shaw 1995).

Setting aside biogeographic objections to attempts at re-introduction, wetland habitats are sufficiently under threat on a national scale for the accusation of 'robbing Peter to pay Paul to be particularly pertinent, providing at the most, a salve to the conscience of extraction companies and ineffective conservation strategies. Wetland habitats, however, do possess one important advantage over many other threatened environments: they encapsulate the seeds of their own history, found in the pollen and other fossil records preserved in their anaerobic sediments. It is therefore possible to examine in minute detail the genesis of a lowland raised mire, its development, and the demise of individual species, and to employ the ensuing retrodictive model or models to confine the future. If we arc to begin anew, the point of departure has to be a vision which encompasses the palaeoecological record of long-term change, and inadvertent management strategies, rather than the current exercises merely in damage limitation. This paper presents a series of alternative models, all falsifiable (*sensu* Popper 1968), for the origins of Thorne and Hatfield Moors and, by inference, other raised mires. Emphasis is placed upon the macroscale rather than the detail of species composition and change, although these data are also available from the fossil record. The relationships between human activity, climate, geomorphic change and succession are also considered.

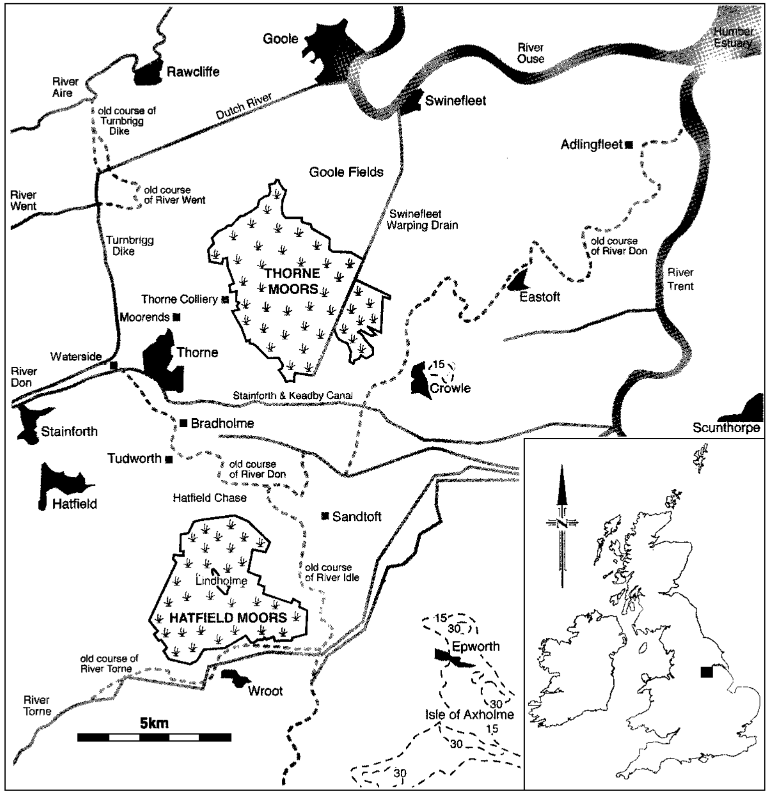

Figure 1. Thorne and Hatfield Moors in their regional context.

The geological framework

The Humberhead Levels, at the junction of the historical counties of Lincolnshire, Nottinghamshire and Yorkshire (Figure 1), lie in the angle between the confluence of the Rivers Trent and Ouse, and once formed one of the largest areas of wetlands in lowland Britain. To the west, the area is bounded by the dipslope of the Lower and Upper Magnesian Limestones, west of Doncaster, and to the east, the River Trent flows at the base of the Liassic escarpment at Scunthorpe. Southwards, a ridge of Sherwood Sandstone and Mercia Mudstone between Bawtry and Gainsborough closes the Levels and, to the north, the region grades into the middle part of the Vale of York.

During the 1960s, the Quaternary deposits of the southern part of the Vale of York were largely re-mapped, principally by Gaunt (1981, 1994), who also considered the detail of the Late Devensian and Holocene sequence in the Humberhead Levels (Gaunt, Jarvis & Matthews 1971; Gaunt 1975, 1976, 1987a). Deglaciation of the lowlands lying within the Humber Gap, and the silting up of an extensive proglacial lake, Lake Humber, left a plain of clay-silts, falling from about +8m O.D. at Selby to about +5m O.D. south-east of Doncaster (Gaunt 1987a). The date of formation of this gently sloping, featureless topography is constrained by radiocarbon dates to more recent than about 18,000 years B.P. and older than 11,100±200 B.P. (Gaunt, Jarvis & Matthews 1971), although fossil insect faunas from Sandtoft (Buckland, unpubl.) indicate a date earlier than 12,500 B.P.. Southwards, the plain overlies and abuts upon a similarly subdued topography of sands and gravels of earlier fluvioglacial origin. Its form is only broken by the Mercia Mudstone hills of the Isle of Axholme and Crowle to the east, and the Devensian glaciolacustrine sands and gravels on which Thorne, and the villages and farms of Bradholme, Tudworth, Lindholme and Wroot, stand (Gaunt 1976).

The rivers of the Levels initially spread out across the plain, building sand levees along the old courses of the Ouse, Aire, Went, Don, Torne and Idle. Eventually, the combined rivers cut down through the morainic deposits blocking the Humber Gap, leading to the progressive incision of the river channels. The low sand levees were partly reworked by aeolian action, dated elsewhere in north Lincolnshire (Buckland 1982) and the Vale of York to the terminal cold phase of the late glaciation and earliest Holocene (Matthews 1970), about 10,500–9500 B.P.. The remnant levees and dunes provide the remaining slightly higher ground in the Levels, with the alluvium of the former River Don dividing Thorne Moors to the north from Hatfield Moors. Low sea-level during the late Devensian and early Holocene led to the rapid and deep incision of major river courses, to the extent that the channel of the Don reaches -17.5m O.D. south of Crowle, and the much smaller River Went cuts to -7.6m O.D. east of the Turnbrigg Dike, the present course of the Don (Gaunt 1987a, figure 4; 1987b, 1994). Infilling of these channels had begun by *c.*8500 B.P. (Norris, Bartley & Gaunt 1971) and, by *c.*5000 B.P., sea-level lay within a metre or two of O.D. (Gaunt & Tooley 1974). Dates are available on the bed of the Don at Thorne Waterside of 4230±100 B.P., and of the Idle at Misterton Carr of 4330±100 B.P. (Table 1), but it is apparent that neither necessarily reflects the beginnings of sedimentation in the rivers.

