Recent vegetational changes on blanket mire at Mynydd Llangatwg, South Wales

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ABSTRACT

The Countryside Council for Wales identified that considerable areas of blanket mire in South Wales currently support impoverished vegetation as a result of recent anthropogenic influences such as grazing, burning, atmospheric pollution and climate change. One such area is at Mynydd Llangatwg, South Wales, here the blanket mire is now largely dominated by graminoids, particularly *Molinia caerulea* and *Eriophorum vaginatum*, and with reduced amounts of ericaceous and *Sphagnum* species. However, there are few detailed multidisciplinary palaeoecological and palaeoenvironmental studies from South Wales to determining the precise nature and causes of the vegetation degradation.

This study aims to firstly, reconstruct a high-resolution vegetational history using plant macrofossil and pollen diagrams from two sites at Mynydd Llangatwg; secondly, to elucidate possible causes of the vegetation degradation using plant macrofossil, pollen, charcoal and peat humification analyses; thirdly, to assign a temporal framework by using spheroidal carbonaceous particle (SCP) analysis.

At Mynydd Llangatwg two peat profiles *c.*1 km apart reveal marked but different vegetational changes. Most notably a rise to dominance of *Molinia* at profile MLM at a time of around the mid 19th century and the onset of the industrial revolution, and a rise to dominance of *Calluna* at MLC sometime before the mid 19th century. Both profiles have also experienced a decline in *Sphagnum*. The vegetation changes both appear to have come from a vegetation assemblage co-dominant in Ericaceae and *Sphagnum* with moderate amounts of Gramineae and Cyperaceae.

Examination of the evidence in this study suggests burning, and in particular the frequency of burning may have played a crucial role in the vegetational changes at Mynydd Llangatwg. Grazing may have also been a contributing factor, and grazing and burning may have had combined effects. There is no conclusive evidence for climate change or atmospheric pollution initiating the principal vegetation changes at Mynydd Llangatwg and these would require further examination before firm conclusions of their effects on the vegetation changes could be drawn. A multidisciplinary approach nonetheless limits the potential for misinterpretation of the evidence for past vegetation change and its underlying causes.

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AUTHOR'S DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of the University of Gloucestershire and is original except where indicated by specific reference in the text. No part of the thesis has been submitted as part of any other academic award. The thesis has not been presented to any other education institution in the United Kingdom or overseas.

Any views expressed in thesis are those of the author and in no way represent those of the University of Gloucestershire.

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Signed ....

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CHAPTER ONE

INTRODUCTION

> *"Blanket mires in Britain represent a habitat and landscape type which is rare in global terms, where the vegetation has adapted to the specialised and hostile environment thus providing a significant part of global diversity" (Lindsay 1995 cited in Brookes & Stoneman 1997).*

Degradation is a term which may be equated with a deterioration of quality. This in turn relates ideas of value. The value ascribed by conservationists to blanket mire is variously defined by the combination of biological, physical and hydrological features and processes that result in an ecosystem which is largely autogenic. Blanket mire degradation may occur either entirely through natural processes, through the direct or indirect consequences of human activity, or through a combination of the two (Coupar *et al.* 1997).

Yeo (1997) reported on blanket mire degradation in Wales and suggested three types of degradation. Firstly, there is the direct replacement of blanket mire with non-native vegetation or man made habitats. Foresters have often targeted peat soils, and commercial afforestation has contributed significantly to the loss of blanket mire habitat. Other activities such as the construction of reservoirs and roads have also affected blanket mires, but the total loss of habitat has been relatively small. Secondly, there is peat erosion where networks of gullies can sometimes lead to substantial removal of the peat blanket. This is a major problem on several Welsh peatlands such as the Brecon Beacons. Erosion leads to changes in the vegetation cover of mire systems. Eroded peat surfaces typically develop some form of heath, usually *Calluna vulgaris -Vaccinium myrtillus* (H12) National Vegetation Classification (NVC). The third form of degradation, and where most of the concern lies, is the succession to impoverished forms of semi-natural vegetation. Many localities of blanket mire in Wales no longer support peat-forming ombrogenous mire vegetation, and as a result are considered to be of limited conservation interest. Impoverished vegetational communities, typically dominated by graminoids and with reduced amounts of ericoids and *Sphagna* cover extensive areas of blanket mire in many parts of Wales. Loss of *Sphagnum* diversity is also a feature of modified blanket mire throughout Wales.

Blanket mires are an important resource and mires throughout the world act as a significant part of global biodiversity. The remarkably unique conditions of waterlogging, low nutrient status and high acidity combine to create a specialised flora and associated fauna. Examples of the specialised flora are the carnivorous plants such as *Drosera spp.* (sundews) and *Pinguicula spp.* (butterworts) which are found mainly on mires in Europe (Brookes & Stoneman 1997). Welsh Mires provide an important habitat for scarce flora such as *Sphagnum imbricatum* and *Carex pauciflora* and fauna such as the Golden Plover and Dunlin (Yeo 1997). Blanket mires have a very restricted international distribution, and Britain holds a significant proportion of the world resource. The rarity of the habitat has been acknowledged by its inclusion in Annex I of the EC directive on the Conservation of Natural and Semi-Natural Habitats and of Wild Fauna and Flora (Directive 92/43/EEC), and is a key habitat within the UK Biodiversity Action Plan. In Wales, important blanket mire sites are included within Environmentally Sensitive Areas and the Tir Cymen scheme (Yeo 1997).

Peatlands also represent a gigantic store of carbon, which may otherwise reside in the atmosphere. Immirizi *et al.* (1992) estimate that peatlands globally hold 3 - 3.5 times the amount of carbon of tropical rainforests and Brookes & Stoneman (1997) suggest that as much as 600 million tonnes of carbon are released into the atmosphere every year to due peatland exploitation.

Mires hold a multi-proxy archive of environmental change and past biodiversity. They are the *only* plant community to lay down *in situ* a detailed record of their own history in the form of macrofossil remains of the plants themselves. Included within these plant remains are stratified records of pollen of their own and surrounding communities, of some invertebrates, of wind blown dust, charcoal and magnetic particles, of volcanic ash and of past hydrological conditions on the mire surface. This record considerably enhances the conservation value of peatlands, for it is only by understanding the recent past that we can evaluate fully the present situation (Barber 1993).

A preliminary assessment of the extent and nature of blanket mire vegetation degradation in Wales was made by Yeo (1997). This recognised that considerable areas of blanket mire were currently supporting impoverished vegetation dominated by graminoids particularly *Molinia caerulea* and *Eriophorum vaginatum* and with reduced amounts of ericaceous and *Sphagnum* species. In particular, the overwhelming local supremacy of *Molinia caerulea* concerns farmers owing to its relatively low palatability for grazing stock, and conservationists, owing to the monotonous species poor landscapes that often result under Molinietum (*Chambers et al.* 1999).

Yeo (1997) suggested that the vegetation changes have largely been brought about by anthropogenic influences such as grazing, burning, atmospheric pollution and climate change. It was also noted that there had been relatively few detailed palaeoecological studies of recent (< 500 years) vegetation changes on Welsh blanket mires.

Blanket mire at Mynydd Llangatwg, South Wales was identified as one area supporting impoverished vegetation communities by the Countryside Council for Wales (CCW) based on the reports by Yeo (1997). At this locality there were still some patches of *Calluna vulgaris* in an area otherwise dominated by *Molinia caerulea* or *Eriophorum vaginatum.*

The aims of this thesis which are set out in more detail in section 2.4, were firstly, to reconstruct a high-resolution vegetational history at Mynydd; secondly, to apply palaeoecological and palaeoenvironmental techniques to help elucidate possible causes of vegetation degradation; thirdly, to assign a temporal framework. Chapter two examines the nature of vegetation degradation on blanket mires in Wales, its possible causes and the need for palaeoecological research. It covers a detailed review of literature from Welsh blanket mire research but also covers research elsewhere in Britain and Europe where appropriate. Chapter three firstly explores the sampling strategy where two peat profiles *c.* 1 km apart were taken: one from a *Molinia caerulea* dominated area (MLM) and another from a *Calluna vulgaris* dominated (MLC) area. This is followed by a discussion of the palaeoecological and palaeoenvironmental techniques adopted and detailed descriptions of the laboratory methodology. Chapter four sets out the results and interpretation of the laboratory analyses for profiles MLM and MLC. It also consolidates the results in tables and diagrams as to aid comparison of the data and make interpretations based on all lines of palaeoecological and palaeoenvironmental evidence. Chapter five discusses the major vegetational shifts in both profiles MLM and MLC and in particular the behaviour of *Calluna vulgaris, Sphagnum* and *Molinia caerulea.* Dating of the principal vegetation changes and the possible causal factors are also explored. The findings are put in the context of other palaeoecological research conducted at Mynydd Llangatwg and elsewhere in Wales, Britain and Europe. The contribution of the research to the history of blanket mires in South Wales and to the conservation management at Mynydd Llangatwg are also discussed. Lastly there is an evaluation of the palaeoecological and palaeoenvironmental techniques adopted. Chapter six draws conclusions, in terms of the major vegetational changes and their possible cause(s) on blanket mire at Mynydd Llangatwg, the implications for conservation management and recommendations for further research.

In this study the pollen nomenclature follows Moore *et al.* (1991) and botanical nomenclature largely follows Clapham *et al.* (1978).

CHAPTER TWO

WELSH BLANKET MIRE VEGETATION DEGRADATION

This chapter examines the nature of vegetation degradation on blanket mires in Wales, its possible causes and the need for palaeoecological and palaeoenvironmental research. It also includes a review of research undertaken elsewhere in Britain, and where appropriate Europe. The chapter ends with the study's aims and research questions.

2.1 Blanket Mire Vegetation Degradation in Wales

In Wales blanket peat is only extensive above 250 m altitude, where annual precipitation is in excess of 1,200 mm, and is concentrated in the uplands, which comprise the central spine of Wales. Blanket peat is an especially distinctive feature of the North-central Moorlands and the South-central Moorlands in Wales (Yeo1997). Information on the extent and distribution of peat deposits in Wales is available from various sources. Yeo (1997) reviewed these and produced a reinterpretation of the data to estimate the area of blanket mire. The data sources included the following. A Soil Survey of England and Wales by Rudefoth *et al.* (1984) which used a definition of >40cm peat and gave a total peat area of 70,600 ha. From this Yeo (1997) estimated the area of blanket peat to be *c.* 63,500 ha. An inventory and interpretation of peat deposits (>0.91m) in Wales by Taylor & Tucker (1968) based on British Geological Survey and Soil Survey data, a field survey and aerial photograph analysis gave a total area of peat in Wales of 84,200 ha. From this Yeo (1997) estimated the area of blanket peat to be *c.* 78,000 ha. These two surveys use slightly different criteria to define peat, but both estimated exclude mineral soils with peaty upper horizons, such as stagnopodzols and peaty gleys. Yeo (1997) suggests that the Soil Survey data by Rudeforth *et al.* (1984) may underestimate the extent of blanket peat as the survey by Taylor & Tucker (1968) who produced a map in 1983 that shows considerably larger areas of blanket peat on the Brecon Beacons and Mynydd Eppynt. British geological Survey maps interpreted by Lindsay & Immirzi (1996) estimated an area of 21,449 ha of blanket peat (> 1m) in Wales; however, Yeo (1997) notes that this survey was very incomplete with large gaps particularly in mid Wales.

Yeo (1997) suggests that, in Wales, where anthropogenic influences have been limited, deeper peats typically support ombrogenous bog with a prominent *Sphagnum* component. He suggests that the communities described below comprise most of the peat-building bog on Welsh blanket mires.

- *Calluna vulgaris - Eriophorum vaginatum* mire (NVC M19), which is the main form at mid (200-400 m) to high (>400 m) altitudes throughout Wales.
- *Scirpus cespitosus - Eriophorum vaginatum* mire (M17), typical of low (<200 m) to moderate (200-400 m) altitudes in oceanic regions
- *Erica tetralix - Sphagnum papillosum* mire (M18), widely distributed in upland situations.

- In central Wales and on larger blanket mires, areas of deeper peat give way to *Calluna vulgaris - Eriophorum spp.* vegetation.
- Additionally, shallow upland peats across Wales exhibit *Scirpus cespitosus - Erica tetralix* mire (M15) or more rarely *Erica tetralix - Sphagnum compactum* mire (M16).

A Welsh upland vegetation survey conducted by the Joint Nature Conservation Council (JNCC) between 1979-1989 (Day 1989), and a complementary habitat survey of lowland Wales since 1987 conducted by the Countryside Council for Wales (CCW) (Yeo 1997) provided a comprehensive record of the vegetation cover of Wales. From the surveys, Yeo (1997) made a preliminary assessment of the extent and nature of blanket mire vegetation degradation in Wales. He recognised that considerable areas of blanket peat were currently supporting impoverished vegetation dominated by graminoids, particularly *Molinia caerulea* and *Eriophorum vaginatum*, with reduced amounts of ericaceous and *Sphagnum* species. Loss of *Sphagnum* cover and reduced diversity is a feature of modified blanket mire throughout Wales, but is not always associated with other floralistic changes. Characteristic impoverished communities include *Eriophorum vaginatum* mire (M20), *Molinia caerulea - Potentilla erecta* mire (M25) and *Juncus squarrosus - Festuca ovina* grassland (U6), each of which may be derived from a variety of precursors (Yeo 1997).

Yeo (1997) also assumed that low levels of *Molinia caerulea* in mire communities had been derived from *Calluna vulgaris -Eriophorum spp.* or *Erica spp.-Sphagnum* mire, as on sites such as Elynydd - Drygarn Fawr, mid Wales there are remnants of near natural bog. He suggested it was also possible that *Scirpus-Eriophorum spp.* mire once occurred more extensively on the plateaux in the south-central Moorlands, and it is this vegetation that has been replaced by *Molinia caerulea* dominated vegetation. In the north and east of Wales *Eriophorum vaginatum* mire is the most common, particularly a replacement for *Calluna vulgaris - Eriophorum spp.* mire. In the north *Molinia caerulea - Potentilla spp.* grassland is mainly confined to low altitudes and appears to have replaced *Scirpus spp. - Erica spp.* or *Scirpus spp. - Eriophorum spp.* mire. Throughout mid and south Wales *Molinia caerulea* becomes increasingly abundant at higher elevations and many sites in the south-central moorlands support vast expanses of impoverished *Molinia caerulea* dominated vegetation.

Yeo (1997) discovered what appeared to be a well marked geographical variation in the type of vegetation degradation between the North-central and South-central Moorlands of Wales. In the absence of detailed historical management data the environmental variables of geology, altitude, annual precipitation, grazing intensities, burning regimes and annual sulphur and nitrogen deposition were compared and found to be broadly similar between the groups of sites. However,

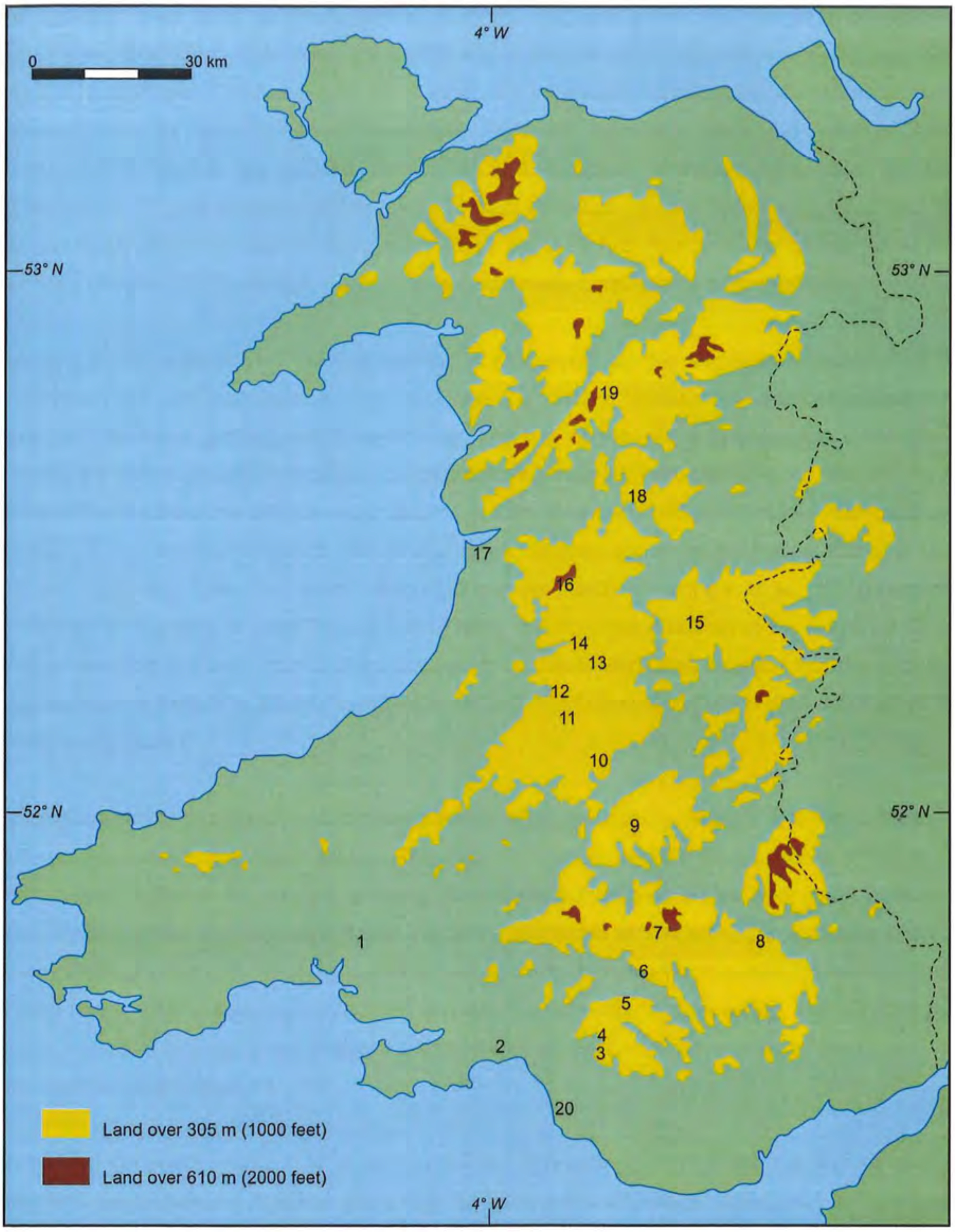

Fig. 2.1 Distribution of Welsh Palaeoecological and Palaeoenvironmental Sites.

1. Llanllwch Bog (Rosen 1998)
2. Crymyln Bog (Rosen 1998)
3. Ffoston Cenglau (Rosen 1998)
4. Cefn Ffordd (Chambers 1983)
5. Hirwaun (Chambers & Mauquoy 1998)
6. Coed Taf (Chambers *et al.* 1979)
7. Brecon Beacons (Chambers & Mauquoy 1998)
8. Mynydd Llangatwg (Chambers & Mauquoy 1998, Chambers *et al.* 2001, Pearson 2001)
9. Llangorse (Jones *et al.* 1991)
10. Mynydd Eppynt (Yeo 1997)
11. Drygarn Fawr (Chambers & Mauquoy 1998)
12. Tregaron (Turner 1964)
13. Pwll-Nant-ddu (Wiltshire & Moore 1983)
14. Esgair Nantybeddau (Wiltshire & Moore 1983)
15. Rhayder (Wiltshire & Moore 1983)
16. Plynlimon (Moore & Chater 1969)
17. Borth Bog (Moore & Chater 1969)
18. Carneddau (Ratcliffe 1959)
19. Berwyn (Tallis 1995)
20. Kenfig Pool (Rosen 1998)

the southern sites were generally warmer than the northern group. Multivariate analysis using constrained ordination techniques confirmed that temperature was significantly correlated with the vegetation differences between groups of sites. He suggested temperature was a major factor influencing the distribution of *Molinia caerulea - Potentilla* vegetation, which over most of Britain rarely extends far into the uplands, in contrast to *Eriophroum vaginatum* mire, which is highly characteristic of cold climates at moderate to high altitudes. He tentatively suggested that the comparatively warm climate in the South Wales uplands has favoured the spread of *Molinia caerulea* at quite high elevations, particularly in response to burning and other treatments.