The palaeoecological record from their silts, however, is relevant to the origins of the adjacent mires. By the beginning of the third millennium B.C., the scene was set for the progressive paludification which led to the development of raised mire in the Humberhead Levels. Later oscillations of base-level, and variations in the sedimentary regime as a result of changing patterns of human land use (Buckland & Sadler 1985), have led to further changes. These were particularly around the margins of the mires before drainage and large-scale exploitation of the peatlands began (*cf.* Van de Noort & Ellis 1997, Limbert 1998). It is, however, the problems of lowland raised mire initiation and development that are addressed here.

Site	Date (B.P.)	Lab. no.	Depth†	Comments
Crowle Moor				
Site CLM1	3475±65	CAR-208	2.29m	base of peat
Site CLM2	4230±70	CAR-309	4.15m	base of peat
Goole Moor				
Site GLM1	4515±70	CAR-232	1.95m	base of peat
Rawcliffe Moor				
Site RWM1	4545±75	CAR-221	2.11m	base of peat
Thorne Waste				
Site TM1	3060±65	CAR-180	0.90m	base of peat
Trackway site	3260±100	BIRM-335	1.10m	base of peat
Hatfield Moors				
Site HAT1	4180±70	CAR-168	2.00m	base of peat
Site HAT 2	4335±75	CAR-254	2.00m	base of peat
Thorne Waterside				
River Don	4230±100	BIRM-358		?base of channel
Misterton Carr				
River Idle	4330±120	BIRM-359		?base of channel

† Depths for sites on Thorne and Hatfield Moors are below the cutting surface at the time of sampling in the 1970s, before large scale milling and rotavation of the peat.

Table 1. Radiocarbon dates on the base of the peat, Thorne and Hatfield Moors.

Alternative models for the origins of raised mires

Despite their apparent simplicity in terms of species composition, raised mires reflect a complex interaction between biotic, climatic and hydrological factors that takes place independent of the groundwater table. Their rapid development, and maintenance of a structure largely divorced from local edaphic factors, means that they may provide an effective barometer of climate (*cf.* Barber 1983, Barber *et al.* 1999). The anaerobic nature of the organic sediments accumulating in an undamaged mire also ensures the preservation of the regional pollen 'rain', and thereby provides an archive of environmental change and human impact (*cf.* Godwin 1981). The interaction among these three aspects lies at the core of the interpretations of both mire stratigraphy and genesis. If human impact may be at least temporarily subsumed within environmental change, then two schools of thought may be identified. The first is that which sees climatic change as the driving force leading to paludification of forest and growth of mires, perhaps typified by the work of the late Sir Harry Godwin (Godwin 1975). The second considers that Man (*cf.* Moore 1992) or local geomorphic change initiates growth, and the dynamics of the mire itself maintains development (*cf.* Ingram 1982, Clymo 1984), until constrained by topography.

Figure 2 provides five (a - e) alternative, although not necessarily exclusive, models for the origins of lowland raised mire in the Humberhead Levels. Each is ultimately constrained by the Rivers Ouse, Went and Don (Figure 1), although the amount of direct influence of a river is variable, from merely limiting development in model (a) to being directly instrumental in its origins in (d). A progressive rise in the water-table, rather than a wetter climate, however, is seen as the prime mover in mire origins, although climatic influence is not thereby excluded. The horizontal scale is approximately 10km, and the maximum recorded thickness of peat is of the order of 6m (Parsons 1878, Buckland 1995). The convention of a gross exaggeration of vertical scale has been adopted, and the lines within the mire on the various models reflect as yet undefined isochrones, not necessarily features visible in the surviving peat stratigraphy, which is indicated by shading.

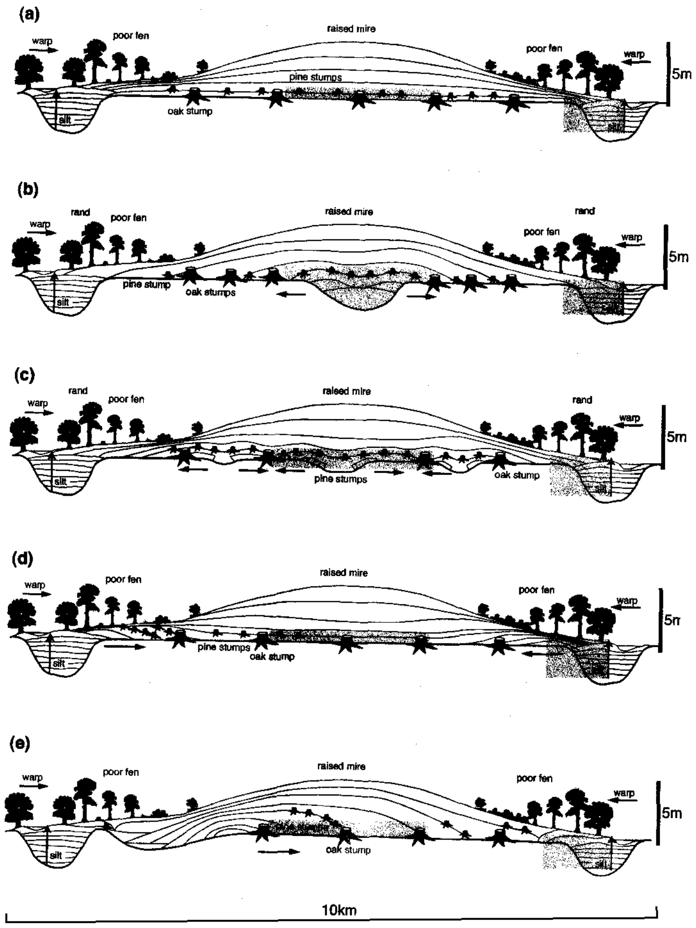

Figure 2. Five alternative theoretical models for the origins of the Humberhead Levels raised mires.