Ratcliffe (1959) was one of the first researchers to report on the vegetation succession from Callunetum to acidic grassland on moorland in the Carneddau, Wales which was considered to be controlled by sheep-grazing and moor-burning. There is corroborating palynological evidence for the change from Callunetum to grass domination from a number mire sites through mid and south Wales. These exhibit the striking recent decline in Ericaceae and Sphagnum pollen, mirrored by an increase in the representation of Gramineae pollen, as also shown at Borth Bog, Cardiganshire (Moore 1968) and Coed Taf, South Wales (Chambers 1983). Chambers *et al.* (1979) recorded these distinct changes at Coed Taf and Cefn Ffordd, both in close proximity to the industrial valleys of Rhondda and Merthyr. From radiocarbon dating (un-calibrated) they suggest that the transition from heather moorland to *Molinia caerulea* moor seems to have taken place after the start of the industrial revolution.

Other palaeoecological studies of mire vegetational changes include Witshire & Moore's (1983) at Pwll-nant-ddu and Esgair Nantybeddau, Rhayader. These revealed the recent decline (in the top *c.* 5 cm of the profile) in Ericaceae and rise in Gramineae but differed in that *Sphagnum* increased; again these profiles have not been dated. Turner (1964) found at Tregaron, Cardiganshire a rise in Gramineae in the top *c.* 7 cm of the profile but did not record Ericaceae. In addition, she attributed a distinct rise in Gramineae around AD 1160, established from radiocarbon dating, to the initiation of Strata Florida Abbey as there is documentary evidence for Cistercian monks utilising mountain pastures for grazing sheep.

Analysis of the pollen record in lake sediments and ^{210}Pb dating has indicated that loss of heather moorland began several hundred years ago in some parts of Wales (Stevenson & Thompson 1993), but few of the sampled lakes were situated in catchments with significant cover of blanket mire.

2.1.1 Other Palaeoecological Research from Mynydd Llangatwg

A pilot study conducted by Chambers & Mauquoy (1998) and commissioned by the Countryside Council for Wales (CCW) provided a preliminary interpretation of the recent human impact on blanket mire vegetation, and an appraisal of the methodology adopted. The study was based on three sites in Wales. These were Mynydd Llangatwg and Hirwaun Common in South Wales, and Elenydd (Drygarn Fawr) in mid-Wales. The study used the palaeoecological and palaeoenvironmental techniques of plant macrofossil analysis or pollen analysis, charcoal analysis, spheroidal carbonaceous particle (SCP) analysis and radiocarbon dating.

At Mynydd Llangatwg two monoliths were examined. The first, MLA-S, contained abundant macroremains of *Sphagnum*, but was topped by living *Calluna vulgaris*. Concerns in the field that the contemporary *Calluna vulgaris* dominated vegetation may have slumped onto a previously eroded surface, and so possibly had sealed a hiatus in peat accumulation, led to a second monolith, MLA-E, from intact peat (5 m behind) being taken. The second monolith came from an area where *Calluna vulgaris, Eriophorum vaginatum* and *Molinia caerulea* ,were growing. Radiocarbon dating confirmed the earlier suspicions of a hiatus which may have been due to erosion and removal of *Eriophorum vaginatum*-rich upper layers earlier his century, followed by a slumping of *Calluna vulgaris*, rooted in recent peat, onto the *Sphagnum*-rich layers below where abundant *Sphagnum imbricatum* remains were found (Chambers & Mauquoy 1998).

In monolith MLA-S the top 12 cm of the profile above the hiatus shows an increase in *Eriophorum vaginatum* between 10-12 cm, followed by a substantial local fire between 2-4 cm which is associated with a rise to dominance of Ericales roots and *Calluna vulgaris* wood. The SCP records date the rise to dominance of *Calluna vulgaris* to a time around the 1950-60s. In monolith MLA-E there has been a recent rise in *Molinia caerulea* and some Ericales roots in the top 2 cm of the profile. There is also a decline in *Eriophorum vaginatum* (from 14 cm) and in *Sphagnum* (from 16 cm). Radiocarbon dating at MLA-E suggests that the decline in *Sphagnum* was *cal.* AD 1050-1300, which dates approximately to the so-called Medieval climatic optimum. High charcoal counts coincide with the demise of *Sphagnum,* followed by the rise in *Molinia caerulea*. The SCP rise that Rose (1994) correlates to the 1950-60s in Britain occurs around 5-7 cm, hence the rise to dominance of *Molinia caerulea* took place some time after this. However, Chambers & Mauquoy (1998) suggest that that the major rise in SCPs at Mynydd Llangatwg may relate not to the twentieth century, but to earlier parts of the industrial revolution as for South Wales sites there was a longevity and intensity of the Industrial revolution.

The other sites studied by Chambers & Mauquoy (1998) included Hirwaun Common, South Wales, which is presently dominated by *Molinia caerulea.* Here the pollen profile exhibits a recent (in top 5 cm) rise in Gramineae and decline in Ericaceae, Sphagnum and Cyperaceae that coincides with a rise in charcoal. Chambers & Mauquoy (1998) suggest that from the SCP records the Gramineae rise, which cannot be confirmed to be *Molinia caerulea* in the absence of macrofossil records, has been since the start of the industrial revolution. The last site they studied was Elynydd (Drygarn Fawr) where the macrofossil record reveals a recent rise in *Molinia caerulea* (top 10 cm of the profile) and which is not associated with a charcoal peak. Ericales roots and *Eriophorum vaginatum* also decline towards the top of the profile and *Sphagnum* records are absent from the top 35 cm to the surface. From radiocarbon dating Chambers & Mauquoy (1998) suggest that the rise in *Molinia caerulea* has taken place relatively recently, almost certainly since the end of the 17th century AD and quite possibly all within the 20th century.

2.1.2 Blanket Mire Vegetation Degradation Elsewhere in Britain and Europe

The phenomenon of recent changes in mire vegetation is not only limited to Wales but extends geographically across Britain and Europe. Stevenson & Thompson (1993) examined the *Calluna vulgaris*/Gramineae ratio owing to concerns over the loss of Heather in upland Britain and Ireland and concluded this has been occurring over the last 1-4 millennia but most rapidly in the last 150-200 years. Todd (1995) claims that in some Environmentally Sensitive Areas Molinietum is believed to have ousted Callunetum in recent decades. Chambers *et al.* (1999) reported a recent rise to dominance of *Molinia caerulea* at Exmoor and Damblon (1992) at sites in Belgium. Studies on heathland have included Gimmingham & Smidt (1983) and Hiel & Diemont (1983) who demonstrate the decline in heather and replacement of grasses in The Netherlands.

On blanket mires, vegetation changes in South Wales, and in particular the dominance of *Molinia caerulea,* show similarities with upland landscapes in south west England and west Scotland (Ward *et al.* 1972, McVean & Ratcliffe 1962 and Birse & Robertson 1976 *cit.* Yeo 1997). There has been particular interest on the southern Pennines, for example Tallis (1997) and Lee (1988) but the extent of *Molinia caerulea* dominance appears to be unparalleled elsewhere in Britain (Yeo 1997)

2.2.Possible Causes of Blanket Mire Vegetation Degradation in Wales

Yeo (1997), amongst other authors outlined the possible causes of blanket mire vegetation degradation and these are reviewed in a series of themes below, including grazing, burning, atmospheric pollution and climate change.

2.2.1 Grazing

In Wales almost all blanket mire is utilised as rough grazing for domestic livestock. The types of livestock and intensity of grazing in the Welsh uplands have changed considerably over the past few hundred years (Hester 1996 *cit.* Yeo 1997). Since the Medieval period there has been a gradual shift from grazing by a mixture of animals, including sheep, cattle, horses and goats, to an agricultural system based almost exclusively on sheep rearing (Yeo 1997). Between the late 19th century and the mid 20th century, sheep numbers in Wales fluctuated but showed an overall upward trend (Williams 1985 *cit.* Yeo 1997). Since the 1950s, sheep numbers have continued to rise, particularly since the introduction of the hill livestock compensatory allowances and ewe premiums in the late 1970s (Williams 1985, Thompson *et al.* 1995 and Fuller 1998 *cit.* Yeo 1997, Stevenson & Thompson 1993). Yeo (1997) reports that the impact of increased sheep numbers has been exacerbated by the gradual loss of rough grazing land, and by changes in stock management practices, such as the demise of shepherding and the increased use of supplementary feeding.

Grazing intensity and its impact on vegetation change has been studied by a number of authors on mire and moorland habitats. On blanket mire communities, Hughes *et al.* (1973) suggested from historical documents that low grazing intensities (*c.* 0.6 ewes ha^{-1}) reported from North Wales in the mid-late medieval period may have been sufficient to reduce *Calluna vulgaris* owing to Cistercian monastery influences. Yeo (1997) claims experimental work in Scotland and Northern England has demonstrated that blanket bog and wet heath have a very low stock carrying capacity, and that grazing at levels in excess of 0.5^{-1} ewes ha^{-1} are likely to induce changes in both vegetation structure and floralistic composition. Grant *et al.* (1985) conducted experimental research into the response of blanket bog vegetation under grazing pressure, and revealed that a stocking density >1ewe ha^{-1} induced floralistic changes and that, with increased stocking rates, there was a reduction in heather. Research on moorlands includes that of Bargett *et al.* (1995) who concluded from their moorland survey that 43% of heather was suppressed in Wales (<25% cover) and 38% showed signs of over-grazing by sheep and management neglect. They suggest that grazing pressure greater than 1.5 ewes ha^{-1} induced heather suppression. According to Stevenson & Thompson's (1993) review covering upland Britain and Ireland, there have been considerable shifts of heather moorland to grassland during the last 1-4 millennia, particularly in the last 150-200 years. These dates were established from ^{210}Pb dating using the CRS dating model. Their study concluded the vegetation shift was a result of increasing grazing pressures and prolonged burning.

The sequence of vegetation changes associated with grazing are well documented for moorland. Ratcliff's (1959) classic paper on the Carneddau, North Wales was one of the first detailed accounts of a change from *Calluna vulgaris* dominance to replacement by grasses owing to pressure from sheep grazing Thompson *et al.* (1995) suggest a typical sequence of vegetation change under chronic grazing can replace heather domination with graminoids such as *Molinia caerulea, Nardus stricta, Eriophorum vaginatum* and *Scirpus cespitosus* such that eventually these become dominant. Other studies of grazing relating to moorland include Anderson & Yaldon (1981), Welch (1984 & 1986) and Hobbs & Gimmingham (1987). Tallis (1964) *cit.* Stevenson &Thompson (1993) showed the dominance of *Eriophorum vaginatum* in blanket mires on the southern Pennines was at the expense of dwarf shrubs as a result of intense grazing and burning *c.* 500 BP (^{210}Pb date).

A number of factors need to be considered which may lead to vegetation changes under grazing. It is generally accepted that the intensity and extent of vegetation damage varies according to the stocking rates, wetness and condition of the site, species of grazing animal, time of year and length of time on the site (Shaw *et al.* 1996). High stocking rates tend to lead to the replacement of grazing sensitive plants, in particular *Calluna vulgaris* and other ericoids, by species such as *Eriophorum vaginatum* and *Molinia caerulea.* Yeo (1997) also notes that sustained high sheep numbers on many Welsh moorlands are likely to have contributed substantially to the spread of *Eriophorum vaginatum* mire, *Molinia caerulea-Potentilla spp.* grassland and allied communities on blanket peat.

Direct effects of grazing can reduce competitive vigour or kill plants through defoliation or direct damage. Grazing can have a profound effect on species composition, (e.g. tussocks of species more tolerant of grazing, such as *Molinia caerulea* and *Eriophorum vaginatum,* or species less palatable are likely to become more prominent). Sphagna are particularly susceptible to trampling, and microtopographical changes may occur, especially the reduction of hummock-forming species such as *Sphagnum papillosum* (Shaw *et al.* 1996).

The type of grazer can effect different changes in vegetation. Grant *et al.* (1987) *cit.* Shaw *et al.* (1996) compared cattle and sheep diets on a blanket bog. This revealed that sheep diets were slightly more variable but there were many components that were selected or avoided in common by sheep and cattle. Species avoided by sheep and cattle included *Calluna vulgaris, Erica spp.* and *Empetrum nigrum*; these were mainly eaten outside the main growing season when the preferred species were less available. The preferred species included *Molinia caerulea* and other grasses, *Carex spp.* and *Scirpus cespitosus.* They suggest cattle would be best suited to wet areas, at least in summer, for example where large areas of *Molinia caerulea* and *Calluna vulgaris* occur together. Sheep tend to prefer the more palatable grasses and young heather. On blanket bog, *Calluna vulgaris* and *Eriophroum vaginatum* form the main part of the diet in winter, while *Scirpus* spp. and *Molinia caerulea* are preferred in early summer. They also showed that the superior feeding value of blanket bog (*Calluna vulgaris-Eriophorum spp.-Scirpus* spp.) vegetation over virtually pure stands of heather is due to the contribution of the various grasses and sedges to the diet.

In general on blanket bogs, grazing selectively is likely to be more evident at low stocking densities (Shaw *et al.* 1996), which can increase *Calluna vulgaris* cover and shoot production (Rawes & Williams 1973 *cit.* Shaw *et al.* 1996, Hobbs & Gimmingham 1987). A reduction in grazing can thus help the recovery of stands of badly degraded *Calluna vulgaris,* e.g. Merrell *et al.* (1993) *cit. Shaw et al.* (1996). The period of grazing can influence the effect, and land may be understocked in summer and overstocked in winter when there is a year-round fixed stocking density (Lance 1983 *cit.* Shaw *et al.* 1996).

Another effect of grazing on the vegetation is the supply of nutrients from faeces, urine or supplementary animal feeds. Berendse *et al.* (1994) state the supply of nitrogen and other plant nutrients is one of the most important environmental factors determining the dynamics of species composition in many ecosystems. Increased nutrient solution application on heathland ecosystems in The Netherlands, one *Calluna vulgaris* dominated and the other *Molinia caerulea* dominated, caused *Calluna vulgaris* to decline and grass species to increase sharply (Berendse *et al.* 1994). This contradicted research by Aerts *et al.* (1990) who found on heathland *Calluna vulgaris* could out-compete *Molinia caerulea* if the *Calluna vulgaris* was sufficiently tall before nutrient enrichment.

On blanket mires Shaw *et al.* (1996) state increased nutrients could give a competitive advantage to faster growing graminoids and may shift the mire from ombrotrophic to mesotrophic, although such effects are likely to be localised. Harrison (1985) and Marrs *et al.* (1989) *cit.* Shaw *et al.* (1996) claim there is a long-term loss of nutrients from the mire as they are either locked up in the peat or leave the system in the animals. However, Rawes & Heal (1979) *cit.* Shaw *et al.* (1996) concluded there was little or no net income or loss of nutrients from blanket bog under grazing as the main transfers were by water.

Other forms of pollution may have severe but localised impacts. For example, Slater (1984) *cit.* Yeo (1997) attributed enhanced *Sphagnum recurvum* at Figyn Blaen Brefi, mid Wales to fertiliser contamination from adjacent conifer plantations. Such localised effects may also be expected with supplementary feeding and defecation of grazing animals.

2.2.2 Burning

In Wales burning is typically carried out either in large swathes to provide better foraging for livestock or in small patches for the benefit of grouse which only continues in small areas today. Additionally, uncontrolled accidental burning occurs sporadically and this may have especially severe consequences for the vegetation cover (Yeo 1997). Although no detailed fire histories are available, charcoal particles have been found throughout peat profiles at several localities in Wales, indicating a long history of fire management. For example, Chambers (1982), Wiltshire & Moore (1983), Mighall & Chambers (1995) *cit.* Yeo (1997) and Chambers & Mauquoy (1998).

An extensive amount of the literature on burning and its effects on vegetation relate to heathland rather than mire habitats probably as burning has formed an integral part of traditional heathland management for centuries, for example, Hobbs and Gimmingham (1987). Unless otherwise stated, the following review is of the effects of burning on blanket mire. The effects of burning on the vegetation will depend on the vegetation composition, intensity and frequency of the fire, time of burning and wetness of the substratum (Shaw *et al.* 1996). These are explored in the following paragraphs.

According to Yeo, (1997) vegetation changes associated with frequent burning and/or severe intensity burns, especially in combination with high stocking densities, cause loss of dwarf shrubs, damage to *Sphagnum* carpets, and drying out of the peat blanket, and typically encourage the development of species-poor swards dominated by *Molinia caerulea* or *Eriophorum vaginatum.*

Fire can rejuvenate heather as it increases the nutritional value for grazers by stimulating new growth especially if burning younger heather. A very hot fire and/or heather in a degenerate phase may have a slower regeneration, as prolonged burning reduces *Calluna vulgaris* root stock and prevents seed bank regeneration or may be completely killed (Shaw *et al.* 1996).

Burning can also induce other changes in species composition. For example, tussocks of species more tolerant of burning, such as *Molinia caerulea* and *Eriophroum*, are likely to become more prominent. However, such changes may represent a temporary phase, depending on the frequency of the burning (Shaw *et al.* 1996). Other authors report on *Molinia caerulea's* resistance to burning in moorlands (Damblon 1992, Grant *et al.* 1996)

The pre-fire vegetation composition may also be important and Hobbs (1984) *cit.* Shaw *et al.* (1996), in a study on blanket bog at Moor House, Pennines found that variations in post-fire species abundance were related to pre-fire stand composition. Usually species regeneration is of those species *in situ* before the fire; however, seedlings of *Calluna vulgaris* and *Erica tetralix* may occur.

The rotation of burning is also important in vegetation changes. In addition to the above, Hobbs (1984) *cit.* Shaw *et al.* (1996) found that a short rotation burn (every 10 years) resulted in an increased dominance of *Eriophorum spp.*, while a longer rotation (every 20 years) resulted in a greater abundance of *Calluna vulgaris.* A similar effect was found in *Molinia caerulea*-dominated communities as *Molinia caerulea* is well adapted to withstand fire, owing to buried tiller buds (for example, Curall (1981) *cit.* Hobbs & Gimmingham (1987), Grant *et al.* 1963). Hobbs & Gimmingham (1987) suggest that a burning rotation of 7-20 years in heathland can be beneficial to heather, and *Calluna vulgaris* can regain dominance after only 1-2 growing seasons in well managed dry heath. However, they stress that such frequent burning may not be beneficial to wetter heaths as this may shift the dominance from *Calluna vulgaris* to graminaceous species. The effect on vegetation is also affected by the time of burning and wetness of the substratum. In winter the effect of vegetation burning is less severe as the substratum is wet (Shaw *et al.* 1996).

The physical effects of burning include the following. Ignition of peat waxes during very intense fires can lead to the formation of a tarry bitumen hard crust which may prevent recolonisation of some plants and impede infiltration of water (Shaw *et al.* 1996). Mallik *et al.* (1984) also came to similar conclusions. Removal of a protective vegetation layer also leaves the surface prone to erosion by wind, water, and moisture loss by heat and freeze/thaw processes (Shaw *et al.* 1996). Burning can release nutrients in the smoke and ash, some of which may enter the substratum, but there is potential for loss through leaching, runoff or in the smoke (Hobbs & Gimmingham 1987).

2.2.3 Atmospheric Pollution

Acid deposition can cause pollution from high levels of atmospheric sulphur and/or nitrogen. Since the 1950s, sulphur levels have dropped and current concerns are focused on high levels of atmospheric nitrogen deposition (Yeo 1997, Press *et al.* 1986, Lee *et al.* 1988). Evidence from ice cores and historical data demonstrate a marked 2-3 fold increase in nitrate deposition in the Northern Hemisphere this century (Lee *et al.* 1992). A number of studies have focused on acid deposition and its effects on mire vegetation in the southern Pennines. For example, Lee *et al.*

(1988) used historical and experimental research and concluded pollution caused by high levels of atmospheric sulphur and nitrogen had drastically affected vegetation, notably destroying *Sphagnum spp.* cover from large areas of blanket mire in the nineteenth and twentieth centuries.

Evidence for similar impacts on Welsh peatlands is more tenuous (Yeo 1997). Fritz *et al.* (1990) used palaeolimnological reconstruction of lake pH of upland lakes in north and mid Wales by diatom analysis. This revealed the acidification of Welsh lakes began as early as the 19th century, and this may have affected terrestrial ecosystems such as blanket mires. Chambers *et al.* (1979) investigated upland peats from two localities in South Wales, close to industrial valleys of Rhondda and Merthyr, that are now dominated by *Molinia caerulea*. From pollen analysis they tentatively posed the question that the increased acid deposition after the onset of the industrial revolution may have contributed to the loss of heather and increase in grasses as surface deposits were heavily contaminated with soot. However, the vegetation changes may also be explained by the intensification of agricultural practices. They radiocarbon dated (uncalibrated) the transition to be after the onset of the industrial revolution. However, Stevenson & Thompson (1993) consider that this may have missed earlier reductions in heather and incorrectly attributed the onset, rather than the exacerbation of the decline, to atmospheric pollution. They conclude from their palaeoecological study on moorland that the heather decline and increase in grasses is due to grazing and burning.

Nitrogen does not always have a fertilising effects on plants, and this is particularly true for bryophytes. Press *et al.* (1986) found NO_2 concentrations in the southern Pennines to be almost double those measured in north Wales. The former experienced inhibited *Sphagnum cuspidatum* growth, induced by elevated nitrogen levels, which resulted in an accumulation of nitrogen in the tissue. From laboratory experiments they also state that only a relatively small increase in nitrogen deposition reduces the growth of *Sphagnum cuspidatum* and hence this may be sufficient to bring about significant changes. Woodin *et al.* (1991) *cit.* Woodin & Farmer (1993) also found from experimental work on blanket mire at Migneint, North Wales that a small increase in nitrogen deposition reduced the growth of *Sphagnum*. They also suggested that in central Wales some peatlands had experienced *Sphagnum* deterioration. Their experimental research, measuring the tissue nitrogen in *Sphagnum cuspidatum* and *Sphagnum capillifolium*, demonstrated a positive correlation between altitude and nitrogen deposition. Thus vegetation in the upland peatlands of Wales are exposed to greater rates of atmospheric nitrogen deposition than suggested by deposition maps (Woodin & Farmer 1993). Based on the above research it may be expected that mires in South Wales, like the southern Pennines, may be more greatly affected as they have been potentially more polluted owing to their close proximity to large urban and industrial centres, especially since the mid-nineteenth century and the onset of the industrial revolution.

There are conflicting views on nitrogen deposition inhibiting *Calluna vulgaris* growth or encouraging grasses such as *Molinia caerulea*. Lee *et al.* (1992) state that, as yet, there is no convincing evidence for this on upland moorlands in Britain. Stevenson & Thompson (1993) claim that the moorland *Calluna vulgaris* decline across upland Britain and Ireland occurs at many sites well before emissions from large-scale industrialisation and particularly in areas of low sulphate and nitrate deposition. Other authors, such as Heil & Diemont (1983), Berendse & Aerts (1984) and Heil & Bruggink (1987) have shown via field experiments involving fertiliser applications that nitrate deposition may enhance conditions for succession from *Calluna vulgaris* to *Molinia caerulea* on heathland in The Netherlands. Roelofs (1986) attributed the change from heather into grass dominated heathland to the high atmospheric nitrogen enrichment in The Netherlands. Pitcairn *et al.* (1995) suggest atmospheric nitrogen may be responsible for a decline in *Calluna vulgaris* in Breckland heaths and exacerbating long term-loss of bryophytes in Cumbria. *Eriophorum vaginatum* was not adversely affected by levels of sulphur dioxide (*c.* 300μg m^{-3}) which had inhibited *Sphagnum* growth (Crittenden 1975 *cit.* Lee *et al.* 1988). However, there appears to be a lack of studies into the effects of atmospheric pollution on *Calluna vulgaris* and grasses in Britain and on mire habitats.

2.2.3.1 The Industrial History of the Lower Swansea Valley

The nearest region of industrial activity to Mynydd Llangatwg is the Lower Swansea Valley. Jones et al. (1991) reported long distance aerial transportation of heavy metals from the Swansea region to Llangorse Lake. This site is situated to the north-west of Mynydd Llangatwg so long distance transportation of pollution could be expected at Mynydd Llangatwg. The Lower Swansea Valley was essentially an agricultural area until the end of the Medieval period. From the sixteenth century there was small-scale domestic use of coal and smelting of copper iron and lead (Keen 1995). There was massive industrial growth in the second half of the eighteenth century through to the end of the nineteenth century in South Wales as coal became an important industrial fuel, a main feature being the coal-based iron industry on the north-eastern rim of the South Wales coalfield. During this period other metallurgical industries such as copper and tinplate manufacture also expanded (Rosen 1998). The industrial decline began after the first world war when traditional industries began to experience recession, the demand for coal decreased from the late 1950s as new fossil fuels were introduced (Rosen & Dumayne-Peaty 2001). During the post-World War II period there was industrial diversification in South Wales with light manufacturing and service industries (Keen 1995). Rosen (1998) found from her study on the recent industrial impact on the environment of South Wales that the patterns of SCP accumulation do not correspond to any of the depositional regions defined by Rose (1995) and that considerable variations in SCP accumulation within South Wales presumably reflects the diversity of past industrial activity. The SCP appearance at Crymlyn Bog and Kenfig Pool were in the mid to late nineteenth century, at a similar time to those observed elsewhere in Britain by Rose (1995). Earlier dates were ascribed at Ffoston Cenglau (*c.* AD 1757) and at Llanllwch Bog (*c.* AD 1750). At Ffoston Cenglau she attributed this to coal-based iron working at Hirwaun. The 1950-60s peak, attributed to the establishment of coal-based power stations, was evident at her sites and at Crymlyn Bog the date was earlier due to local fossil fuel works. Additional peaks were found at a time of around the 1930s at Kenfig Pool and Ffoston

Cenglau, these were attributed to regional tinplate and steel production. The 1970s SCP decline was apparent at Crymlyn Bog, Kenfig Pool and Ffoston Cenglau, but not at Llanllwch Bog, where perhaps local industrial output expanded steadily during the early twentieth century.

2.2.4 Climate Change

Increased attention has been paid recently to the importance of blanket peats as proxy records of climate change, for example, Blackford (1990), Blackford and Chambers (1991), Chambers *et al.* (1997), Mauquoy (1997), Mauquoy and Barber (1999) and Barber *et al.* (1999). Yeo (1997) notes there have been few studies on Welsh mires to reconstruct past climates, although Blackford and Chambers (1991) used peat humification and Tallis (1995) plant macrofossil remains. Yeo (1997) claims the evidence is highly suggestive of a close correlation between climatic fluctuations over the last millennium and the vegetation composition of blanket bog vegetation. However, he stated careful interpretation is required to distinguish between natural and anthropogenic-induced climate change.

Warmer and or drier conditions may lead blanket bog vegetation conversion to dry heathland vegetation (Bargett *et al.* 1995). If future climate change does lead to warmer, drier conditions, blanket mires at the fringes of its British distribution, including comparatively low rainfall zones of south and east Wales, may be vulnerable to even quite small increases in temperature (Yeo 1997).

Drier climates may lead to a decline in *Sphagnum*. For example, Tallis (1995) found on Berwyn, Wales, that a documented dry phase between *c.* AD 1150 and 1300 corresponded with a demise of Sphagna in the macrofossil record, indicating the mire had desiccated. The demise of *Sphagnum imbricatum* is a common feature of macrofossil assemblages from mires across British and has been studied by many authors. Mauquoy & Barber (1999) used plant macrofossil, peat humification and testate amoebae analyses on a number of sites in northern England and the Scottish Borders and found some evidence that the demise of *Sphagnum imbricatum* is associated to climatic deterioration and wetter mire conditions, although at one site it may have been due to interspecific competition between *Sphagnum* species. *Sphagnum imbricatum* has a wide tolerance to different water levels but the authors suggest it may have not been able to change ‘rapidly’ enough under both climate change and species competition.

A geographical trend in the extent of degradation of Welsh blanket mires in terms of the abundance of *Molinia caerulea* has been noted by Yeo (1997). A clear contrast is found between North-central and South-central Wales, with the latter supporting greater quantities of *Molinia caerulea.* He makes a tentative explanation based on climatic variations, as this is the only differing environmental characteristic in an absence of detailed historical management data (other factors included geology, altitude, precipitation, grazing and burning regimes and nitrogen and sulphur deposition and were broadly similar). Multivariate statistical analysis confirmed that temperature was significantly correlated with vegetation between these two groups of sites. It is possible that the slightly warmer climate in the South Wales uplands has favoured the spread of *Molinia caerulea* at quite high elevations, when over most of Britain *Molinia caerulea* rarely extends far into the uplands. In contrast *Eriophorum vaginatum* is highly characteristic of cold climates at moderate to high altitudes (Rodwell 1991 *cit.* Yeo 1997).

2.2.5 Other Causes

2.2.5.1 Direct impacts

Other causes of blanket mire degradation can be direct anthropogenic impacts (e.g. such as afforestation, construction of reservoirs, recreational pressure) and natural erosion. However, these impacts are localised.

2.2.5.2 Drainage

Drainage is another important cause of mire degradation and is often linked to peat cutting. Extensive networks of drainage ditches are a feature of many Welsh blanket mires, but little research has taken place on associated vegetation changes (Yeo 1997). Stewart & Lance (1983) *cit.* Yeo (1997) reviewed evidence from England and Scotland and concluded 'moor grips' (drainage networks) generally have a limited impact on mire hydrology and vegetation, but are likely to have exacerbated the effects of grazing and burning. However, Ardron *et al.* (1997) reviewed drainage in the southern Pennines blanket mires and suggest that extensive drainage networks are likely to have significantly affected the hydrology and thereby reduced the abundance of *Sphagnum.* Drying out of the mire may also lead to erosion by wind and water.

2.2.5.3 Peat Cutting

Peat cutting in Wales has been localised and small-scale as the majority of blanket mires occur in relatively remote and inaccessible upland regions (Yeo 1997). Yeo (1997) also states that the ecological impact is difficult to establish in Wales, but may have been considerable locally, *Sphagnum*-rich communities having become established in abandoned peat cuttings on many sites. However, Ardron's *et al.'s* (1997) review of peat cutting in the southern Pennines blanket mires stated many cut-over areas are now dominated by *Nardus stricta and Molinia caerulea* communities, which occur contiguously with the *Calluna vulgaris-Eriophorum vaginatum* bog on the intact blanket mire.

2.2.5.4 Burning and Grazing Combined

All of the possible causes of blanket mire degradation may work in combination so as to make disentangling cause and effect difficult especially when conservation measures are the long-term objective. The interactions between grazing and burning are considered here. Shaw *et al.* (1996) recognise that there have been studies on this relationship on moorland, for example, Hobbs & Gimmingham (1987), but there have been no direct studies on blanket bog. However, there is some anecdotal evidence.

Bunce (1989) *cit.* Shaw *et al.* (1995) states that burning and grazing have led to the removal of heather from extensive areas of blanket bog in Wales. Shaw *et al.* (1996) also notes that many Welsh examples of blanket bog are subject to severe gully erosion attributed to grazing and burning which dry the mire surface and result in a loss of *Sphagnum* cover.

Grazing after burning can affect the vegetation. For example, Rawes & Welch (1969) *cit.* Shaw (1995) noted that under free-grazing regimes, the early flush from *Eriophorum spp.* resulting from a winter fire attracts sheep, and that densities of 0.33 ewes ha^{-1} can be maintained. Limited grazing on blanket bogs retards, but does not prevent heather regeneration after fire, and *Eriophorum vaginatum* may become temporarily dominant (Lance 1983 *cit.* Shaw *et al.* 1996). Other studies, such as Chapman & Rose's (1991) *cit.* Shaw *et al.* (1996) on Coom Rigg Moss bog, northern England, suggest a lack of low-level grazing and autumn burning may have contributed to the decline of *Sphagnum* abundance, perhaps through the accumulation of standing dead material from grass and sedge species.

However, burning and grazing can reinforce and accelerate effects; for example there can be an accelerated *Calluna vulgaris* decline, expansion of grasses and prevention of heather regeneration by sheep grazing (e.g. Ratcliffe 1959). Light grazing alone can produce better *Calluna vulgaris* growth (Shaw *et al.* 1996).

2.2.5.5 No Grazing or Burning

As Shaw *et al.* (1996) note, if blanket bog lies below the tree line, theoretically, a succession back to a climatic climax vegetation of trees and shrubs may occur slowly; hence some blanket mires are semi-natural as a result of anthropogenic influences and management may be necessary. Heather in the uplands is less likely to enter the degenerate phase in a lack of management, particularly when there is a *Sphagnum* carpet as this promotes rejuvenation by layering (Hobbs 1984 *cit.* Shaw *et al.*1995).

Doyle (1982) *cit.* Shaw *et al.* (1996) found in western Ireland blanket bog pools protected from burning and grazing by water, supported more diverse flora (*Juniperus communis, Empetrum* *nigrium* and more graminoids and bryophytes) than the main bog and, additionally, on the islands mature *Calluna vulgaris* and *Molinia caerulea* were more abundant than on the main bog. However, Shaw *et al.* (1996) note there is some evidence that grazing and burning may be important in maintaining blanket bog vegetation.

2.3 Need for Palaeoecological and Palaeoenvironmental Research

Yeo's (1997) preliminary assessment of blanket mire degradation revealed that considerable areas of blanket mire in Wales are currently supporting impoverished vegetation dominated by graminoids, particularly *Molinia caerulea* and *Eriophorum vaginatum*, with reduced amounts of ericaceous and *Sphagnum* species (described in section 2.1). In addition, Yeo (1997) acknowledges that little is known of the factors involved in the spread of *Molinia caerulea* in mid and South Wales, and that detailed investigations of vegetation history would provide valuable information to guide blanket mire conservation in Wales. The main issues that arise from this study are; what were the former vegetational communities, how long has the current vegetational community been in existence and what were the causes of the vegetational changes in Welsh blanket mires.

The pilot project of Chambers & Mauquoy (1998) appraised the palaeoecological and palaeoenvironmental methods used in their preliminary interpretation of recent human impact on Welsh blanket mire vegetation. They suggested that research could be undertaken at existing sites, especially more detailed study at Mynydd Llangatwg. This included additional palaeoecological and palaeoenvironmental techniques such as those to examine the influence of climate on the mire, pollen and macrofossil analysis to be used in moderately humified peats to supplement each other, and a contiguous count of charcoal so as not to miss important fire events.

Mires hold a multi-proxy archive of environmental change and past biodiversity. Peatlands are the *only* plant community to lay down *in situ* a detailed record of their own history and this record considerably enhances the conservation value of peatlands, for it is only by understanding the recent past that we can evaluate fully the present situation (Barber 1993). Straker & Crabtree (1995) also emphasised the need for palaeoenvironmental research for understanding the nature of upland vegetation changes, the response to land-use changes, and therefore, for providing the background for management plans. From a conservation perspective it is particularly important to distinguish between natural changes and those induced by human perturbation (Yeo 1997). He concluded that detailed investigations of vegetation history at a representative range of sites would provide valuable information on the nature and causes of degradation, to guide blanket mire conservation in Wales and inform restoration initiatives for the Countryside Council for Wales.

If the conservation management plans aims to maintain status quo it is essential to know the if the site is undergoing successional change and if the present structure and composition of the site are the result of a particular management practice in the past. If the aims are based on habitat enhancement or ecosystem restoration for conservation purposes it is essential to know what to try and enhance or to restore to the site. These are all areas where detailed palaeoecological studies of the recent past can make valuable and potentially unique contributions to practical conservation problems (Birks 1996). Applied palaeoecological studies of the recent past raises the general questions of ' naturalness' and what is a 'natural system' in a continuously changing environment and Birks (1996) suggests that site specific palaeoecological studies can assist by providing a historical perspective and baseline data.

2.4 Aims and Research Questions

This thesis aims to:

1) To reconstruct a high-resolution vegetational history at Mynydd Llangatwg.

Peatlands are the *only* plant community to lay down *in situ* a detailed record of their own history in the form of macrofossil remains of the plants themselves and in a stratified pollen record. These results provide an archive of past biodiversity and ecological changes. For example, individual species can be used to infer past hydrological conditions and as indicators of grazing and nutrient status of the mire. These records considerably enhance the conservation value of peatlands, for it is only by understanding the recent past that we can evaluate fully the present situation (Barber 1993). A high temporal resolution allows better understanding of ecological succession and causes of recent changes (Damblon 1992). He also acknowledges that restoration and management of semi-natural vegetation can be facilitated by knowledge of the succession of plant communities leading to the present-day vegetation. As Barber (1993) stresses a lot of conservation effort is dominated by neoecology, which most certainly does not express the full conservation value of mire habitats.

2) To elucidate possible causes of blanket mire vegetation degradation.

Also included within the peat record are stratified records of some invertebrates, of wind blown dust, charcoal and magnetic particles, of volcanic ash and of past hydrological conditions on the mire surface (Barber 1993). These records along with the vegetational archive provide a multi-proxy record of past environmental change that can be used to elucidate possible causes of vegetation degradation. For example, the history of fire and a proxy-climate record were established on several Welsh mires from palaeoecological techniques by Chambers & Mauquoy (1998). From a conservation perspective, it is especially important to be able to distinguish blanket mire degradation that has been caused by natural changes and those induced by human perturbation as to guide management prescriptions (Yeo 1997).

3) To assign a temporal framework to the vegetational changes.

Assigning a chronology to the vegetational changes will enable inter-site comparison to dated profiles and may help elucidate possible causal factors in the vegetation changes. As described by

Rose *et al.* (1995) spheroidal carbonaceous particle (SCP) analysis can be used as a indirect method for dating peat sediments and can provide a record of atmospheric fossil fuel pollution deposition (see section 3.3.5).

Although recent developments in palaeoecological philosophy have included a deductive approach to reconstructing past environments (Oldfield 1993 *cit.* Rosen 1998), rigorous hypotheses testing in palaeoecology is not always easy or even possible due to the subjective nature of data obtained (Birks 1995 *cit.* Rosen 1998). As a result, research questions, rather than strict hypotheses, were investigated in this thesis.

i) How has the vegetated landscape of blanket mire at Mynyyd Llangatwg changed ?
ii) What are the possible casual factors of the vegetational changes on blanket mire at Mynydd Llangatwg ?
iii) When did the vegetational changes on blanket mire at Mynydd Llangatwg occur ?
iv) What management prescriptions could be adopted on blanket mire Mynyyd Llangatwg ?

CHAPTER THREE

METHODS

This chapter will explain the choice of sampling sites and fieldwork and palaeoecological and palaeoenvironmental techniques. The laboratory methods used are also described.

3.1 Site Selection

Mynydd Llangatwg was identified as a blanket mire in South Wales supporting impoverished vegetation communities by the Countryside Council for Wales (CCW) based on reports compiled by Yeo (1997). It is largely dominated by impoverished *Molinia caerulea* or *Eriophorum vaginatum* but still retains some patches of *Calluna vulgaris*. Mynydd Llangatwg is an upland plateau, in part comprised of limestone but with a significant area overlain by gritstone, which in some places has apparently collapsed into limestone solution-hollows (Chambers & Mauquoy (1998). Here blanket mire covers an area of *c*. 4 km^2 and is situated at NGR SO 17 15, approximately 12km west of Abergavenny, South Wales. Profile MLM (Mynydd Llangatwg *Molinia* Monolith) was taken from NGR SO 18803 15054 (GPS, +/- 9.8m) at 500m OD and profile MLC (Mynydd Llangatwg *Calluna* Monolith) at NGR SO 17867 15368 (GPS, +/- 9.0m) at 495 m OD. At Mynydd Llangatwg there is some evidence for attempts of drainage, though it is difficult to distinguish man-made drainage channels ('grips') and those of natural origin. There is also evidence of some erosion taking place on the margins of the doline.