The concept which lies at the base of each model is that the accumulation of litter, initially in a poor-fen environment, leads to progressive acidification and the development of a plant community. This latter is characterised by various species of *Sphagnum*, capable of sustaining growth largely on nutrient input from rainfall. This is, in itself, perhaps surprising in an area which has one of the lowest rainfalls in Britain, approximately 660mm p.a., but it supports the view that raised mire once formed a significant part of the natural plagioclimax for eastern England. As the nuclei become independent of the groundwater, and biological activity is inhibited by increasing acidity, engendered by the *Sphagna*, compared with the adjacent fen, accumulation comes to dominate over decomposition. A hydrological gradient develops between core and perimeter, further transporting nutrients out to the margins or rand. The consequence is that the mire is able to expand outwards, pushing the poor-fen and paludification process before it, until some barrier, either a river or significant slope, is reached. The extent and rates of natural lateral expansion are highly variable, and there are few sites with sufficient basal radiocarbon dates to provide any assessment. In a study of coastal raised mires in southern Finland, Korhola (1992) obtained lateral expansion rates varying from 4mm to in excess of 5m *p.a.*, mostly during the initial phases of paludification. The lower figures largely reflect the topographic limits to growth reached in the late Holocene, although much higher figures have also been recorded as a result of so called bog bursts (cf. McIntire 1941).

Five possible models, each resulting in a similar final product, are presented in Figure 2. The simplest model (a) envisages a rising water-table leading to widespread paludification of the forest floor and accumulation of litter, leading to poor-fen, acidification and eventually raised mire. Lateral growth is slight and the poor-fen of the margins is more a reflection of riverbank conditions than the growth of the mire. The channel deposits of the rivers consist of organic silts, which interdigitate with deposits from Alder *Alnus glutinosa* carr and poor-fen. These result from the rivers occasionally overtopping their levees and flooding across on to the raised mire, leading to a complex inter-relationship of deposits, which was only terminated by nineteenth century embankment and warping (Creyke 1845). The nature of the basal peat below the raised mire varies as to the character and rate of waterlogging. The forest floor and overlying litter may be preserved virtually intact where establishment of anaerobic conditions was rapid, but oscillation in the water-table and occasional drying out may lead to extensive humifaction, a feature frequently seen in blanket mire. After raised mire initiation, or during the acidification process, drying may be sufficient to allow the development of heathland vegetation or Scots Pine *Pinus sylvestris* woodland across the mire, and these may be contiguous with similar vegetation on adjacent heavily podzolised soils.

The second model (b) is perhaps the most widely used view of a dynamic, rather than autochthonous, approach to raised mire development (*cf.* Clymo 1984). The infilling of a basin by limnic sediments leads to the growth of fen and poor-fen from the margins of the lake in the classic seral succession discussed by Walker (1970). Litter accumulation again leads to independence of the groundwater table and the invasion of acidophilous species, until *Sphagnum* comes to dominate the core focus community. With the establishment of a hydrostatic gradient, the mire is able to grow outwards, preceded by paludification, fed by runoff from the nascent mire and the poor-fen community. The edge (rand) is marked by Pines in the drier parts, but these are also eventually overwhelmed by the developing mire. Other than control of base-level and an eventual limiting role to lateral expansion, the rivers and associated sea-level have no direct influence on the development of the raised mire, although there may be some marginal interleaving of sediments.

Whilst this model is usually seen as the result of basin infilling through the early and mid-Holocene, the third model (c) does not rely on a long sequence. It is essentially a polyfocal version of (b), with several small ponds, rather than lakes, forming on the forest floor. Their developing poor-fen communities lead again to raised mires, and these eventually coalesce into a larger raised mire. Expansion of Pine may also be a feature of the initiation of mire by this mechanism.

The importance of base-level and the progressive filling of deeply incised river channels through the mid-Holocene, is given prominence in the remaining models (d and e), which differ in terms of the latter being asymmetric, developing from the margins of either a river or riverine mere. The origins lie in the expansion of Alder carr to poor-fen along the levees and in the back swamps of the poorly constrained rivers. The mire then grows inwards towards its 'core' (Figure 2d), or laterally until confined by slope or a more active nutrient-rich environment. The margins show a similar complexity of fen, carr and raised mire sequences, as river-level and sediment-load vary through time. The whole is again closed by modern embankment and warping.

Alternative models and the Humberhead mires

Figure 3, revised from Smith (1985) and published in Smith (2002), provides some idea of what a cross-section through Thorne Moors would have looked like before extensive peat cutting began, and provides a basis for discussion. Buckland (1979, revised by Buckland & Sadler 1985) has provided a flow-diagram, which summarises the probable factors in the overall development of the wetlands of the Humberhead Levels. This model stresses the influence of rising base-level associated with increased runoff, consequent upon forest clearance elsewhere in the catchment of the major rivers draining through the Humber Gap. It was also pointed out that the clearance of forest on the Levels themselves would have further exacerbated the problems of a rising water-table, leading to the direct paludification of the landscape, rather than to freshwater flooding. It has to be emphasised that the palaeoecological evidence from Goole Moor, the 'trackway' site (Figure 4) on Thorne Waste (Buckland 1979), Thorne Waterside, and the old Don at Sandtoft, where the succession extends through to the Roman period (Buckland & Sadler 1985), provides no evidence of estuarine conditions. This contrasts with the Ancholme Valley, where the Humber estuary had extended beyond Brigg before 2720±50 B.P. (Buckland 1981, Switzur 1981, Van de Noort & Ellis 1998). Smith's (1985, 2002) extensive pollen studies on Thorne and Hatfield Moors also lack evidence of direct marine influence. It has to be noted however, that, if mire development spread laterally from the Ouse and Trent, as in model (e) (Figure 2), the relevant areas are now either buried beneath recent warp and alluvium or destroyed by peat cutting. It is probable that the present extension of tidal influence up the major rivers of the region is a reflection of the impact of post-medieval embankment of the main channels (*cf.* Jones 1995).

It is this context which provides the basis for discussion: did growth result from lateral expansion from the margins of the river courses, or was it *in situ* overall growth that led to the development of the raised mire complexes of Thorne and Hatfield? The most complete evidence comes from Thorne, and discussion will concentrate upon this site, before reviewing the Hatfield evidence. The modern division of Thorne Moors into Rawcliffe, Snaith & Cowick, Goole and Crowle Moors and Thorne Waste (or Moor), does not reflect the progress of individual mires coalescing from separate nuclei, but the ascription of turbary resources to individual parishes.