Palaeoecological research had already been conducted at Mynydd Llangatwg from two profiles in a pilot project on 'recent human impact on Welsh blanket bogs' by Chambers & Mauquoy (1998) that was commissioned by CCW. This aimed to help determine the former vegetation of degraded peatlands in Wales and help elucidate the factors giving rise to contemporary impoverished vegetational communities. Chambers & Mauquoy (1998) identified a *Calluna vulgaris*-dominated area of the mire with an eroding peat front on the northern perimeter of a doline. Contemporary vegetation was recorded as *Calluna-Eriophorum vaginatum* mire, *Erica tetralix* sub-community (M19a). Floralistic composition was fairly typical of this variant but with Sphagna sparse and *Calluna vulgaris* dominant with *frequent Molinia caerulea, Eriophorum vaginatum, Eriophorum angustifolium* and *Erica tetralix*. Here they chose a sampling site (SO 177153) and two profiles were obtained. The first was MLA-S from the eroding peat front which was topped with *Calluna vulgaris* but abundant in *Sphagnum* macro remains. However, concerns that contemporary *Calluna vulgaris* dominated vegetation had slumped onto a previously eroded surface resulted in another profile being taken. This second profile, MLA-E, was situated 5 m behind the original. Here *Calluna vulgaris, Eriophorum spp.* and *Molinia caerulea* were growing. The stratigraphy of this was different from the first and contained abundant *Eriophorum spp.* remains.

Chambers & Mauquoy (1998) suggested that there was scope to carry out further study at Mynydd Llangatwg including chronicling the recent sequence of vegetation changes, to detect the timing and possible influence of climate and the use of pollen analysis to supplement the macrofossil vegetation changes. Therefore, this project studies a new peat profile from an area supporting impoverished *Molinia caerulea* (MLM) compared to another from a different area still largely dominated by *Calluna vulgaris* (MLC) to ascertain the nature and timing of past vegetation changes and to elucidate factors giving rise to contemporary degraded vegetation communities *via* the palaeoecological techniques described below.

3.2 Field Sampling Strategy

3.2.1 Mynydd Llangatwg *Molinia* (MLM) Monolith

This site is shown in Fig. 3.1

To the east-north-east of MLA-S and MLA-E, NGR SO 177153 (Chambers & Mauquoy1998), by one kilometre a shallow depression containing vegetation locally dominated by *Molinia caerulea*. Here profile MLM (Mynydd Llangatwg *Molinia* Monolith), NGR SO 18803 15054 (GPS, +/- 9.8m), was extracted. The CCW Upland Survey team mapped this area as being species-poor *Molinia caerulea* but in the field the vegetation was not that easy to place within the NVC, as it contained some characteristics of both M20 (*Eriophorum vaginatum* mire) and M17 (*Scirpus cespitosus* [syn. *Trichophorum cespitosus*] - *Eriophorum vaginatum* blanket mire) (P.Jones, pers. com. 1999).

Field Vegetation Survey (CCW, Dr. P. Jones, 13 /10/1999):

Vegetation was sampled from a measured area of 2 x 2 m placed within 5 m of the sampling site. Percentage cover was assessed on a 10-point Dominance (Do) scale, and height range (Ht.) of major structural components was assessed. Presence of species within four representative stands of *c.* 2 x 2 m (not measured) adjacent to the quadrat was also assessed (Const.) and abundance within overall stand (*c.* 25 x 25m) was estimated using the DAFOR scale (Dominant, Abundant, Frequent, Occasional, Rare). NR = not recorded.

Table 1 MLM Vegetation Survey

Species	Do.	Ht.	Const.	DAFOR
Eriophorum vaginatum	8	20-40	4/4	D
Molinia caerulea	5	20-25-(40)	4/4	A
Scirpus cespitosus	3	-	3/4	0-F
Eriophorum angustifolium	3	-	4/4	F
Juncus squarrosus	3	-	4/4	O
Sphagnum cuspidatum	4	3-5	4/4	A
Polytrichum commune	3	-	2/4	F
Campylopus (?introflexus)	1	-	1/4	O
Bare peat	2%	-	NR	F

Species noted within stand but not in quadrat

Empetrum nigrum ssp. nigrum	-	-	1/4	R
Vaccinium myrtillus	-	-	1/4	R

At the time of sampling the water table ranged from +4 to 0 to -4 across surface of the quadrat. Open water was present over *c.* 2% of quadrat. Sheep droppings were also present. (Source Dr. P. Jones, CCW, pers. com.)

3.2.2 Mynydd Llangatwg *Calluna* (MLC) Monolith

This site is shown in Fig. 3.1

Fifteen to twenty to the north of MLA-E & MLA-S one kilometre south-west of MLM an area of *Calluna vulgaris*-dominated vegetation existed from which profile MLC (Mynydd Llangatwg *Calluna* Monolith), NGR SO 17867 15368 (GPS, +/- 9.0m), was extracted. The vegetation was recorded as impoverished M19a: *Calluna vulgaris - Eriophorum vaginatum* blanket mire, *Erica tetralix* sub - community, (P.Jones, pers. com. 1999).

Field Vegetation Survey (CCW, Dr. P. Jones 13/10/1999):

The vegetation was sampled as described in section 3.2.1.

Table 2 MLC Vegetation Survey

Species	Do.	Ht.	Const.	DAFOR
Calluna vulgaris	8	20-25 (40)	4/4	D
Eriophorum vaginatum	4	20-25	4/4	A
Eriophorum angustifolium	4	-	4/4	A
Erica tetralix	1	-	0/4	R
Cladonia (?portentosa)	3	-	4/4	F
Sphagnum subnitens	3	-	2/4	O
Sphagnum fimbriatum3	to 7.0	-	2/4	O
Sphagnum cuspidatum	2	-	1/4	R
Campylopus (?introflexus)	2	-	-	R?
Calypogeia fissa	2	-	-	O?
Cephalozia spp.	2	-	-	O?
Polytrichum commune	1	-	1/4	O
Bare peat	5	-	N/R	-

Species noted within stand but not in quadrat

Juncus squarrosus	-	-	1/4	R

Vaccinium myrtillus	-	-	1/4	R
Sphagnum papillosum	-	-	1/4	R
Dicranum scoparium	-	-	1/4	0

At the time of sampling some wet peaty depressions were noted nearby, some water filled. *Sphagnum* was absent from the sampling location; however, three clumps of *Sphagnum subnitens* and one of *Sphagnum fimbriatum* and *Sphagnum cuspidatum* were noted within the quadrat. Cover of bare peat was only noted when top canopy of vegetation parted, not so obvious otherwise. The water table was *c.* 4cm below the peat surface. (Source Dr. P. Jones, CCW, pers. com.)

At each locality a monolith tin of 50 cm x 10 cm x 10 cm was used for extraction of the peat. Firstly, peat was cut away using a specially designed peat cutter and a spade to leave behind a vertical peat face of greater than 50 cm depth; then an open-ended aluminium monolith tin was inserted vertically into the top 50 cm and finally cut away using the peat cutter. As the most recent vegetation changes were to be established in this project a 50 cm monolith was sufficient to record these.

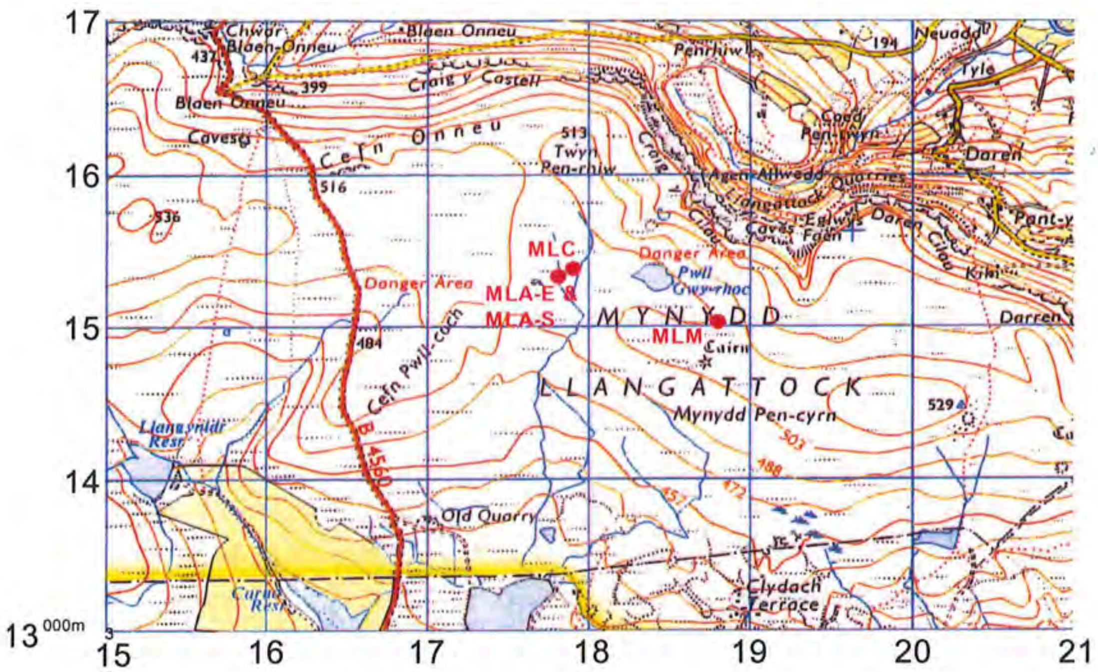

Fig. 3.1 Map showing Mynydd Llangatwg locality
(Figure reproduced from the Ordnance Survey 1:50,000
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3.3 Selection of Methods and Laboratory Procedures

In profile MLC, the top 4 cm was fresh *Calluna vulgaris* vegetation and so was not analysed. Therefore 4 cm represents the most recent peat surface. In profile MLM analyses were made to a depth of 55 cm as an extra 5 cm of peat came away in extraction.

3.3.1 Plant Macrofossil Analysis

Plant macrofossils can be defined as all plant remains (leaves, rhizomes, stems, fruits, seeds, wood remains and bryophytes) that can be recognised by the naked eye or with the aid of a strong lens (Berglund 1986). The identification and quantification of plant macrofossils are used to reconstruct former blanket mire vegetation assemblages at Mynydd Llangatwg to determine how the current vegetation developed and infer past climatic and anthropogenic influences via species preference to different micro-habitat conditions.

Birks & Birks (1980) acknowledge plant macrofossil analysis has a number of advantages in comparison with pollen analysis. Firstly macrofossils were once part of a living plant rather than just the reproductive stage of its life cycle and, therefore, are usually identifiable to species level so that ecological inferences are relatively precise. This is particularly important for identifying *Molinia caerulea* of which the epidermal tissue is very distinctive but which pollen analysis could not detect owing to poor taxonomic separation of graminaceous species (Chambers *et al.* 1999). Secondly, macrofossils are not transported far from the point of their origin so indicate the local presence of a species.

To provide a high-resolution reconstruction of vegetation history, identification and quantification of plant macrofossils was undertaken at 1 cm intervals. The semi-quantitative Quadrat and Leaf Count Macrofossil Analysis Technique (QLCMA), developed by Haslam (1987) and Clark (1988) was employed. This experimental methodology had been adopted by many authors such as Stoneman (1993), Barber *et al.* (1994, 1998) and Mauquoy & Barber (1999) principally for raised mires as it was previously perceived that blanket mires were too highly humified for palaeoecological reconstruction using plant macrofossils. However, this misconception has been overturned by successful studies on blanket mires such as Chambers and Mauquoy (1998), Mc Tiernann *et al.* (1998) and Barber *et al.* (1999). The adoption of this methodology allows for direct comparison with the literature.

The samples measuring 1 cm x 1 cm x 4 cm were cut from each 1 cm level with a surgical scalpel. The samples were then washed through a 125 μm sieve using a high pressure jet of water obtained through a plastic pipe attached to a tap. This removed the finer highly humified particles and disaggregated the sample. The plant macrofossils retained in the 125 μm sieve were placed into a glass petri dish and sufficient distilled water was added to create a monolayer and that was examined at x10 magnification using a Meiji EMZ -TR stereozoom microscope. The abundance of peat components such as unidentified organic matter (U.O.M), identifiable *Sphagnum,* identifiable monocotyledon epidermal tissue, monocotyledon undifferentiated, monocotyledon roots, *Eriophorum vaginatum* roots, ericaceous roots or other identifiable peat components were estimated using 10 averaged quadrats of a 10 x 10 square-grid graticule. Where a component covered more than half of one square on the graticule square-grid a score of 1% was assigned.

Inidentifiable monocotyledon epidermal tissues visible in the petri dish were removed using watchmaker's forceps and mounted on a slide using aquamount and examined at x100 and x400 magnification using a Nikon labophot microscope to identify the taxa present. Where more than one taxon was present, each taxon was expressed as a percentages of the identifiable monocotyledon epidermal tissue and if the tissue could not be identified, particularly when made up of rhizome material, it was classified under monocotyledon undifferentiated. If *Sphagnum* leaves were found in the petri dish a random selection of 100 leaves were removed and identified to the lowest taxonomic level at x 400 magnification using a Nikon labophot microscope and expressed as percentages of the total identifiable *Sphagnum. Eriophorum vaginatum* spindles, *Calluna vulgaris* leaves, seeds and flower heads, *Erica tetralix* leaves or other identifiable leaves, seeds, seed boxes or fruits were recorded on a 1-5 point scale, where 1= rare, 2= occasional, 3= frequent, 4= abundant and 5= very abundant. To aid identification of the monocotyledon epidermal tissue, *Sphagnum* leaves or other peat components a reference collection of type material and slides, drawings in Smith (1978) and Daniels & Eddy (1990) were consulted. The analysis provided a total of 55 samples for profile MLM and 47 for profile MLC. The macrofossil data were then represented in diagrams created by the software package Tilia and Tilia Graph (Grimm 1991) where peat component percentages are expressed on the x axis and depth of the peat on the y axis to display vegetation assemblage changes over time.

Zonation of the macrofossil diagrams was made by visual inspection of the principal macrofossil components, with more emphasis on the identifiable components, to detect principal changes. For profile MLM this provided a total of six zones (MLM-a, MLM-b, MLM-c, MLM-d, MLM-e and MLM-f) and for profile MLC provided six zones (MLC-a, MLC-b, MLC-c, MLC-d, MLC-e and MLC-f).

3.3.2 Pollen Analysis

Pollen analysis is used to supplement and complement the vegetation reconstruction obtained from plant macrofossil analysis for a number of reasons outlined by Chambers & Mauquoy (1998). Despite plant macrofossil analysis working for some humified peats in Wales, they found the level of taxonomic separation varied considerably down the profile. Firstly, this may be due to the degree of humification resulting in many horizons not giving the level of detail that had been anticipated. Secondly plant macrofossils in the near-surface horizons (the acrotelm) will generally be less humified and so will be more easily recognisable than they would be once they had passed into the catotelm and in a more advanced state of decay. Therefore, vegetational shifts towards the surface might be exaggerated by plant macrofossil analysis or indicate towards a recent vegetational shift when in fact none had occurred. Blackford & Chambers (1993) recognise that graminaceous species break down more readily than some species in therefore in particular *Molinia caerulea* may be over represented in the upper horizons in comparison to horizons further down the profile. Additionally, for detection of a species in plant macrofossil analysis it must be growing at the sampling point so it is possible that some taxa remain undetected whilst others may be over represented and an assemblage therefore may not be fully representative of the area. The extent to which vegetative macrofossils reflect the past mire community depends largely on the degree of preservation of the plant material, which varies within species and between species and between separate parts of individual plants. The main cause of the different frequencies in peat identifiable plant remains lies in the original conditions of peat formation. High PH values, greater base content and temporally low water levels enable aeration of the mire and result in the formation of strongly humified peats containing few preserved macrofossils. The opposite is true in conditions of high and scarcely varying water levels and especially if nutrient supply and PH are low - in which case well preserved macrofossil remains are found in these lightly humified peats. The specific decomposition resistance of species is important, as is the depth of their penetration into the ground, for example *Eriophorum vaginatum* disintegrates slowly due to its histological and chemical composition and the deep penetration of their rhizomes into the peat (Gross-Braukmann 1996). Experimental peat decomposition experiments on blanket peat by Coulson & Butterfield (1978) showed that the slow decomposition rate of peat-forming *Sphagnum* and *Eriophroum vaginatum* is due to their unattractivness to soil fauna.

To overcome the possible problems encountered with plant macrofossils and to supplement an often incomplete data set obtained from plant macrofossil analysis, Chambers & Mauquoy (1998) recommend that a combination of pollen and plant macrofossil analyses to be used in moderately humified peats. Pollen analysis can give a good indication of the major peat-forming components, and despite being at a somewhat generalised taxonomic level, it does have the advantage that the level of taxonomic separation achieved is the same throughout a profile. An additional advantage of using pollen to interpret recent vegetational changes is in peat the preservation of most pollen types is likely to be similar in both the acrotelm and catotelm and with some noticeable exceptions (e.g., Juncaceae pollen) there is thought to be relatively little differential destruction between pollen types in acidic mires. Thus any major pollen analytical shift, particularly in near-surface horizons where plant macrofossil data may be most problematic, would provide independent conformation of a vegetation change (Chambers *et al.* 2001). Variable pollen preservation between species and within different deposit types may affect the interpretation of a pollen profile (Havinga, 1964; Hall 1981; Havinga 1984). Berglund and Ralska-Jesiewiczowa (1986) display classes of pollen deterioration as constructed by Delcourt & Delcourt (1980). The classes are corrosion, degradation, mechanical damage and concealed grains. Pollen preservation depends to a large extent on sedimentary conditions, for example Havinga (1967,1984) found considerable pollen degradation in clays but very little in *Sphagnum* peat. Certain pollen grains are thought to corrode more rapidly than others.

For example, *Lycopodium* and *Polypodium* were found to be most susceptible to oxidation (Havinga 1967).

Samples of 0.5 cm^3 were taken at resolution of 2 cm from both MLM and MLC. The pollen preparation methodology largely follows that of Barber (1976). Samples were put in labelled large centrifuge tubes (size 50 ml) and *c.* 20 ml 10% NaOH (sodium hydroxide) added. This was placed in a water bath of 100°C for 10 minutes in a fume cupboard. Samples were then sieved through a 180 µm mesh sieve into labelled large centrifuge tubes to remove coarse organic and mineral material. Samples were then centrifuged at 3000 rpm for 5 minutes and supernatant liquid decanted. Water washes followed where *c.* 20 ml of distilled water was added to the samples, centrifuged at 3000 rpm for 5 minutes and supernatant decanted. This process was repeated until the supernatant became clear, which could be up to 4 washes. This process removed humic acids. Then two CH_3COOH (glacial acetic acid) washes dehydrated the samples for the following stage of acetolysis. *c.* 20 ml of CH_3COOH was added to samples, centrifuged at 3000 rpm for 5 minutes and supernatant decanted and this process repeated. An acetylation mixture, of 6 ml concentration sulphuric acid added to 54 ml acetic anhydride, was freshly made and 7ml added to each sample and placed in a water bath of 100°C for 60 seconds exactly. This process hydrolyses the cellulose. Immediately after *c.* 30 ml CH_3COOH was added to the samples, to stop acetolysis. This was followed by a CH_3COOH wash where *c.* 20 ml of CH_3COOH was added to samples, centrifuged at 3000 rpm for 5 minutes and supernatant decanted. A water wash follows where *c.*20 ml distilled water is added to samples, centrifuged at 3000 rpm for 5 minutes and supernatant decanted. Two alcohol washes follow the first with *c.* 10 ml of 95% ethanol and the second with *c.* 10 ml of 100% ethanol; each in turn were added to the samples, centrifuged at 3000 rpm for 5 minutes and supernatant decanted. Finally, two isopropanol washes, the first with *c.* 20 ml, centrifuged at 3000 rpm for 5 minutes and supernatant decanted. The samples were then poured into labelled glass vials, isopropanol added to half fill the vials then centrifuged at 3000 rpm for 5 minutes and supernatant pipetted off to leave behind the final pellet. One or two drops of 2000 cs silicone oil were added and the samples left in a fume cupboard for any isopropanol traces to evaporate and more silicone oil were added if the consistency became too thick.

At profile MLM a pollen sum of 200 total land pollen (including *Sphagnum* spores) was counted by Freya Pearson, this number was found sufficient for a preliminary pollen count. At profile MLC a pollen sum of 250 total land pollen (TLP) was counted as local trends were evident from this. These were prepared by Freya Pearson but counted by Prof. F. Chambers as part of a CCW report (Chambers *et al.* 2001). To aid identification Moore *et al.* (1991) and an extensive reference collection of type slides were consulted.

The MLM pollen diagram was created in Tilia and Tilia Graph (Grimm 1991) by Freya Pearson. In profile MLC the original diagram, created by Dr. J. Daniel for a CCW report (Chambers *et al.* 2001), is reproduced but for this study their zones were removed and those of the MLC plant macrofossils added so as to aid comparison of vegetation changes. All taxa are represented as percentages of TLP, with spores included in the sum. Arboreal taxa are arranged in conventional order, whilst the non-arboreal types are arranged in broad ecological groups, from woodland, through woodland edge, ruderal, arable, grassland, and mire habitats. Pollen nomenclature largely follows Clapham *et al.* (1978). For profile MLM the pollen diagram zonation follows that of the MLM plant macrofossils so as to aid comparison of the vegetation changes.

3.3.3 Charcoal Analysis

The reconstruction of fire history on a mire can be investigated by examining macroscopic charcoal fragments in the peat profile so that the frequency and possible severity of fire events can be established. MacDonald *et al.* (1991) and Clarke (1988) concluded that large charcoal fragments (50-10,000μm) correlate well with fires of local origin, whilst pollen-sized charcoal fragments are capable of long-distance transport and do not consistently correspond with local fires. Large particles can only be transported short distances by aeolian saltation and traction (Wein 1987) and also, since surface flow is inefficient owing to its low velocity, hydrological processes only result in short-distance transportation Clark (1988).

Fire history reconstruction using macroscopic charcoal fragments has been used by many authors including Aaby & Tauber (1975), Tallis (1975) and MacDonald *et al.* (1991). The method adopted was that of the modified version of MacDonald *et al.* (1991) created and employed by Mauquoy (1997) and used in the subsequent studies of Chambers & Mauquoy (1998) and Mauquoy & Barber (1999). This involves counting fragments at the same time as plant macrofossil analysis. Macroscopic charcoal fragments were recorded at the same time as the plant macrofossil peat components were determined, at a resolution of 1 cm intervals throughout the profile. Fragments can be identified by their silky lustre and tendency to break into angular fragments (Wein *et al.*, 1987). The 10 x 10 graticule in the Meiji EMZ - TR stereozoom microscope was used to assign charcoal fragments to the six size classes of <15,625 μm^2, 15,625-62,500 μm^2 , 62,500 μm^2-0.25 mm^2, 0.25-1 mm^2 and 1-4 mm^2 . The size classes aid the distinction between *in situ* and *ex situ* burning (MacDonald *et al.* 1991). The total number of charcoal fragments in each size class was recorded for 10 quadrats for each depth and the totals for each depth were expressed on the plant macrofossil diagrams to aid visual interpretation of fire history and vegetation changes with depth in the peat profile. The analysis provided a total of 55 samples for profile MLM and 47 for profile MLC.

3.3.4 Humification Analysis

As an indicator of hydrological changes and therefore a proxy-climate record peat humification provides an appropriate method as it reconstructs mire surface wetness. Peat humification is an indication of the condition of the mire at the time of peat formation. The rate of peat-bog growth is dependant on the relationship between biological production on the bog surface and the decay of plant litter. Most decay takes place in the aerobic layer above the bog water table, termed acrotelm (Chambers & Mauquoy 1998). Acrotelm thickness is directly related to the humidity of the mire surface, and consequently on precipitation, temperature and evaporation (Aaby 1976). Climate is therefore the most important allogenic factor determining the degree of humification of the peat. A change of mean water table by only a few centimetres can significantly affect the rate of peat humification (Clymo 1984) and the peat will become more humified if the dry season is exceptionally long or dry (Blackford 1993). So, peat of low humification is indicative of wet and possibly cooler conditions; peat of high humification indicates dry and possibly warmer condition (Chambers & Mauquoy 1998). Blackford & Chambers (1993) reviewed the methods of humification analysis: visual examination; physical property measurements; chemical property measurements; and the alkali-extraction of humic acids and concluded that the latter was the best methodology as results showed that continuous samples can provide a robust and replicable record. Humic and fulvic acids are produced as peat decomposition takes place. These are dark brown in solution and can be extracted to calculate the degree of peat humification by colorimetric analysis. This methodology has been employed widely including in the work of Aaby and Tauber (1975), Blackford (1990), Blackford & Chambers (1991), Chambers *et al.* (1997), Mauquoy (1997), Mauquoy & Barber (1999) and Barber *et al.* (1999).

The Bahnson colorimetric method was applied to the profiles in this study where samples of 0.5 cm x 1 cm x 4 cm at 0.5 cm resolution were cut using a surgical scalpel, dried under a heat lamp, ground into a powder using a pestle and mortar and then weighed to 0.2 g (max. weight of 0.2020 g and no less than 0.2 g) in batches of 16 samples per humification run. However, samples between 0-1 cm in profile MLM and 4-10 cm in profile MLC had a 1 cm resolution as the peat here was too fibrous to cut at a 0.5 cm resolution. The humic acids produced during decomposition were extracted by adding 100 ml of 8% sodium hydroxide (NaOH) solution to each sample in a labelled beaker and gently boiled for 1 hour on a hot plate in a fume cupboard. Any solids deposited on the sides of the beaker during the process were re-suspended to ensure complete extraction of all humic acids in the sample. The filtration process removed solid material and diluted the samples over a number of stages. Firstly beaker contents were poured into 200 ml labelled volumetric flasks ensuring all residue transferred by rinsing beakers with distilled water. Flasks were filled to 200 ml with distilled water, stoppered and shaken. Samples were then filtered into 50 ml flasks through grade 1 filter papers and finally 50 ml samples poured into 100 ml flasks ensuring all residue transferred via rinsing 50 ml flasks with distilled water; flasks were filled to 10 ml with distilled water, stoppered and shaken.

Colorimetric analysis performs on the principle that absorption of light from an alkaline extract of peat is proportional to the amount of humic matter dissolved, with greater transmissions of light through less humified material (Aaby & Tauber 1975). Flasks were shaken to ensure uniform distribution of humic acids in the samples and three readings, to obtain an average, of percentage light transmission, were recorded using the spectrophotometer. The analysis provided a total of 104 samples for profile MLM and 87 for profile MLC. The data were represented untransformed as percentage light transmission as Blackford & Chambers (1993) maintain preference to this in portrayal of humification. They recognise that the transformation of the recorded measurements to produce data in the form of percentage humification is questionable owing to the variety of humic acids produced by different peats under different conditions. They also acknowledge that the results of alkali-extraction method are distorted by changes in different peat-forming plants having different decomposition rates. However, they argue directional response of these changes makes this method preferable for palaeoclimatic studies as if a 'dry' assemblage of mire plants dominated by *Calluna vulgaris* gives way to a *Sphagnum* dominated 'wetter' community, the degree of humification would be reduced, as *Sphagnum* decays at a lesser rate under the same conditions. So a change to wetter conditions, then, should have exaggerated the effect on the extract colour when species composition changes.

The data were then zoned on the basis of the plant macrofossil zones to aid comparison of the data, especially with Unidentified Organic Matter (U.O.M) with which it has a direct relationship. A high U.O.M value indicates higher decomposition which should be reflected by a low percentage light transmission as more humic and fulvic acids (being brown in colour) are produced the higher the rate of decomposition. The opposite should be true of low U.O.M and high percentage light transmission where there is lesser rate of decomposition.

3.3.5 Spheroidal Carbonaceous Particle (SCP) Analysis

The need to assign a chronology to the vegetation changes is of importance as Yeo (1997) noted the vegetation changes in Wales had been dated with little accuracy. Whilst investigating the age, origin and vegetational history of upland blanket peats in south Wales Chambers *et al.* (1979) found that the application of radiocarbon dating to young sample material produced erroneous results. This was due to the Suess effect where the concentration of atmospheric ^{14}C is diluted by CO_2 containing negligible ^{14}C from the burning of fossil fuels from the onset of the industrial revolution, as this CO_2 is incorporated in growing plants radiocarbon dating of young plant material tends to produce spuriously old dates. Additionally, the dates obtained were substantially older than those expected from the Suess effect acting alone. They concluded they were derived from contamination of particulate pollution during the industrial revolution and therefore radiocarbon dating of recent vegetation changes near industrial areas is likely to produce erroneous results.

Owing to the above problems with radiocarbon dating recent vegetation changes another method needed to be applied. Rose (1995) showed that SCP profiles could be used as an indirect dating tool on very recent lake stratigraphy by associating changes in the SCP profile to documentary sources of combustion histories in the region. He also stated that SCP dating would become increasingly valuable for mid-late 19th century sediments as continual decay renders ^{210}Pb dating less useful for this time interval. Despite the first SCP profiles being produced for lake sediments

(Griffin & Goldberg 1981, Renberg & Wik 1985, Rose *et al.* 1995) a number of studies have successfully used SCP dating in peat, for example, Chambers & Mauquoy (1998), Barber *et al.* (1999), Chambers *et al.* (1999) and Chambers *et al.* (2001).

The principal behind the technique is that as peat accumulates, it can store a historical record of atmospheric pollutants deposited. These pollutants include Spheroidal Carbonaceous Particles (SCP) which are formed from the incomplete high temperature combustion of fossil fuels. SCP are resistant to chemical degradation and so are well preserved in the sedimentary sequence (Rose 1995), whilst they remain relatively immobile after deposition in peat sediments (Punning & Alliksaar 1997 *cit.* Rosen 1998). Rose *et al.* (1995) investigated 23 sediment profiles which revealed characteristic trends and highlighted the main features in the SCP curves. From this he produced an 'idealised' SCP profile for dating sediments in the UK and Ireland. Firstly, the start of the SCP record dated to the mid-nineteenth century is generally attributed to the developments of industrial revolution and the burning of fossil fuels; variability in the start between and within regions can be accounted for by local industries. The second feature is the rapid increase in SCPs, a feature dated usually to the 1950s and 1960s and attributed to increased coal consumption from the 1920-30s which accelerated after the second world war owing to considerable increase in total energy demand, the onset of mass electricity generation due to an abundance of cheap oil and the lack of particle emission legislation. Thirdly, there is a SCP concentration peak in the 1970-80s as coal consumption continued to rise until the late 1970s and oil consumption increases from the 1950s to 1973 when massive price increases imposed by OPEC (Organisation of Petroleum Exporting Countries) and the oil shortage of the 1973-74 Arab oil embargo caused oil consumption to decline. A subsequent decline in the SCP profile to most recent times is due to improvements in the removal of particulates implemented by various air pollution legislative control and a small decrease in fossil fuel consumption. Rose (1995) also noted that with very low sediment accumulation rates the generalised features of the 'idealised' SCP curve may not be evident.

SCP accumulation rates can vary according to the nature and proximity of industrial activity. As a result, the timings of features in the SCP profile may vary geographically and Rose *et al.* (1995) have used these temporal variations in SCP accumulation to divide Great Britain into three SCP deposition regions. These being i) northern Scotland, ii) southern Scotland, northern England and Wales and iii) southern England. In particular, local coal-based industrial activity before the major industrial development of the mid-nineteenth century appears to lead to variations in the date of SCP appearance within and between regions. Rosen (1998) suggests that although *Rose et al.* (1995) found this feature varied only by a decade or so across England, the limited number of cores analysed by may have precluded the identification of larger temporal differences as age differences of up to 40 years were found in Scotland and Wales. In addition, Rosen (1998) suggest the start of the rapid increase in SCP concentration may fall anywhere between the 1940s and the 1970s. Variations in total sedimentary SCP accumulation do however, occur both within and between regions and this suggests spatial differences in the extent of atmospheric fossil fuel pollution deposition. For example, Rose & Juggins (1994) found from analysis of lake sediments in Scotland that the highest SCP concentrations were from Galloway in south-west Scotland, Aberdeen to the east, and around Glasgow suggesting that the higher levels were a result of closer proximity to major industrial areas.

The method used in the present study is based on that of Rose *et al.* (1990,1994) and modified by Chambers and Mauquoy (1998) & Chambers *et al.* (1999). Samples of 1 cm x 1 cm x 4 cm were cut from each 1 cm level with a surgical scalpel, oven dried at oven at 50°C and weighed to 0.1 - 0.4 g. The high resolution of sampling ensures that no important peaks or troughs in the profile are missed and the smaller sample size allows a higher proportion of the digested material to be counted (Rosen 1998). The samples were then placed into Gerhardt acid digestion tubes with 25ml of nitric acid and placed on the hotplate of the Gerhardt acid digestor unit for ca.1 hour at 180°C to remove organic matter. A Gerhardt scrubber containing unit was employed to neutralise acidic fumes. The residue was then poured into disposable centrifuge tubes and centrifuged at 3000 rpm for 3 minutes, decanted to leave a pellet, mixed with distilled water, poured into labelled pre-weighed small glass vials and centrifuged at 3000 for 3 minuets. The supernatant was removed with disposable pipettes and the residue and vial weighed. Using a disposable pipette a small amount of residue was sucked up and dropped onto a slide, the slide was then placed on hotplate to evaporate water, a single drop of glycerol jelly added and then a coverslip. Finally the unused residue and vial were re-weighed. During the laboratory procedure very few spheres are thought to be lost (Stoneman 1986 *cit.* Rosen 1998).

SCP in the size range of 5-30 μm were identified by scanning the entire slide sample area under x 400 magnification using a Nikon labophot microscope following the identification characteristics. SCPs appear as black, shiny and perfectly spherical particles under the microscope, and a major advantage of the technique is the lack of ambiguity in their identification (Rose *et al.* 1995). Rose *et al.* (1995) recommends the entire cover slip is examined to raise sphere detection limits at the lower end of the SCP record where fewer particles occur, and to preclude any effects of SCP aggregation on the coverslip. Rosen (1998) classified spheres in size classes, but this yielded little additional information on trends in past industrial activity or pollution deposition. Only entire spheres or fragments larger than half were counted to avoid multiple counts of the same particle where sphere fragmentation had occurred. The weight of the residue on the slide was calculated and the SCPs expressed as per gram of dried soluble sediment (gDM^{-1}) in order to account for large variations in mineral matter content throughout the sediment. The data was then plotted to express SCP concentration on the x axis and depth on the y axis for both profiles MLM and MLC.

CHAPTER FOUR

RESULTS AND INTERPRETATION

This chapter sets out the results and interpretation of the laboratory analyses of the two profiles MLM and MLC. It also consolidates the results in tables as to aid comparison of the data and interpretations based on all lines of evidence.

4.1 Mynydd Llangatwg Molinia Monolith (MLM)

4.1.1 Description and Interpretation of Plant Macrofossil and Charcoal Diagrams

The plant macrofossil and charcoal data for MLM are presented in figure 4.1.

4.1.1.1 Zone MLM-a (55-47.5 cm)

A high proportion of monocotyledonous remains (55-70%) dominates this zone and U.O.M levels are relatively high (20-40%) but low in comparison to the subsequent three zones. *Ericales* roots reach their highest frequency in the diagram at 5-10%, *Calluna vulgaris* and *Erica tetralix* leaves are at the highest levels in the diagram; the former is frequent to abundant (3-4 points) and the latter abundant to v. abundant (4-5 points). *Sphagnum* is absent from the zone except for the lowermost horizon where a low level of around 1-2% *Sphagnum imbricatum* is detected. *Eriophorum vaginatum* roots are present at levels of 5-10% which are typical frequencies for much of the diagram.

This zone contains high charcoal counts but particularly in the larger size ranges of 0.25-1 mm^2 (up to 150) and 1-4 mm^2 (up to 50) both occurring in the upper half of the zone. Counts for these two size classes are highest within the diagram. Medium and smaller size classes of <15,625 μm^2 (up to 250),15,625-62,500 μm^2 (up to 200) and 62,500 μm^2-0.25 mm^2 (up to 300) occurred at levels that were higher than the subsequent zones apart from zone MLM-e and the highest frequencies are recorded in the upper end of the zone.

This zone suggests that the mire supported a vegetation community with relatively significant amounts of ericaceous species, in particular *Calluna vulgaris* and *Erica tetralix. Eriophorum vaginatum* roots were also present at similar frequencies throughout the diagram, except for the uppermost horizons, suggesting this cyperaceous species is a long-established member of the plant community. *Sphagnum* is absent except for a small amount of *Sphagnum imbricatum* at 53-54 cm which can grow in lawn or hummocks on mires. As the majority of the peat components is classified as monocots. undiff. a dominance of grasses and/or sedges can be inferred but exact species cannot be distinguished. The charcoal record indicates an extensive local fire took place during this zone, especially at the end where the charcoal fragments peak in the larger size ranges.

From the presence of ericaceous species and lack of *Sphagnum* it appears that the mire surface must have been relatively dry throughout the zone.

4.1.1.2 Zone MLM-b (47.5-30.5 cm)

This zone is once again dominated by monocots. undiff. (25-80%). *Ericales* roots remain relatively high (1-10%) compared to the previous zone MLM-a and in relation to the whole diagram. *Calluna vulgaris* leaves are absent except at 33-34cm, towards the bottom of the zone, where they are occasional (2 points); *Erica tetralix* leaves remain at similar levels to the previous zone, being rare to frequent (1-3 points). *Sphagnum* is once again largely absent from the zone except for small recordings at 43-44cm where *Sphagnum imbricatum* (<1%) makes its last sighting in the diagram, at 39-40 cm (3%) which is unidentifiable and at 35-36cm as *Sphagnum papillosum* (<1%). *Eriophorum vaginatum* root frequencies are similar to the previous zone at 1-10% and all preceding zones, except the upper most MLM-f; *Eriophorum vaginatum* spindles are present towards either end of this zone being frequent to abundant (3-4 points) and *Eriophorum vaginatum* epidermis is detected at very low amounts (<1%) at the top of this zone.

Charcoal counts for all size classes decline in this zone from levels experienced in MLM-a; <15,625 μm^2 (up to 125), 15,625-62,500 μm^2 (up to 100), 62,500 μm^2-0.25 mm^2 (up to 125), 0.25-1 mm^2 (up to 75) and 1-4 mm^2 (up to 10). Amongst the size classes, the larger 0.25-1 mm^2 is the most frequent, peaking mid-way (39-40 cm), dropping immediately after and increasing again towards the end (32-36 cm) of the zone.

The vegetation community on the mire during this zone is similar to the previous; but with *Erica tetralix* but *Calluna vulgaris* largely absent. Again unknown grass and/or sedge species dominate in the form of monocots. undiff. The main changes in species from the previous MLM-a zone include increasing *Sphagnum* records. The last recording of *Sphagnum imbricatum* at the start of the zone is significant, as it is now rare across Wales and the UK. *Sphagnum papillosum* detected towards the end of the zone can grow in wetter microforms. *Eriophorum vaginatum* roots are present in the assemblage at similar amounts to the previous zone; however, *Eriophorum vag*inatum spindles and epidermis appear which may indicate a greater presence in the mire vegetation assemblage. Charcoal levels have dropped but the small rises in larger fragments may indicate local fires that may have not been as intense as in the previous zone. The environment on the mire during this zone suggests the site was relatively dry as in the previous zone but may have become locally wetter towards the close.