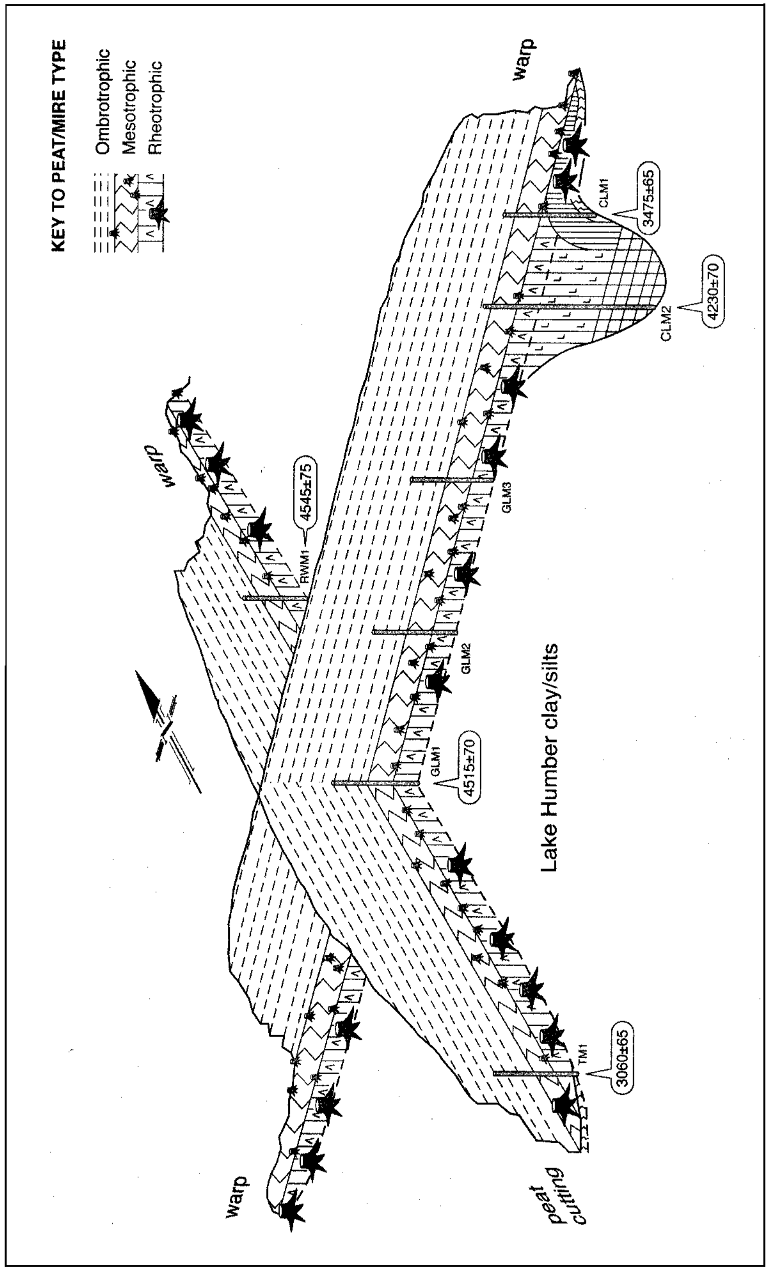

Figure 3. Schematic reconstruction of the stratigraphy and ontogeny of Thorne Moors.

Radiocarbon dates, location of cores and gross stratigraphy are indicated.

Any attempt to test the various models is beset by the problems of an incomplete palaeoecological record, and the limited amount of research which has been carried out. Although the schematic diagrams (Figure 2) suggest that what remains includes the base of the 'core' of the mire, indicated by shading, this is purely a convention, reflecting the survival into the twentieth century of those areas of the mire most remote from settlements cutting peat for fuel and animal litter. Encroachment on the north side has been the greater since the Ouse provided easy transport for the turves to major urban centres like York and Hull. In addition, the several monastic houses of the Vale of York and north Lincolnshire had rights of turbary on the north side of what was then known as Inclesmoor (Beresford 1986). A further problem arises from the conventional form of the diagram, having a single core rising to perhaps in excess of 7m (Smart, Wheeler & Willis 1986, figure 5). Rogers & Bellamy (n.d.) describe both Thorne and Hatfield Moors as if each was a single cupola. Casson's (1829) description of the dome rising to obscure the view of Crowle Church from Thorne also tends to be taken to imply a single centre (*cf.* also Woodruffe-Peacock 1920–21). Hatfield Moors, with the limestone gravel moraine of Lindholme at its centre, reached by a causeway across the mire, is unlikely to have had a single cupola form. Freshwater flooding and infringement by peat cutting are likely to have shifted any points of maximum growth and accumulation episodically about the mires.

Although this discussion concentrates on the gross morphology of the mires, recent developments in the interpretation of mire growth are relevant. By these, the previous model of pool replacing hummock in an almost orderly fashion (Moore & Bellamy 1974) has been in part replaced by one in which the pools may remain stable over several hundred years of active growth (Johnson & Damman 1991, Buckland 1995). This change has served to stress the relative stability of mire ecosystems once developed, but does not imply a single central pool, or 'well' as nineteenth century topographers and naturalists termed pools on Thorne Moors (Limbert 1987). The six inches scale Ordnance Survey maps of 1853-55 would suggest at least four 'topographic centres' to the mire in the southern and western part of the mire complex, and there were undoubtedly others. Such morphological clues to the form of the uncut surface provide little indication of the nature of the base of the peat. Each of the models presented leads to a similar final product; the concept of equifinality holds.