4.1.1.3 Zone MLM-c (30.5-26.5 cm)

The major changes in this zone compared to the previous MLM-a and MLM-b are the disappearance of *Calluna vulgaris* and *Erica tetralix* leaves. *Ericales* roots are still present (1-5%) but have slightly decreased; *Eriophorum vaginatum* roots are at levels consistent to the previous zones (1-6%), but a cluster of *Eriophorum vaginatum* spindles are found at frequencies of occasional to very abundant (2-5 points). As in the previous two zones, monocots. undiff dominates the zone at frequencies between 35-75% and U.O.M increases to a diagram peak at the top of the zone.

Charcoal fragments are largely absent from this zone. There are no recordings for the larger size classes (0.25-1 mm^2 and 1-4 mm^2) and very low levels of medium and small sized fragments (<15,625 μm^2, 15,625-62,500 μm^2 and 62,500 μm^2-0.25 mm^2) are present.

The mire was dominated by grasses and/or sedges during this zone and ericaceous species were not as abundant in the vegetation assemblage with no macrofossil recordings for *Calluna vulgaris* and *Erica tetralix*. *Eriophorum vaginatum* may be more abundant due to the high proportion of *Eriophorum vaginatum* spindles. The absence of *Calluna vulgaris* and *Erica tetralix* could be interpreted as a shift to wetter conditions; however, there are no *Sphagnum* remains to support this and overall the U.O.M record is highest within the diagram which suggests drier conditions. The charcoal record could suggest that the site was too wet for substantial fires to have occurred or quite simply that no fires took place during this period regardless of mire hydrological features.

4.1.1.4 Zone MLM-d (26.5-15.5 cm)

The most significant feature of this zone is the first appearance of *Molinia caerulea* epidermis (<1%) in the uppermost horizon. Monocots. undiff. are still dominant in this zone (60-90%) and have slightly increased from the previous zones. Associated with this is a small decrease in U.O.M to 10-45%. *Ericales* roots are only detected mid-way through the zone and are present at similar levels to the previous zones (2-8%). *Eriophorum vaginatum* roots increase slightly from the previous zones to 3-12% and *Eriophorum vaginatum* spindles were not recorded. There are no records of *Sphagnum* in this zone.

Charcoal fragments increase slightly in size classes <15,625 μm^2 (up to 65), 15,625-62,500 μm^2 (up to 100), 62,500 μm^2-0.25 mm^2 (up to 200), 1-4 mm^2 (up to 10), but the sharpest rise is in the larger size range of 0.25-1 mm^2 where initial small rises culminate in a peak towards the end of the zone where levels reach up to 75.

The vegetation on the mire during this zone is dominated by grasses and/or sedges. *Eriophorum vaginatum* is more abundant than the previous zones; there is a lack of ericaceous species and no *Sphagnum*. The first detection of *Molinia caerulea* suggests some environmental parameter has changed to allow this species to enter the mire vegetation assemblage in the uppermost horizon. The environment on the mire during this zone may have been wetter as there is a drop in U.O.M and an absence of *Ericales* roots, except for a recording mid-way through the zone suggesting some ericaceous species remained growing on the mire. *Eriophorum vaginatum* shows an increased representation during this zone. A peak in larger charcoal fragments occurs mid-way through the zone suggesting a local fire took place. This coincides with the recording of *Ericales* roots that may indicate drier mire conditions at this point in the zone.

4.1.1.5 Zone MLM-e (15.5-11.5 cm)

Monocots. undiff remains at similar levels to the previous zone, dominating at 60-85%, while U.O.M declines marginally to 10-25%. *Ericales* roots appear in the middle of the zone at 3% - a level similar to the rest of the diagram. *Eriophorum vaginatum* roots rise to 10-20% and the first significant recording of *Eriophorum vaginatum* epidermis occurs mid-way through the zone at 10%. *Molinia caerulea* epidermis frequencies begin to rise, reaching 12% at the end of the zone. Again there are no recordings of *Sphagnum* within this zone.

A characteristic feature of this zone is that charcoal fragments of all size classes rapidly increase, the smaller size ranges <15,625 μm^2 (up to 1200), 15,625-62,500 μm^2 (up to 590), 62,500 μm^2-0.25 mm^2 (up to 1100) all reaching peaks within the diagram. The larger size classes 0.25-1 mm^2 (up to 85) and 1-4 mm^2 (up to 25) show marked rises from the previous zones, but do not quite reach the levels seen in the first zone MLM-a. In all size classes, the peaks occur mid-way through this zone.

The vegetation on the mire during this zone is dominated by grasses and/or sedges, evident from the abundance of monocots. undiff. Graminoids *Eriophorum vaginatum* and *Molinia caerulea* become more abundant with a lack of Sphagna and ericaceous species. U.O.M declining from the previous zone could signify a change to wetter conditions; however, there are no *Sphagnum* remains to support this. The most distinctive feature is the peak in charcoal of all sizes classes suggesting that both fires *in situ* and *ex situ* took place during this phase which may have had influence on vegetation changes and possibly the increase in graminoids.

4.1.1.6 Zone MLM-f (11.5-0 cm)

This zone is distinctive, having continuous records of *Molinia caerulea* reaching up to 50%; there are also significant records of *Sphagnum* section *Cuspidata*, which gradually increase from the bottom of the zone from 2% to 50-60% near the surface. *Drepanocladus fluitans* also makes its first appearance at the start of this zone at low levels of around 1% but increases towards the end of the zone, peaking at the surface (20%). Associated with these major vegetation changes is a decline in Monocots. undiff. from 75% to 5% by the end of the zone and a slight decline in U.O.M from around 20% at the start of the zone and more markedly towards the surface, declining to levels of 5%. *Eriophorum vaginatum* roots are at levels very similar to the previous zone (5-15%) as is *E. vaginatum* epidermis at 2-5%, but both are absent from the upper horizons.

Charcoal fragments rapidly decline early in this zone. There are no recordings for the larger size classes of 0.25-1 mm^2 and 1-4 mm^2 and very low levels, similar to zone MLM-c, for the smaller ranges of <15,625 μm^2, 15,625-62,500μm^2 and 62,500 μm^2-0.25 mm^2.

This zone contains the most distinctive vegetational changes. During this zone the mire vegetation was dominated by *Molinia caerulea and Sphagnum* section *Cuspidata* throughout, and also by the bryophyte *Drepanocladus fluitans* in upper horizons. The cyperaceous species *Eriophorum vaginatum* was present in the lower two-thirds of the zone and absent from the rest. There was also a lack of ericaceous species. *Sphagnum* section *Cuspidata* and *Drepanocladus fluitans* both rise to high frequencies through this zone; which indicates that the mire surface was wet. The latter is often found submerged in pools. U.O.M is low which is another indicator of a wetter mire surface. Wetter mire conditions may inhibit the growth of ericaceous species. The rise of the graminaceous species *Molinia caerulea* may have been caused by the *in situ* fire present in the previous zone MLM-e or by change in another environmental parameter. It must also be considered that *Molinia caerulea* and *Sphagnum* may be over represented due to increased preservation in near surface horizons.

The contemporary vegetation survey at MLM (P.Jones, CCW, pers. com. 1999) shows a number of species present, with their relative abundance. These include *Eriophorum vaginatum* (dominant), *Molinia caerulea (abundant), Scirpus cespitosus* (occasional - frequent), *Eriophorum angustifolium* (frequent), *Juncus squarrosus* (occasional), *Polytrichum commune* (frequent) and *Campylous* (occasional) from an area within 5 m of the sampling site. *Empetrum nigrum ssp nigrum* and *Vaccinium myrtillus* were also detected in the stand but not in the quadrat. In comparison to the macrofossil data there are a number of species not detected in the MLM record. These include *Scirpus cespitosus, Juncus squarrosus, Polytrichum commune, Campylous, Empetrum nigrum spp. nigrum* and *Vaccinium myrtillus.* Of the species detected by macrofossil analysis and in they vegetation survey frequencies of species vary. *Eriophorum vaginatum,* despite not being present in the upper third of the macrofossil zone MLM-f, was dominant in the vegetation survey and *Drepanocladus fluitans* was not detected in the survey. The contemporary vegetation survey does confirm that *Molinia caerulea* and *Sphagnum* section *.cuspidatum* were abundant and that a lack of ericaceous species and other sphagna are actual features of the macrofossil diagram.

This suggests that species are not always recorded and/or at different frequencies in the macrofossil record compared to the actual vegetation growing on the mire. This may be due to different preservation rates between species and also indicates that macrofossil analysis only records species *in situ* and so may not be entirely representative of the sampling area.

4.1.2 Description and Interpretation of Humification Diagram

The humification data, expressed as percentage light transmission, for MLM are presented in figure 4.2.

The description and interpretation are described within the zonation format used for the plant macrofossil data to aid comparison. Comparisons are made between Unidentified Organic Matter (U.O.M) and humification light transmission values as they are intrinsically linked; a high U.O.M

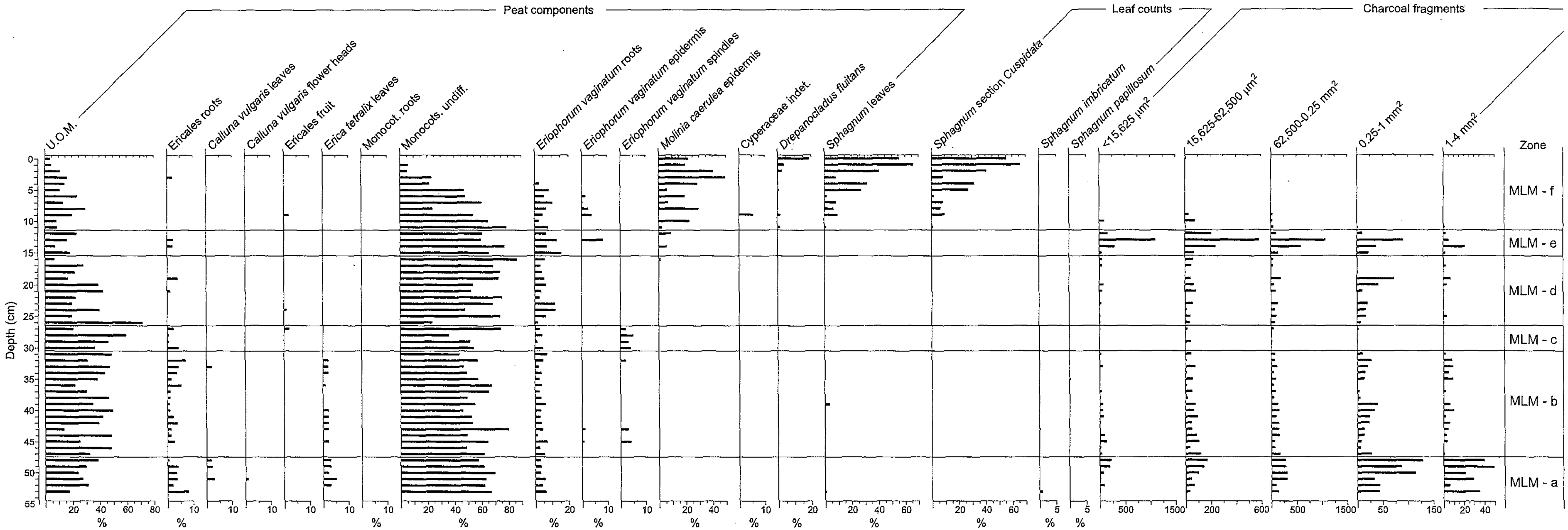


Fig. 4.1 Mynydd Llangatwg
Monolith MLM
Plant macrofossil and charcoal diagram
(Reproduced from Pearson, F. 2001)

value indicates higher decomposition which should be reflected by a low percentage light transmission as more humic and fulvic acids (being brown in colour) are produced the higher the rate of decomposition. The opposite should be true of low U.O.M and high percentage light transmission occur where there is lesser rate of decomposition.

The overall trend of the MLM peat humification curve is that it becomes less humified towards the top from *c.* 29% light transmission at 55 cm to 71% at 0 cm. The whole of the profile is quite 'noisy' so only trends are described, not every individual peak and trough superimposed on this except where they link to U.O.M values.

4.1.2.1 Zone MLM-a (55-47.5 cm)

The base of the diagram at 55 cm and a light transmission of *c.* 29% rises slightly to *c.* 34% at 47cm at the end of the zone. The values in this zone are the joint lowest in the diagram with the second half of the subsequent zone MLM-b. The low percentage light transmission values found here suggests the mire was in its one of its driest conditions of the whole diagram. Within this zone there is also a general trend that the mire became slightly less drier from the start to the end. The humification data do not correspond to the U.O.M data which show relatively low values (*c* .20-40%) in comparison to the subsequent three zones suggesting the mire was in one of its wetter conditions except for the uppermost two zones.

4.1.2.2 Zone MLM-b (47.5-30.5 cm)

From the end of the previous zone light transmission values gradually decline to 29% at *c.* 39 cm mid-way through the zone ending in a sharp isolated peak of *c.* 37% comprising a single sample horizon *c.* 38 cm. This is followed by a decline into a trough in the second half of the zone which is equally low (*c.* 24%) as the previous zone, before rising to *c.* 34 % at the close of the zone.

From the previous zone the mire gradually becomes drier to mid-way through the zone when the isolated peak indicates wetter conditions. However, this quickly plummets into one of the driest phases within the diagram but becoming slightly wetter towards the close of the zone. The U.O.M data fluctuate a lot but show an overall trend for drier mire conditions, which are broadly similar to the following zone.

4.1.2.3 Zone MLM-c (30.5-26.5 cm)

This zone shows an increase in light transmission from *c.* 34% at the start to *c.* 36% at the close of the zone. The mire shows a trend towards wetter conditions through this zone. The U.O.M data are at levels similar to the previous zone, but drop in the last sample horizon. This suggests a drier mire than the humification data, but it possibly became wetter at the close of the zone.

4.1.2.4Zone MLM-d (26.5-15.5 cm)

Within this zone light transmission values rise more steeply than the previous from *c.* 34% at the start, peaking at 20 cm at *c.* 46% and dropping at the same rate to *c.* 42% at the close of the zone. The light transmission data suggest that the mire became wetter up until mid-zone and was wetter than any of the previous zones. In the second half of the zone the mire became drier but was still wetter than all the previous zones. The U.O.M data correspond to the humification data showing overall lower values than the previous two zones implying the mire had become wetter. A small trough between *c.* 22- 24 cm may correspond with the humification data and the slightly drier mire mid-zone. There is an anomaly of the first sample horizon of the zone showing a very high value which does not correspond to the humification data or follow the trend of the rest of the U.O.M.

4.1.2.5 Zone MLM-e (15.5-11.5 cm)

The light transmission values fluctuate greatly here but show an overall sharp upward trend in values from *c.* 42% to *c.* 52% from the start to end of the zone. The humification data represent a rapid increase to wetter mire conditions, surpassing all previous zones' wetness but not the subsequent and final zone MLM-f. The U.O.M reflect these wet mire conditions as the lowest values of the diagram are found within this zone, except for the close of the final zone.

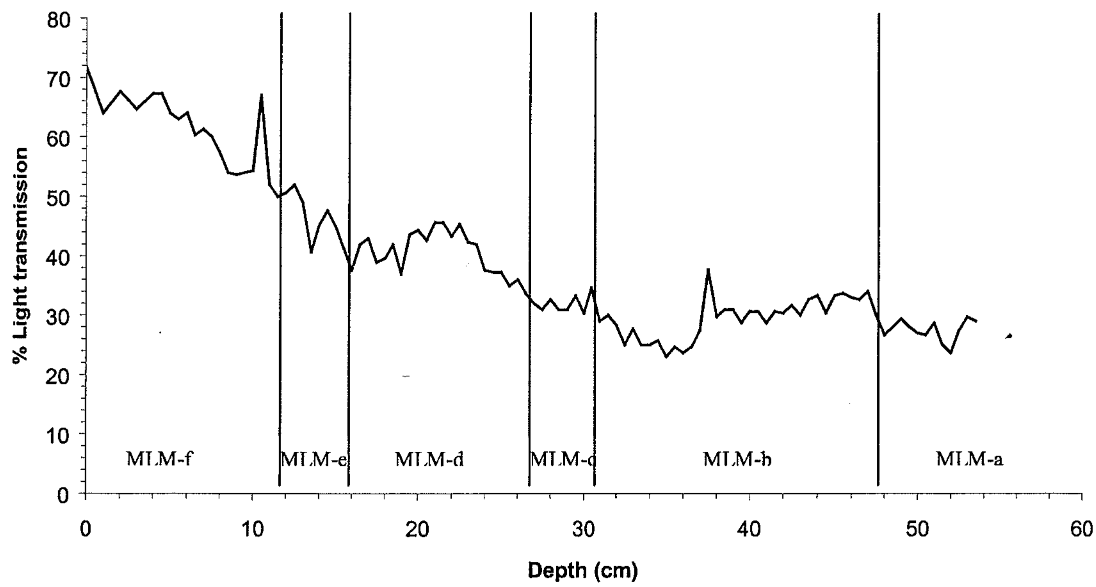
4.1.2.6 Zone MLM-f (11.5-0 cm)

After an initial large isolated peak of *c.* 66% at 10.5 cm in one sample horizon the zone shows an overall trend of increasing light transmission values from *c.* 52% at 10 cm culminating at *c.* 71% at the surface horizon.

This zone shows the mire its wettest condition for the whole profile and the isolated peak, if not an anomaly, may indicate that the mire was particularly wet at 10.5 cm. The U.O.M data also show generally low values indicating towards wet mire conditions.

One important consideration to be made when interpreting humification and U.O.M data is the amount of change occurring near the surface of the mire that can be directly related to the change from the less humified acrotelm near the surface than once the peat has passed into the more humified catotelm further down the profile. From the data it can be inferred that the start of the rapid increase in percentage light transmission at *c.* 15 cm, covering zones MLA-e and MLA-f is the acrotelm. Therefore, the shift in these zones to very wet conditions is most probably not linked to the mire hydrology but the catotelm/acrotelm boundary and hence inferences about the climate change are difficult to extract from these zones.

Figure 4. 2 Monolith MLM: Humification expressed as % transmission.



4.1.3 Description and Interpretation of Pollen Data

The pollen data for profile MLM is presented in figure 4.3. The MLM pollen diagram is shorter than MLC due to the experience of the pollen analyst (see section 3.3.2). The following results only describe *Gramineae, Cyperaceae* and *Ericaceae* pollen and *Sphagnum* spores as these are the principal species to represent the local mire environment.

4.1.3.1 Zone MLM-a (55-47.5 cm)

Ericaceae is the most dominant component ranging between *c.* 23-55%, *Sphagnum* are at levels between *c.* 10-25%, *Gramineae* at *c.* 11-16% and *Cyperaceae* at *c.* 4-7%. The dominance of ericaceous species and low frequencies of *Sphagnum* suggests that the mire may have been relatively dry during this zone. The mire also supported low levels of grasses and sedges.

4.1.3.2 Zone MLM-b (47.5-30.5 cm)

Sphagnum frequencies are the highest of the entire diagram, especially in the last horizon reaching an isolated peak of *c* .80%. Frequencies throughout the rest of the zone range between *c.* 15 and 45%. This is mirrored by a very low frequency of *Ericaceae* at *c.* 2% in the last horizon this then increases towards the close of the zone, ranging between *c.* 20-63%. Levels of *Gramineae* and *Cyperaceae* are both low, the former *c.* 5-13% and the latter *c.* 1-16%.

The start of the zone appears to be relatively wet as indicated by high levels of *Sphagnum* and corresponding low levels of *Ericaceae* pollen. During the mid zone the mire was still relatively wet as although *Sphagnum* had decreased and *Ericaceae* increased, the former was still abundant in comparison to subsequent zones. The close of the zone is the driest as indicated by high *Ericaceae* and low *Sphagnum* levels. The mire also supported low levels of graminaceous and cyperaceous species throughout the zone.

4.1.3.3 Zone MLM-c (30.5-26.5 cm)

Ericaceae pollen dominants at *c.* 50%, with moderately high levels of *Sphagnum*, *c.* 20-35%, and low levels of Gramineae, *c.* 7%, and Cyperaceae at *c.* 7%. The mire must have been sufficiently dry in places to support high levels of ericaceous species and wet enough in others to support the *Sphagnum* species. Levels of graminaceous and cyperaceous species remain at low on the mire and are typical of the previous two zones.