The primary model of autochthonous development of raised mire, consequent upon paludification of the forest floor and acidification of poor-fen (Figure 2a), should be capable of falsification on the basis of both palynology and radiocarbon dating. The primary detailed study by Smith (1958) suggested that the base of Hatfield Moors lay within pollen zone VIIa, predating Neolithic clearance and the approximate isochrone provided by the Elm Decline of *c.*5200 B.P. (Bailey 1992). This would indicate an initiation of peat growth some 2000 years before the origins of Thorne Moors, where Turner (1962) obtained radiocarbon dates around 3200 B.P., close to the base of the peat. Buckland (1979) obtained similar dates to those of Turner from the Thorne 'trackway' site, and dates on the former channels of the Don and Idle over a thousand years older (Table 1). He was therefore inclined to see the origins of the two mires differently, with Hatfield arising like blanket mire (*cf.* Moore 1975, 1993), as a result of the podzolisation of the underlying nutrient-poor fluvial and glacio-fluvial sands and gravels, and aeolian sands. This was interpreted as a consequence of early agriculture. This hypothesis appears to be supported by the abundant comminuted wood charcoal in the top of the underlying sands around Lindholme, and more recently, by the finds of charred oaks and Scots Pines to the north of the island, and of charred oaks in the edge of gravel workings north-east of Torne Bridge on the Hatfield Woodhouse to Blaxton road (Whitehouse 1997). In view of the current climatic lower altitudinal limit to blanket mire growth, however (Moore 1993), such a mechanism would require a significantly wetter/cooler climate. This is not supported by the fossil insect evidence from Thorne Moors, where the assemblages remain essentially more Continental to *c.*3000 B.P. (Buckland 1979, Whitehouse 1997). Most other proxy records of climate for the mid-Holocene favour changes at a later date, the so-called Sub-Boreal–Sub-Atlantic transition (*cf.* Frenzel 1966, Lamb 1981).

The problem was next approached by Smith (1985, 2002). In an intensive as well as extensive study of both Thorne and Hatfield Moors, using palynology and plant macrofossil analysis backed up by radiocarbon dates, he was able to show that the oldest areas of peat which had not been warped over, lay on the edge of Rawcliffe Moor and on Goole Moor. A date of 4545±75 B.P. was obtained from the base of Rawcliffe Moor, and 4515±70 B.P. from Goole Moor (Table 1). Compared with Turner's dates, and the date from the Thorne 'trackway' site of 3260±100 B.P. and from Crowle Moor of 3475±65 B.P. (Table 1 and Figure 4), it would appear that penecontemporaneous paludification of the forest floor, as proposed in model (a) (Figure 2a), across the greater part of the gently sloping surface of the Humberhead Levels, is unlikely. Only two dates are available on the base of Hatfield Moors. On the west side of Lindholme, a date of 4180±70 B.P. was obtained and, eastwards, mid-way between the island and the former course of the River Idle, the basal date is 4335±75 B.P.. Allowing for some slight onlap on to the moraine at Lindholme, these dates, whilst negating a pollen zone VIIa origin as proposed by Smith (1958), are insufficiently distinct to disprove model (a). As Korhola (1992) has rightly stressed in his study of Finnish raised mires, caution has also to be exercised in using radiocarbon dates derived from mor humus and basal peats, where accumulation may have been protracted, and charcoal particles several thousand years old may have been bioturbated into the organic sediments to be dated. Where possible in the Humberhead Levels, dates have been carried out on identifiable macrofossils.

The absence of closely spaced levelling data across the Moors provides further complications. In deep drainage ditches recently cut south of the new limestone road ('Fisons' Road') on Thorne Moors, it is apparent that the southern part of the base of the former mire complex is significantly higher towards the 'trackway' site. By how much is uncertain, and the few levelled points on the Ordnance Survey maps would imply that the slope on the present surface at least is the reverse of this. This problem of relative levels is further exacerbated when the dates on riverine sediments are also considered. The date on the Crowle 'depression' (Figure 3) presumably once occupied by the meandering Don, of 4230±70 B.P., is sufficiently close to that on the Don from Thorne Waterside and the Idle at Misterton Carr (Table 1) to suggest a relationship with contemporary base-level. All are significantly younger than the Rawcliffe and Goole Moors dates. Levelling data, however, are presently insufficient to be certain whether this is topographically relevant, since the surface of the Lake Humber clay-silts appears to slope north-eastwards.

The simple model of penecontemporaneous paludification of a forested or recently cleared landscape, has further problems when new evidence from Goole and Snaith & Cowick Moors is considered. The presence of charred Scots Pine stumps over at least 3km^2 of the remaining basal 0.5m of peat has excited interest among archaeologists, in terms of the discussion of the incidence of natural wildfire and the use of fire as a management tool by past communities. Few British landscape archaeologists (*e.g.* Rackham 1980) would consider fire to be part of the natural sequence in European woodland, a point of view also taken by many palynologists (*cf.* Simmons 1992, Smith 1985, 2002). The Thorne evidence could therefore encapsulate a Late Neolithic or Early Bronze Age clearance or *landnam* episode. Similar evidence of burning on oaks and Alder adjacent to the Thorne 'trackway' site was interpreted by Buckland (1979) as evidence of a small temporary clearance in a forested landscape. Stratigraphically the Pines do not, however, all lie at the base of the sequence, and their tree-ring sequence covers at least 200 years (Boswijk 1998). They appear largely to represent a phase of relative drying-out during the early genesis of the mire complex. The one date obtained on Pine by Smith (1985, 2002 and Table 1) from Crowle Moor of 3545±70 B.P. may be relevant, although as a caveat, the date on the bark of a small Pine from the 'trackway' site is 2980±110 B.P. The importance of fire in the expansion of blanket mire has been considered by Moore (1992), and the frequent association of charcoal with the base of raised mire may also be significant.