4.1.3.4 Zone MLM-d (26.5- 15.5 cm)

Ericaceae ranging between *c.* 44-70% dominates this zone. This has increased from the previous zone and are the highest frequencies of the diagram. *Sphagnum* spores decrease from the previous zones and at levels of *c.* 18% at the start of the zone drops to *c.* 1% towards the end. *Gramineae* levels rise slightly from the previous zones ranging between *c* 8-20% and *Cyperaceae* remains at low level of *c.* 3-10%.

The dominance of ericaceous species and the lack of *Sphagnum* suggests the mire surface became drier during this zone. Levels of graminaceous species increased slightly but were still not abundant in the vegetation assemblage. There were also low levels of *Cyperaceae* on the mire.

4.1.3.5 Zone MLM-e (15.5-11.5 cm)

This zone is characterised by a dominance of *Gramineae (c.* 30-38%) rapidly increasing from all previous zones. *Cyperaceae* also increases from all previous zones reaching frequencies of *c.* 15-25%. *Sphagnum* is present at very low frequencies of *c.* 2% and *Ericaceae* has rapidly declined from the previous zone to *c.* 10-23%.

This zone reveals a rapid change in mire vegetation, to one dominated by graminaceous species with moderate levels of cyperaceous species, low levels of ericaceous species and virtually no *Sphagnum*.

4.1.3.6 Zone MLM-f (11.5-2 cm)

Gramineae continues to increase from the previous zone and dominates at *c* .40-60%, these frequencies are the highest for the entire diagram. *Cyperaceae* also increases, reaching highest diagram frequencies at *c.* 40% at one horizon at the start of the zone and ranging between *c* .2-13%. *Sphagnum* and *Ericaceae* are both at the lowest levels of the diagram, *c.* 1-6% and 1-7% respectively. The pollen evidence suggests that the mire was dominated by grasses with moderately high frequencies of sedges and very low amounts of *Sphagnum* and ericaceous species.

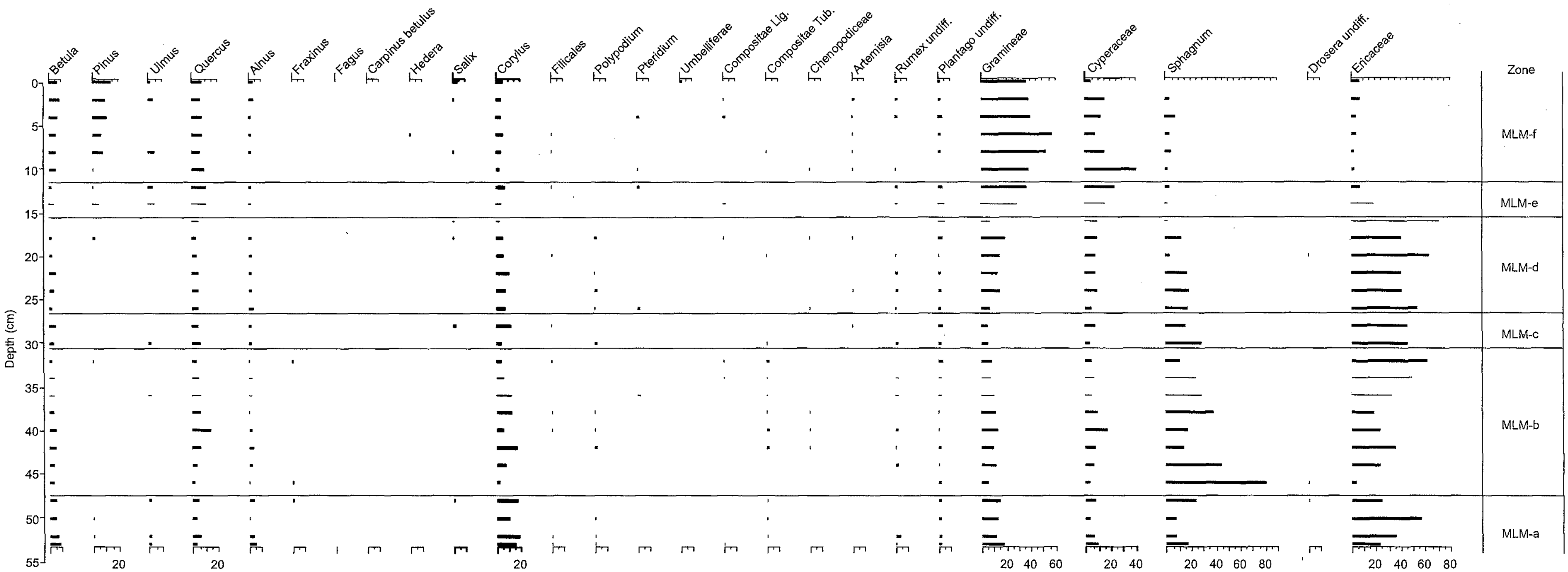


Fig. 4.3 Mynydd Llangatwg
Monolith MLM
Percentage pollen diagram (% TLP)
(Reproduced from Pearson, F. 2001)

4.1.4 Description and Interpretation of the SCP profile

The SCP profile for MLM is plotted in figure 4.4.

The SCP record begins at a depth of 17-18 cm with a very low concentration of 0.9 gDM^{-1} . This is followed by an over all trend of gradual increase up to 4-5 cm with an isolated peak at 6-7cm of 251 gDM^{-1} and final high values towards the surface culminating at a concentration of 299 gDM^{-1}.Superimposed on this trend are small fluctuations which are as follows: initially a rise to a small peak of 20-25 gDM^{-1} between 18-14 cm, following this a slight decline to 7-18 gDM^{-1} between 14-12 cm, then a rise to 48-53 gDM^{-1} between 12-9 cm 53 gDM^{-1}, a drop at 8-9 cm (23 gDM^{-1}), a rise to the isolated peak at 6-7 cm (251 gDM^{-1}), a fall of 90-54 gDM^{-1} between 6-4 cm and finally the final large near-surface increase from 254 gDM^{-1} at 3-4 cm to 299 gDM^{-1} at 0-1 cm.

The SCP record is used in the interpretation as an independent method for dating the peat profile based on Rose et al.'s (1995) research and application of an 'idealised' SCP curve applicable for dating profiles in the UK and Ireland. This is described in more detail in chapter 3. The onset of consistent SCP recordings in the profile at 17-18 cm may be interpreted as the start of the industrial revolution in the mid-19th century. However, in reality it may vary according to local industry and hence be slightly earlier. The rapid increase in SCPs dated by Rose et al. (1995) to the 1950-60s is not clearly detected in MLM nor is the post-1970s SCP decline to modern times. The rapid 1950-60s increase may be the peak at *c.* 6-7cm or that it is the rapid increase in the sub-surface horizons between 4-0 cm, if the latter is the case then the post-1970s SCP decline has not been detected at MLM. As Rose *et al.* (1995) notes, very low accumulation rates of peat don't always show the SCP decline, this maybe the case at Mynydd Llangatwg. The same feature is found in profile MLC and other possible causes are discussed in section 4.2.4.

4.2 Mynydd Llangatwg Calluna Monolith (MLC)

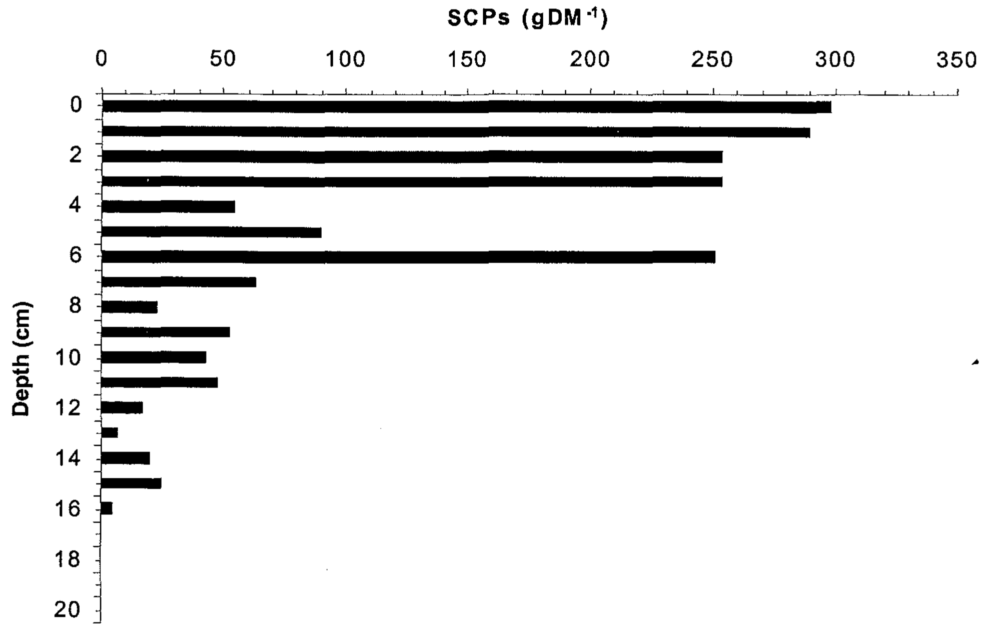
4.2.1 Description and Interpretation of the Plant Macrofossil and Charcoal Diagrams

The plant macrofossil and charcoal data for MLC are presented in figure 4.5. There are no recordings of *Molinia caerulea* throughout this macrofossil diagram.

4.2.1.1 Zone MLC-a (51-50 cm)

This zone comprises one sample horizon in which all the *Sphagnum* remains despite, only being 0.1%, are those of *Sphagnum imbricatum* and are what distinguishes this zone. Monocots. undiff (*c.* 45%) and U.O.M (*c.* 45%) are at similar levels to the start of the subsequent zone. *Eriophorum vaginatum* roots are present at *c.* 2% and Ericales roots at *c.* 7 %, with both *Calluna vulgaris* and *Erica tetralix* leaves being rare.

Figure 4. 4 Monolith MLM: SCP profile.



The charcoal fragments are very low in this zone for the larger size classes 62,500 μm^2-0.25 mm^2 (*c.* 50), 0.25-1 mm^2 (*c.* 10) and 1-4 mm^2 (*c.* 5) and no recordings for the small size classes <15,625 μm^2 and 15,625-62,500 μm^2.

The mire vegetation at this time contained grasses and/or sedges with some *Eriophorum vaginatum* and ericaceous species, including *Calluna vulgaris* and *Erica tetralix*. However, most significant is the only recording of *Sphagnum imbricatum* in the diagram and therefore it can be assumed that this is likely to be the last record of the species at MLC. This species can grow in lawn or hummock microforms and is now rare across Wales and the UK.

4.2.1.2 Zone MLC-b (50-35.5 cm)

The first half of the zone is dominated by U.O.M. with values (50-80%) rising from the zone below. At 41cm drops to 15-30% and monocots. undiff. remain become dominant at 50-80%. Monocot. roots comprise 1-5% of the peat component and levels are typical for much of the profile apart from the uppermost two zones. *Ericales* roots comprise 2-10% throughout; *Erica tetralix* and *Calluna vulgaris* leaves are absent from the first half of the zone, with the former occasional to abundant (2-4 points) and the latter occasional (2 points) in the second half of the zone. Remains of *Sphagnum* section *Cuspidata* appear at the end of this zone, at very low levels of <1%. *Eriophorum vaginatum* roots are present at the lowest levels throughout the diagram with around 1-2% scattered at horizons throughout the zone. *Eriophorum vaginatum* spindles are very abundant (5 points) but only present at two horizons mid-way through the zone.

Charcoal fragments increase slightly within this zone for the smaller and larger size classes, <15,625 μm^2 (up to 25), 15,625-62,500 μm^2 (up to 25), 0.25-1 mm^2 (up to 30) and 1-4 mm^2 (up to 10) and more rapidly increase for the mid-size range 62,500 μm^2-0.25 mm^2 (up to 350 at the start and up to 200 throughout the rest of the zone).

The first half of the zone being dominated by U.O.M suggests that the mire was in a relatively dry condition. This coincides with a rise of medium/large charcoal fragments indicating an *in situ* fire which is more likely to occur when the mire is desiccated. Wetter conditions may have prevailed in the second half of the zone as there are remains of *Sphagnum* section *Cuspidata* which are found in pools, often submerged. U.O.M levels decline indicating more of the mire vegetation was preserved which is more probable under wetter mire conditions. Associated with this are low charcoal counts that could be expected as a fire could not occur as readily on a wetter mire surface. However, records of *Calluna vulgaris* and *Erica tetralix* leaves, which were absent from the first half of the zone, seem to contradict this. They suggest drier mire conditions, but they do occur after the charcoal peak which may imply regeneration after the burn. The only other species evident from the macrofossil data to be growing on the mire throughout this zone are low levels of *Eriophorum vaginatum.*

4.2.1.3 Zone MLC-c (35.5-26.5 cm)

The most significant feature of this zone is the *Sphagnum* recorded, this is the most abundant of the entire diagram. In the first half of the diagram there are records of *Sphagnum* section *Acutifolia* (3%), *Sphagnum magellanicum* (<1%) and *Sphagnum* section *Cuspidata* (3%) and in the second half records of *Sphagnum papillosum* (5%) and *Sphagnum* section *Acutifolia* (<1%). Monocots. undiff. dominate the zone (70-80%) except for the last few horizons where levels drop (30-55%). Associated with these are corresponding changes in U.O.M; which is at 15-30% at the start of the zone and increases to 40-70% at the end of the zone. Monocot. roots are present consistently at levels seen in the last zone (1-5%). *Ericales* roots decrease marginally from the previous zone (1-5%), except for a larger decline at the end to <1%. *Calluna vulgaris* leaves are only present at one horizon (32-33 cm) being rare and less frequent than the previous zone. *Erica tetralix* leaves increase to the highest levels throughout the profile being abundant to very abundant (4-5 points) at the start of the zone and rare to frequent throughout the rest of the zone. *Eriophorum vaginatum* roots increase slightly in the uppermost horizons to 2-3%, but are generally at similar levels to the previous zone. *Eriophorum vaginatum* spindles are occasional to frequent (2-3 points) but only at horizons near the start of the zone.

Charcoal fragments overall are at low levels (similar to the previous zone) for all size classes but all have a small peak mid-way through the zone where they reach the following levels <15,625 μm^2 (85), 15,625 μm^2-62,500 μm^2 (85), 62,500-0.25 mm^2 (200), 0.25-1 mm^2 (45) and 1-4 mm^2 (15).

In this zone the high percentages of monocots. undiff. reveal that much of the mire community was grasses and/or sedges. *Eriophorum vaginatum* representation is slightly higher than the previous zone. The highest recordings of *Erica tetralix* and *Sphagnum* species are found here. The mire appears to have been relatively wet as indicated by (a) low U.O.M values hence less decomposition and therefore lower amounts of unidentified organic matter; (b) highest diagram recordings of *Sphagnum* remains and (c) the highest recordings of *Erica tetralix* which prefers wetter conditions than *Calluna vulgaris.* The *Sphagnum* species *Sphagnum* section *Cuspidata* at the start of the zone shortly followed by *Sphagnum* section *Acutifolia* then *Sphagnum papillosum* at the end suggest that the site was particularly wet. The small peak in charcoal mid-way through the zone, in association with a lack of *Sphagnum,* may suggest a local fire was significant enough to have affected the mire species and eliminated them from the vegetation community.

4.2.1.4 Zone MLC-d (26.5-14.5 cm)

This zone is broadly characterised by an absence of *Sphagnum.* Monocots. undiff decrease from the previous zone, now representing 20-60% throughout the zone. U.O.M increases to values between 35-80%. Monocot. roots at levels of 1-5% are similar to all previous zones. *Ericales* roots increase slightly to 1-10%, *Erica tetralix* leaves are present at either end of the zone being frequent (3 points), this being their the last recording in the diagram. *Calluna vulgaris* leaves are rare to occasional (1-2 points). *Eriophorum vaginatum* roots are at levels of 2-5%, *Eriophorum vaginatum* epidermis is present at *c.* 1% at either end of the zone and *Eriophorum vaginatum* spindles are present in three horizons near the surface, being rare to occasional (1-2 points).

Charcoal fragments of all size classes are low as in the previous two zones except for an increase in the larger size class, 0.25-1 mm^2 (up to 50) at the start of the zone.

The mire vegetation assemblage during this zone contains a majority of grasses and/or sedges with some ericaceous remains including *Erica tetralix* and *Calluna vulgaris.* There is a small increased representation of the cyperaceous species *Eriophorum vaginatum* and most notably an absence of *Sphagnum* from the highest diagram frequencies of the previous zone MLC-*c.* The higher values of U.O.M., the absence of *Sphagnum,* slight increase of *Calluna vulgaris* and the decline of *Erica tetralix* from the previous zone may suggest that the site was drier than previously. A rise in larger charcoal fragments mid-zone coincides with absences of *Calluna vulgaris* and *Erica tetralix* records which may be as a result of fire suppressing these species.

4.2.1.5 Zone MLC-e (14.5-8.5 cm)

This zone shows a transition from U.O.M. which was initially high in the first half of the zone (50-65%) to high values of monocots. undiff. (55-90%) in the second half of the zone. *Ericales* roots are present at levels of 1-7 % typical of all previous zones except for one reading of 15% at 13-14 cm. *Eriophorum vaginatum* roots are generally the highest levels recorded in the diagram (5-7%), with the highest levels at the start of the zone. There is an absence of *Calluna vulgaris, Erica tetralix* leaves, *Sphagnum* and monocot. roots.

This zone is distinctive owing to its large and rapid increase of charcoal fragments of all size classes. The following levels <15,625 μm^2 (up to 290), 15,625-62,500 μm^2 (up to 280), 62,500 μm^2-0.25 mm^2 (650), 0.25-1 mm^2 (up to 150) and 1-4 mm^2 (up to 45) are all peaks within their size classes for the entire diagram.

The mire vegetation during this zone is dominated by grasses and/or sedges, particularly *Eriophorum vaginatum* and there is also a lack of ericaceous species and absence of *Sphagnum.* The main feature of this zone is the massive rise and peak in charcoal fragments of all size classes. *Eriophorum vaginatum* increasing in this zone may be an initial response to the fire creating suitable conditions for growth immediately after the fire event. The absence of *Sphagnum* and *Erica tetralix* and the very low frequency of *Calluna vulgaris*, in comparison to the much higher frequencies in the previous zone, may indicate locally drier mire conditions. The rise in U.O.M in the last few horizons of the zone maybe a result of drying out the mire surface so decomposition rates were higher.

4.2.1.6 Zone MLC-f (8.5-4 cm)

An abundance of *Calluna vulgaris* remains dominate and characterise this zone. *Calluna vulgaris* wood, previously unrecorded occurs at *c.* 3%, *Calluna vulgaris* leaves are frequent to very abundant (3-5 points), *Calluna vulgaris* flower heads are frequent to abundant (3-4 points) *Calluna vulgaris* seeds are occasional (2 points). Additionally, the top 4 cm of the monolith was not analysed further as it contained fresh undecomposed *Calluna vulgaris* material representing the contemporary mire vegetation. Ericales roots also increase from all previous zones to 5-20%. The first two horizons contain higher monocots. undiff. (60-90%) but this then drops to be overtaken by U.O.M (65-80%). *Eriophorum vaginatum* roots decline from the previous zone (1-3%), but *E.vaginatum* epidermis increases to 3-25%. *Sphagnum* re-appears in this zone with *Sphagnum* section *Cuspidata* (3%) throughout the zone and *Sphagnum magellanicum* occurring in the top horizon.

Charcoal fragments decline in all size classes from the previous zone: <15,625 μm^2 (up to 100), 15,625-62,500 μm^2 (up to 100), 62,500 μm^2-0.25 mm^2 (180), 0.25-1 mm^2 (up to 50) and 1-4 mm^2 (up to 10). However, they all (except mid range, 62,500 μm^2-0.25 mm^2) are comparatively high compared to the other zones in the diagram.