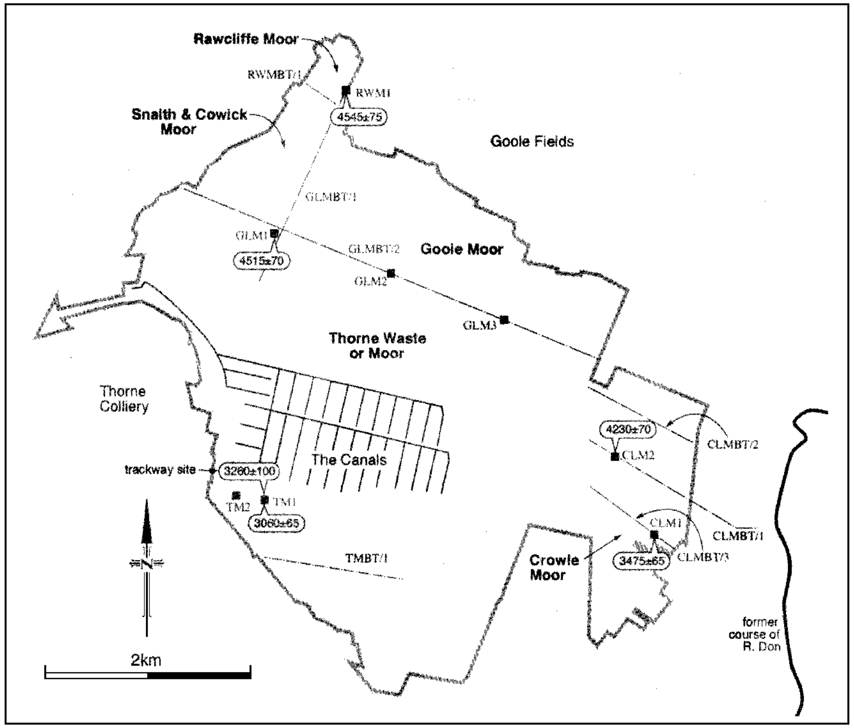

Figure 4. Thorne Moors, to show the location of radiocarbon dates (given as B.P.) on the base of the peat.

Beneath the Pine horizons, at the base of the mire, is a different landscape. The 'trackway' site provides the youngest evidence for the survival of an old forest (*Urwald*) insect fauna in Britain (Buckland 1979, Buckland & Dinnin 1993), clearly reflecting an area of relatively undisturbed forest. The area to the north, recently exposed in peat cutting, provides a picture of a landscape over 1000 years earlier. The close-set net of new ditches provided access to a much larger sample of the exhumed landscape, as it was being destroyed during peat milling. The large trees at the base of the peat consist largely of oaks, and their size and lack of side branches suggest growth in a closed forest environment. Where preservation is sufficient, however, the overall impression is of an open oak woodland, rather than closed forest. Entomological and plant macrofossil evidence show that lime *Tilia*-dominated woodland continued to prevail along the banks of the Don and Idle (Buckland 1979), giving way to wet oak and Alder forest away from the rivers. Elsewhere, by the fifth millennium B.P., pressure upon resources was leading to land management regimes which included pasture-woodland, which persisted for several thousand years, providing refuges for both forest and old grassland insects (Buckland & Dinnin 1993). The model of paludification as a direct result of local large-scale forest clearance is perhaps less tenable (Figure 2a), than one in which freshwater flooding resulted from more regional forest destruction. The later process of acidification leading to raised mire has recently been examined by Roper (1996), using a succession of fossil beetle faunas from Thorne Moors.

The prevailing model of raised mire development (Moore 1990, figure 3.2d) begins with a lake basin and a progressive infilling, through to independence from the water-table and building of a dome with little or no lateral extension. The extensive exposures of the base of both Thorne and Hatfield Moors however, have nowhere revealed origins over eutrophic lacustrine sediments and, at all locations, the early to mid-Holocene sequence is absent. A combination of a primary Holocene basin with later lateral growth (Figure 2b) at Thorne, however, cannot be entirely ruled out. The available radiocarbon dates show that the earliest deposits lie to the north (Figures 3 and 4), and a basin, perhaps with a more complete Holocene sequence, may be obscured by warp between the present northern edge of Thorne Moors and the River Ouse. Gaunt's (1987a, figure 4) map of contours on the base of the Flandrian deposits allows for two such basins, although both are open towards the east, rather than closed structures. That to the north-west of Crowle lies across the line of transect for pollen cores taken by Smith (1985, 2002) (Figure 4), but it is evident that deposition within it did not begin until late in the fifth millennium B.P. (Table 1). It is possible that the structure reflects an abandoned terminal Devensian route of the Don. The similar feature to the north may also be related to the contemporaneous Aire or Went drainage. Gaunt's (1987a) borehole records have also not located any extensive Holocene lacustrine sediments. Although Rogers & Bellamy (n.d.) record fen peat with remains of Common Reed *Phragmites australis* and stoneworts *Chara* in the so called Canals region of Thorne Waste, this is insufficiently substantial to suggest an extended sequence. Later research has shown that deposition in this region only began late in the fourth millennium B.P.. The complex nature of the Quaternary geology beneath Hatfield Moors, with pre-Devensian deposits, Devensian glaciolacustrine deposits, and terminal Devensian blown sands, also leaves little space for initiation of mire over a fen basin, and here also a unifocal model seems unlikely.

The absence of an underlying Holocene lake basin indicates that a rising base-level, leading to paludification of several centres in the form of small pools, rather than lakes (Figure 2c), provides a viable alternative model. The surface of the Lake Humber clay-silts beneath Goole Moor is not a simple surface sloping gently to the north and east; it is crossed by numerous runnels of low amplitude, up to 300mm in depth. These have not yet been mapped in detail. It is evident, however, that with rising base-level, these could have provided foci for fen peat growth and the eventual development of raised mires. As the processes of outward expansion continued, these could eventually have coalesced to form a single structure. Fossil insect evidence from several localities on Thorne Moors indicates the formation of freshwater fen pools at the base of the succession, and there is no trace of any direct estuarine influence, despite the present tidal nature of the rivers to well beyond the margins of the Levels. If the development of open water therefore did involve flooding, it was with fresh rather than saline waters. Buckland (1979) has suggested that the initial mechanisms could have involved backing up of runoff, intensified by upland clearance, by changing patterns in the tidal regime of the Humber. Any flooding, however, does not appear to have been catastrophic. "Alluvium", recorded by Rogers & Bellamy (n.d.) in the Canals region, has not been recorded in the more extensive sections which have become available in recent years. In most exposures, fen peat rests directly on a variously humified mor humus developed on Devensian clay-silts. At the 'trackway' site and the large oak sampled in 1972 (Buckland 1979), it is evident that both oak and Alder continued as living parts of the developing wetland community until overwhelmed by mire growth.

At Hatfield Moors, a similar irregular base for mire initiation was provided by a series of subdued, patchy sand dunes, which had been active across the gently dipping and undulating surface of Older River Gravel and glaciolacustrine sediments. These features were particularly evident (1992) in drainage ditches, cut through the base of the peat in advance of peat milling, north of the causeway from Hatfield Woodhouse to Lindholme. In the absence of the detailed insect macrofossil studies carried out on Thorne Moors, it is difficult to interpret the Hatfield stratigraphy, but it is evident that peat accumulation in the lower areas was fringed by continued growth of Scots Pines on the sandy ridges. Several of the fossil Pine trees again show evidence of destruction by fire, and a tree pit to the north of Lindholme contained the charred remains of a large oak (Eversham, Buckland & Dinnin 1995).

Although all models relate directly to a rising water-table, the first three minimise the influence of riverine sedimentation and the development of fringing fen and carr. Thorne Moors is almost circumscribed by the rivers of Hatfield Chase and, even allowing for the artificial nature of the River Don north of Thorne (Gaunt 1975, Jones 1995), the Ouse, Went and Don provided extensive margins for the lateral development of wetlands (Figures 2d-e, Figure 3). Where examined, at Thorne Waterside and Sandtoft, the channel of the Don is infilled to the top with grey organic silts containing a freshwater insect fauna. Moore's (1993) essentially upland view of valley mire growth envisages the raised mires lateral to the river being the result of slow percolation of acid runoff from adjacent podzolised uplands. Little such flow is likely to have occurred in the gentle topography of the Humberhead Levels, but acidification through poor-fen to raised mire, and hydrostatic flow perpetuating a moving front of paludification, would have led to the development of a raised mire, which grew from the edges inwards. At some stage, probably during the Roman period, the deposits infilling the buried channels were overlain by oxidised silts, indistinguishable from nineteenth century warp soils, which lap on to the raised mires. The change in sedimentation has been noted widely in the Trent Basin (*cf.* Riley, Buckland & Wade 1995), and probably results from the erosion of the topsoil of the region by changing farming activities (Buckland & Sadler 1985).

Figure 2e provides a variant of the river bank initiation of raised mire, perhaps more applicable in the case of Hatfield Moors, where the Torne and Idle to the south and east provide the possibility of asymmetric lateral growth, only eventually constrained to the west and north by marginally higher ground. Runoff from these adjacent areas of podzolised sands and gravels is likely to have been essentially acidic. If the origins of Thorne Moors were to have lain on the northern edge of the mere which Taylor (1987) has mapped north-west of High Levels, towards the town of Thorne, then this model could also apply to Thorne Moors. The available radiocarbon and palynological data, however, do appear to confirm a southward expansion of the mire from areas now warped over close to the River Ouse.

Conclusion

Of the five alternatives presented (Figure 2), only the first and second appear wholly contradicted by the available stratigraphic, palaeoecological and radiocarbon evidence. It has to be stressed, however, that all represent points in a gradational series leading to a similar, now vanished, culmination in raised mire. Sufficient survives, however, on both Thorne and Hatfield Moors, and also beneath warp and in river channel deposits, to constrain the model more closely. If the mires have expanded outwards or inwards from primary foci, either pools or along river courses, then a fuller suite of radiocarbon dates, particularly filling the gap between Goole Moor and the Thorne Waste 'trackway' site, would be particularly useful. The dendrochronology of both Scots Pine and oak sequences, however, offers much closer control and understanding of raised mire evolution on the Levels. The advancing rand of the mires, with *Sphagnum* overwhelming tree growth at the margins, preserves a sequence of poor-fen and mire edge deposits which have the potential to be dated, at least relatively, on the tree-ring sequences. Even with the poor fragments that remain, it is possible to answer some of the problems of the nature and rate of raised mire development; only then can this information be applied to conservation and management strategies.

Palaeoecology and the raising of the mires

The possibility of the renewed development of raised mires at Thorne and Hatfield has to be considered in the light of the palaeoecological record. At Thorne, a potential core is provided by the Canals area. Similar foci remain on Crowle Moor, perhaps on Snaith & Cowick and Goole Moors, and also surprisingly around the ridge of Lindholme on Hatfield Moors. With the exception of the last, these are surrounded by warplands (now largely intensively cultivated), some poor-fen and several km^2 of peat desert, stripped by milling to a level surface through which occasionally protrude the truncated remains of Lake Humber clay-silts or ridges of blown sand. Over most of these areas, extraction has removed virtually all the *Sphagnum* peat, and woody fen peat remains. Lindsay (1989) has noted that milled surfaces in Caithness, worked twenty years earlier, were still devoid of vegetation cover. He ascribes this to the extreme acidity of the substrate. Over much of Thorne and Hatfield Moors, the exposed surface of fen peat is likely to be more eutrophic, but the development of any vegetation cover, at least initially, is unlikely to be towards raised mire. If the water-table can be raised sufficiently, poor-fen may result in the short term; otherwise, invasion by Soft-rush *Juncus effusus* in the wetter areas, and birch and willow scrub elsewhere, is more probable. The current attempts to raise the water-table over the National Nature Reserve on Thorne Moors demonstrate that the hydrostatic gradient is to the north, but it is debatable whether this would be maintained in the event of the cessation of pumping in the extraction area. The cleaning out in 1995 of Swinefleet Warping Drain by the Reedness & Swinefleet Internal Drainage Board, which takes most of the surface runoff from Thorne Moors, can only serve to exacerbate the problems.

The fundamental raised mire structure of inactive but saturated catotelm and developing acrotelm has disappeared from both bogs. If re-creation is to be attempted – the terms conservation and restoration are inappropriate on the macroscale – the palaeoecological record raises a number of serious doubts and problems. Smith (1985, 2002) has provided evidence from the macrofossil record for maximum growth during episodes of wetter climate. The evidence is difficult to quantify, but he suggests conditions certainly wetter than the present average of 660mm of rain *p.a.*. Management of the water-table might allow a reversal of a natural growth pattern which saw paludification beginning to the north of Rawcliffe Moor, and only after 1500 years extending over the Canals region (Figure 3).

However, the stemming of subsurface flow, exacerbated by desiccation of the peat, as well as by numerous drainage ditches and the continued pumping down of the water-table, would need more effective blocking than the peat bungs in existing drains. The pumping of groundwater to maintain water levels would do little to sustain communities whose minimal nutrient requirements should stem entirely from rainfall.

Re-creation has much to commend it to the peat industry, since it provides a license for total destruction and rehabilitation by earth-moving and seeding. In the extreme case, this would be achieved by a cosmetic skim of introduced acidophile plants on an artificial catotelm built of peat residue. It is not surprising therefore that the industry and government saw fit to fund the *Sphagnum* regeneration studies of Wheeler (1989; Wheeler & Shaw 1995) and his students, and not the research into the palaeoecological archive which is being destroyed. That record throws serious doubts on the viability of 'restoration' schemes, and demonstrates the dynamic nature of lowland mires which, without interference, are able to withstand secular variation in climate, and were already in a state of change long before extensive peat cutting and drainage. Some changes may have already begun to put restraint upon mire growth by the medieval period. The loss of various acidophile species from the Lowlands within the period of botanical recording is widely documented (*cf.* Bellamy *et al.* 1960). At Thorne, this is perhaps typified by the fate of Rannoch-rush *Scheuchzeria palustris* (Bennett 1921). Its remains form a significant part of the macrofossil record from the peat of both Thorne and Hatfield Moors (Smith 1985, 2002; Smart, Wheeler & Willis 1986), but by the 1870s it had disappeared, and subsequently in Britain became restricted to Rannoch Moor in Perthshire. Godwin (1975, quoting Bulman, unpubl.) regarded the plant as more characteristic of the larger pools of Continental mires than of the smaller ones of Britain. Both faunal and historical evidence from Thorne Moors (Buckland 1995, Eversham, Buckland & Dinnin 1995) further suggests an affinity with the mires of the Baltic region, rather than with those of the west of Britain.

Perhaps more critical are changes in the *Sphagnum* flora. The major peat-forming moss through the greater part of the preserved record on Thorne and Hatfield Moors was *S. imbricatum* (Smith 1985, 2002), a species now restricted to the extreme west and north of Britain (Dickson 1973, figure 32). Its demise, as the major mire-forming moss in Lowland Britain, has been the subject of much discussion, and its history is clearly relevant to any re-creation attempts which rely upon cosmetic surgery. Dickson (1973), Rose & Wallace (1974) and Slater (1984) favour a human impact explanation, although the latter suggests that fire and drainage accelerated an otherwise natural decline. With the benefit of the palaeoecological record, Barber (1981) preferred an explanation in terms of climatic change, although he later (Stoneman, Barber & Maddy 1993) favoured competition with *S. magellanicum* as a major factor in the decline of *S. imbricatum*. The issue is further complicated by a recent study on the Pennine uplands, where Mackay & Tallis (1995) suggest that a combination of low rainfall and catastrophic fire, rather than atmospheric pollution, was initially responsible for a decline in *Sphagna*, and subsequent erosion. In the Thorne profiles, Smith (1985, 2002) found that *S. imbricatum* had gone from the bog by the twelfth century A.D., whilst it survived at Hatfield to the top of the remaining succession. There is a sad irony in the fact that Smith (1985, 2002) also saw competition with another species, *S. magellanicum*, as a reason for its extinction, since this has now also gone from the Moors (Wall & Limbert 1987). Smart (1983) and Wheeler (1989) have experimented with the reintroduction of *Sphagna* from other localities to Thorne Moors, leading to a number of other, perhaps unwanted, chance introductions. The fossil record of decline long before mechanised peat cutting would imply that such experiments were doomed to eventual failure.

The re-creation of raised mires on the macroscale by the 'quick-fix' approach is unlikely to be successful. The radiocarbon evidence suggests that transition from poor-fen to raised mire may take at least 300 years after primary paludification, given a suitable climatic regime. The problem in restoration would seem not to be the establishment of aquatic *Sphagna* from suitable refuges on the Moors, but the terrestrialisation process leading to raised mire. The preferred approach therefore has to be one of direct intervention in the conservation of what remains, with a view to expanding the frequency of those elements seen to be under greatest threat. Acidophile and rare poor-fen elements still survive in refuges on both Moors, but are in danger of either shading out by developing woodland or invasion of Bracken *Pteridium aquilinum*. Such problems find no direct parallel in the palaeoecological record, but the evidence of the impact of fires on the Bronze Age Scots Pines of Thorne Moors (Whitehouse, Boswijk & Buckland 1997), and Heather *Calluna vulgaris* heath of Hatfield Moors, suggests that a raised water-table, ring-barking of trees and a controlled burn, could be to the advantage of wetland species. It is an experiment that one would not want to get wrong, and the impact of fire on the plant and invertebrate communities can only be worked out from the rapidly disappearing fossil record.

The extent to which grazing has modified our view of mires as treeless areas has recently been raised by Chambers (1997), and the Pines along the edges of Lindholme, outside the limits of the SSSI, should also be entered into any management plan. The Frontispiece shows Storamyren, south of Umeå in northern Sweden, a forested lowland mire, with Rannoch-rush and Cranberry *Vaccinium oxycoccos* in its pools. A Baltic mire, it contrasts with the present form of Thorne and Hatfield Moors, but it gives one model towards which conservation should be striving over the next century, and one which deserves more detailed comparative research.

This paper has deliberately minimised the evidence for the impact of climatic change and, to a certain extent Man, upon the raised mires of Thorne and Hatfield, in order to obtain a broad overview of the genesis of the mires. Crises such as phases of drying out of the surface as a result of either edaphic or climatic factors (Smith 1985, 2002) have, in the past, always been balanced by the survival of species in refugia, an option which is rapidly disappearing from these wetlands. In an interesting study of Minnesota mires, Glaser *et al.* (1997) have shown how raised mires were maintained through drier events by capillary drawing from the groundwater. This serves to stress the need for fully integrated management of both runoff and aquifer recharge for successful mire development, a serious problem in a country where these are split between English Nature, the Environment Agency, and the largely autonomous internal drainage boards.

The rising tide of air pollution has also had its impact upon ombrogenous mire vegetation (Ferguson, Lee & Bell 1978), and this alone may well negate any attempts at re-creation. Energies must be directed towards the conservation of what remains, rather than attempts to recreate a poorly known image of the past. It is possible that proactive management of acidophile fragments may lead to the growth of raised mire along the lines of that proposed in model (c) (Figure 2c), but this requires a time-scale measured in centuries rather than decades, something which few conservation bodies can plan for. What develops will not be, indeed cannot be, an approximation of the past, yet the predicted form can only be constrained by knowledge of what has gone before. There is still an urgent need to examine the record of the past before its final destruction in the wetlands, for it contains not only many cautionary tales, but also clues to future management strategies.

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