The most significant vegetational changes take place within this zone. Where the mire was dominated by *Calluna vulgaris* which continues through to the present day. *Sphagnum* reoccurs and the cyperaceous species, *Eriophorum vaginatum,* appears more abundant at the start compared to the close of the zone. The mire appears to have become drier in the upper horizons indicated by high U.O.M values and ericaceous remains with the abundance of the drier species *Calluna vulgaris* and lack of the wetter species *Erica tetralix. Calluna vulgaris* may have regenerated after the extensive fire in the previous zone and may be left with a competitive advantage if deep roots remained undamaged. Alternatively, it may reflect improved preservation of the macrofossil in near-surface horizons. This may also be the case for the reappearance of *Sphagnum* remains and the increase in *Eriophorum vaginatum*. *Eriophorum vaginatum* continues to increase but declines towards the surface which may be a response to the vegetation succession of the *Calluna vulgaris*. *Sphagnum* remains indicate that the mire was still wet enough for some species of *Sphagnum* to grow and *Sphagnum magellanicum* is important as it is now thought to be rare across South Wales. The larger charcoal fragments in this zone, may indicate that an *in situ* fire was responsible for a drier mire and the higher levels of U.O.M.

The contemporary vegetation survey at MLC (P.Jones, CCW, pers. com. 1999) shows a number of species present, with their relative abundance. These include *Calluna vulgaris* (dominant), *Eriophorum vaginatum* (abundant), *Eriophorum angustifolium* (abundant), *Cladonia spp.* (frequent), *Sphagnum subnitens* (occasional), *Sphagnum fimbriatum,* (occasional), *Calypogeia fissa* (occasional), *Cephalozia spp.* (occasional), *Polyrichum commune* (occasional) and *Erica tetralix* (rare), *Sphagnum cuspidatum* (rare) and *Campylopus* (rare). Within the stand *Juncus squarrosus, Vaccinium myrtillus, Sphagnum papillosum* and *Dicranum scorparium* were found.

In comparison to the macrofossil data there are a number of species not detected in this zone include; *Eriophorum angustifolium, Erica tetralix, Cladonia, Sphagnum subnitens, Sphagnum fimbriatum, Calypogeia fissa, Cephalozia sp.*, *Polyrichum commune, Campylopus, Juncus squarrosus, Vaccinium myrtillus* and *Dicranum scorparium.* The *Sphagnum* species *Sphagnum* section *Acutifolia* and *Sphagnum magellanicum* are present in the macrofossils but not in the vegetation survey. This suggests that species are not always recorded and/or at different frequencies in the macrofossil record compared to actual vegetation on the mire. This may be due to differential preservation rates between species and also indicates that macrofossil analysis only records species *in situ* and so may not be representative of the sampling area.

4.2.2 Description and Interpretation of Humification Data

The humification data for MLC, expressed as percentage light transmission, are presented in figure 4.6. Overall the trend for the MLC humification data is that it becomes less humified towards the surface, from *c.* 22 % light transmission at 50 cm to 67% at 4 cm. The whole of the profile is quite 'noisy' so only trends are described not every individual peak and trough superimposed on this.

4.2.2.1 Zone MLC-a (51-50 cm)

Light transmission in this zone consists of two sample horizons starting at *c.* 22% and rising to *c.* 28%. The mire surface appears to becoming wetter during this zone and the trend cannot be compared to U.O.M as this only consists of one sample horizon.

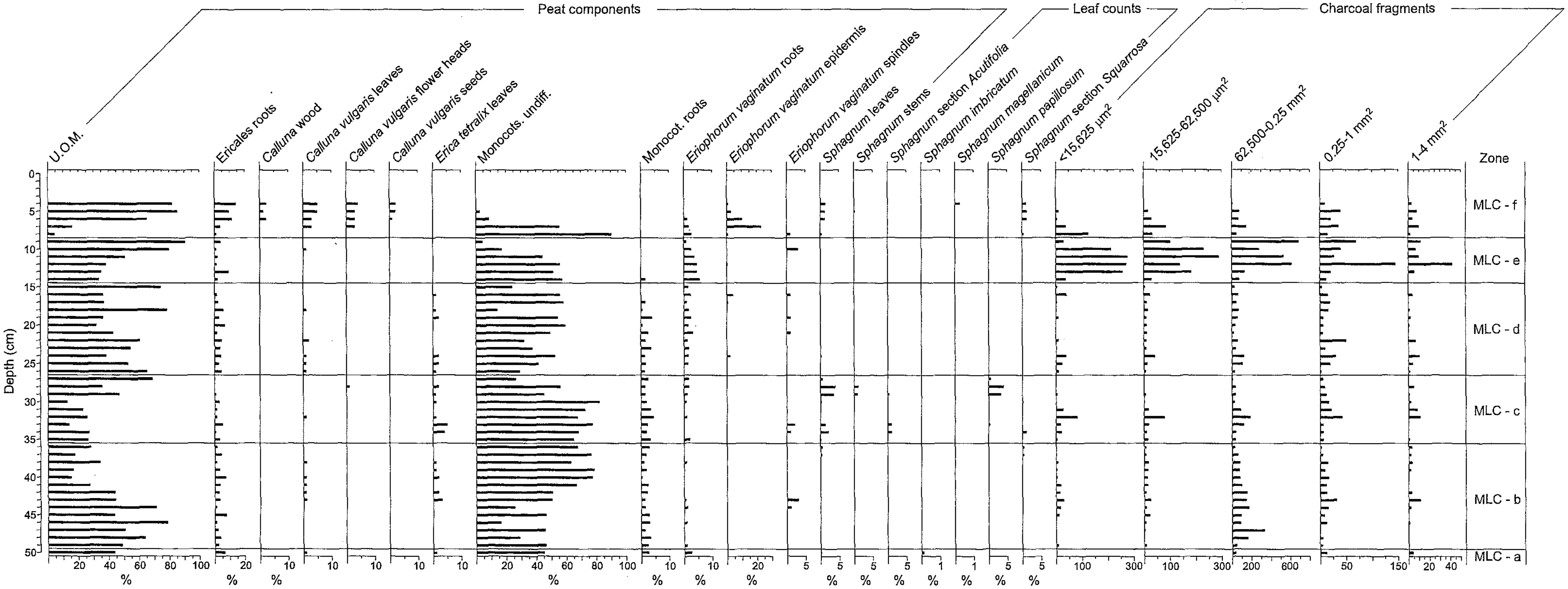


Fig. 4.5 Mynydd Llangatwg
Monolith MLC
Plant macrofossil and charcoal diagram
(Reproduced from Pearson, F. 2001)

4.2.2.2 Zone MLC-b (50-35.5 cm)

The first half of this zones shows a steep increase in light transmission from *c.* 28% at 35.5 cm to *c.* 34% at 44 cm. The second half of the diagram shows a decrease of equal gradient to *c.* 28% at the close of the zone. The first half of the zone shows an increase in mire wetness and the latter half becoming drier. However, the U.O.M data show completely the reverse situation.

4.2.2.3 Zone MLC-c (35.5-26.5 cm)

The first half of the zone shows a slight fall in light transmission from *c.* 28% at 35.5 cm to *c.* 20% at 31 cm, which is the lowest value in the diagram. This is followed by a slight rise despite being 'noisy' to *c.* 24% at the close of the zone. This suggests the mire continued becoming drier and reached its driest point within the diagram after which it became slightly wetter towards the close of the zone. The U.O.M again show the reverse situation.

4.2.2.4 Zone MLC-d (26.5-14.5 cm)

This zone reveals a very gentle rise in light transmission from *c.* 24% to *c.* 26% two-thirds of the way through the diagram . This is preceded by a rapid increase to 42% at the close of the zone.
The first two thirds of the zone show that the mire became slightly wetter than the previous zone, but was still in one of the driest states in comparison to the whole diagram. The last third of the zone shows a rapid increase to wetter conditions. The U.O.M data contain a few isolated large peaks in single horizons but, overall, suggests the mire became a lot drier than the previous zone; however, the data do not show the sharp rise to wetter conditions at the end of the zone.

4.2.2.5 Zone MLC-e (14.5-8.5 cm)

This zone shows an overall trend of a steep rise in light transmission from *c.* 42% to *c.* 52% at the end of the zone.

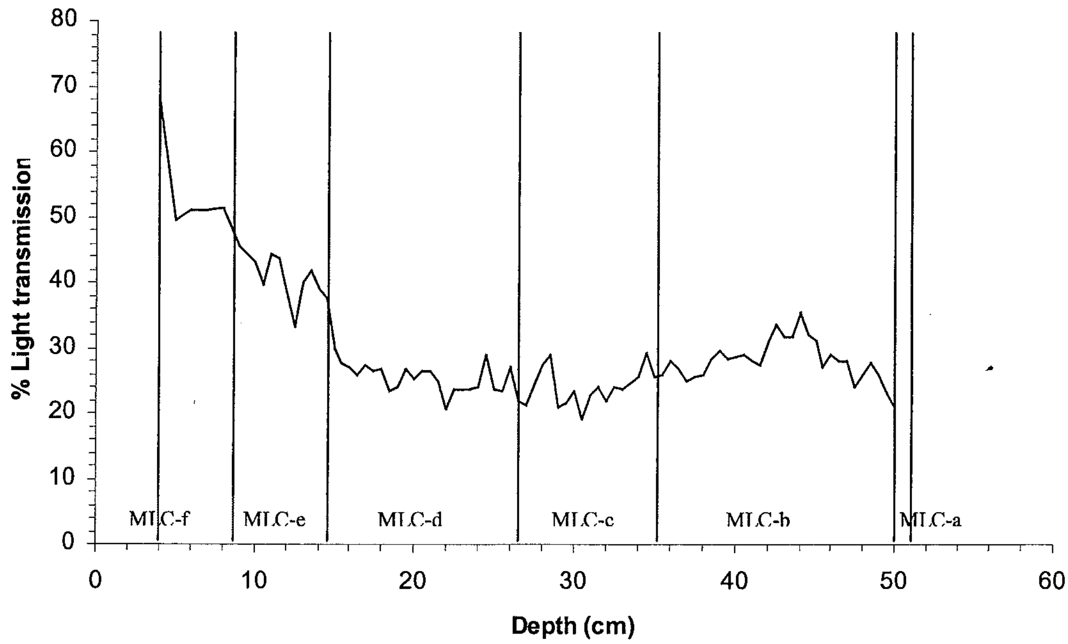
The light transmission data indicate that the mire became wetter during this zone and was wetter than all previous zones. The U.O.M data show slightly wetter conditions at the start of the zone but contradicts the light transmission data at the end of the zone by indicating very dry mire conditions.

4.2.2.6 Zone MLC-f (8.5-4 cm)

This zone begins with a small decline to *c.* 50% light transmission at 5 cm followed by a sharp rise culminating at *c.* 68% at the top of the diagram. This zone indicates the mire became slightly drier at the start but still generally much wetter than any of the previous zones. The mire then became much wetter towards the surface. The U.O.M data contradict this by indicating wetter conditions at the start and drier conditions at the end of the zone.

From *c.* 16 cm, covering the last few horizons of zone MLC-d and all of MLC-e and MLC-f, the rapid increase in light transmission most probably reflects the change from catotelm to acrotelm rather than increased mire wetness. Therefore a climate signal from this data is difficult to disentangle.

Figure 4. 6 Monolith MLC: Humification expressed as % transmission



4.2.3 Description and Interpretation of Pollen Data

The pollen data for MLC is presented in figure 4.7. The preparation of samples was undertaken by Freya Pearson, identification of pollen by Prof. Frank Chambers and creation of diagram by Dr John Daniel using Tilia and Tilia Graph (Grimm 1991) as part of a report for the Countryside Council for Wales. The pollen diagram zones have been replaced by those of the MLC plant macrofossil data to aid comparison. The following description and interpretation are by Freya Pearson and only includes *Gramineae, Cyperaceae* and *Calluna* pollen and *Sphagnum* spores as these are the principal species that represent the local mire environment.

4.2.3.1 Zone MLC-a (51-50 cm)

Sphagnum is dominant at *c.* 40%, *Calluna* at *c* .20%, *Gramineae c.* 7% and *Cyperaceae c.* 5%. This zone only consists of one sample horizon as the zonation of the MLC pollen diagram follows that of the MLC plant macrofossil diagram to aid interpretation. The macrofossil zone MLC-a was established as it contained the only occurrence of the rare taxon Sph*agnum imbricatum*. The pollen interpretation of this zone is therefore included in the subsequent zone.

4.2.3.2 Zone MLC-b (50-35.5 cm)

Sphagnum is dominant (*c.* 60-80%) up to 46cm thereafter declining to *c.* 20-30 % and co-dominant with *Calluna* (*c.* 15-28%). *Cyperaceae* is low at the start of the zone (up to 5%) but rises to *c.* 13% mid-zone declining slightly at the close of the zone. *Gramineae* is at levels of *c.* 7-12%. In this zone, the mire is firstly dominated by *Sphagnum* spores suggesting particularly wet mire conditions. *Calluna* pollen is moderately abundant in this zone indicating the mire must have been sufficiently dry in places to support this species. The mire also supported moderate amounts of Graminaceous and Cyperaceous species.

4.2.3.3 Zone MLC-c (35.5-26.5 cm)

Sphagnum (*c.* 20%) and *Calluna* (12-27%) are co-dominant, except for an isolated peak of *Sphagnum* (*c.* 50%) at 30-31cm. *Cyperaceae* increases slightly from the end of the last zone (*c.* 5-15%) but declines in the last sample horizon of 26-27cm. *Gramineae* is at levels similar to the previous zones (*c.* 9-11%) declining in the last sample horizon to *c.* 5%. The mire supported a vegetation assemblage similar to the second half of the previous zone where *Sphagnum* and *Calluna* were co-dominant with moderate frequencies of graminaceous and cyperaceous species. Additionally, there is a peak in *Sphagnum* mid-zone but only in one sample which may suggest conditions were wetter temporarily.

4.2.3.4 Zone MLC-d (26.5-14.5 cm)

Calluna dominates the start of this zone (*c.* 25-35%), declines mid-zone to reach *c.* 15% at the close of the zone. However, the last sample horizon is dominated by *Calluna* (*c.* 55%). Overall, *Sphagnum* declines from the previous zones ranging between *c.* 15-20% except for an isolated peak mid-zone. *Gramineae* starts at *c.* 5% rising to *c.* 15%. *Cyperaceae* starts at very low levels (*c.* 1%) rising throughout the zone peaking at *c.* 15% towards the end of the zone, only to fall slightly in the last sample horizon. During this zone the mire may have become slightly drier as *Sphagnum* levels decline from the previous zones and *Calluna* pollen increases. Graminaceous and cyperaceous species are generally at levels similar to the previous zone

4.2.3.5 Zone MLC-e (14.5-8.5 cm)

This zone is dominated by *Calluna* (*c.* 40-70%) at frequencies significantly higher than any previous zone. *Sphagnum* declines to levels lower than all previous zones (*c.* 1-10%). *Gramineae* is found at similar frequencies to the previous zone (*c.* 15%). *Cyperaceae* is low in the first sample horizon (*c.* 3%) but peaks at 10-11cm at *c.* 17%. The most dramatic vegetation changes on the mire began in this zone. *Calluna* rapidly expands to become the most dominant species. *Sphagnum* is at very low levels and graminaceous and cyperaceous species are also at low levels. The mire may have become drier leading to these vegetational changes. The peak in charcoal fragments recorded within this zone suggest fire may be responsible for the regeneration and expansion of *Calluna* and demise of Sphagna.

4.2.3.6 Zone MLC-f (8.5-2 cm)

Calluna dominates this zone with the highest levels within the diagram of *c.* 65-88%. Sphagnum declines to the lowest levels of the diagram ranging from *c.* 0-5%, *Cyperaceae* also declines to the lowest diagram recordings at *c.* 0-5% and *Gramineae* declines from *c.* 15% at the start of the zone to *c.* 10% at the close of the zone. This zone was clearly dominated by *Calluna* pollen at levels surpassing all previous zones. *Sphagnum* and *Cyperaceae* is almost non-existent and *Gramineae*

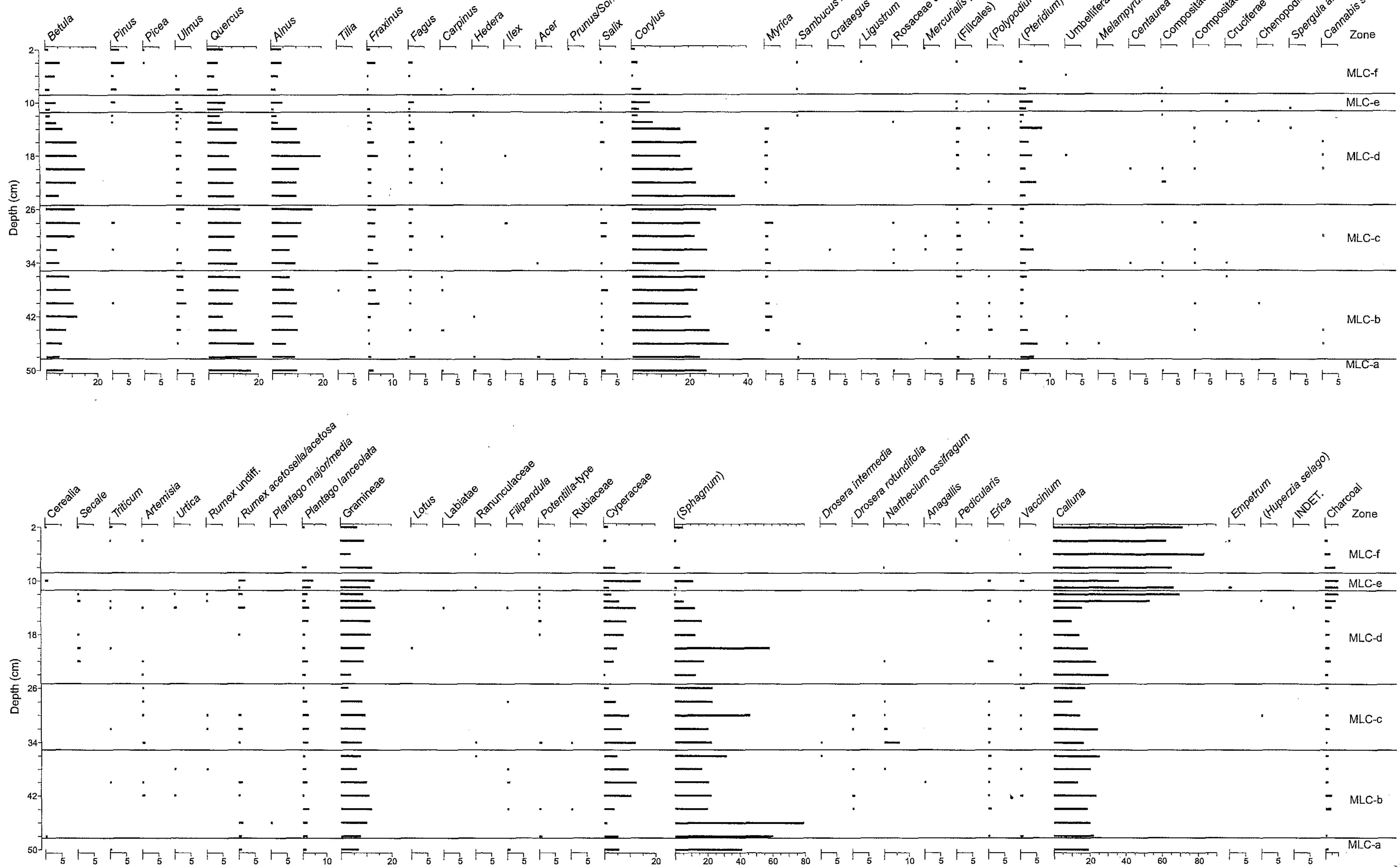


Fig. 4.7 Mynydd Llangatwg

Monolith MLC
Percentage pollen diagram (% TLP)
(Reproduced from Chambers *et al.*, 2001)

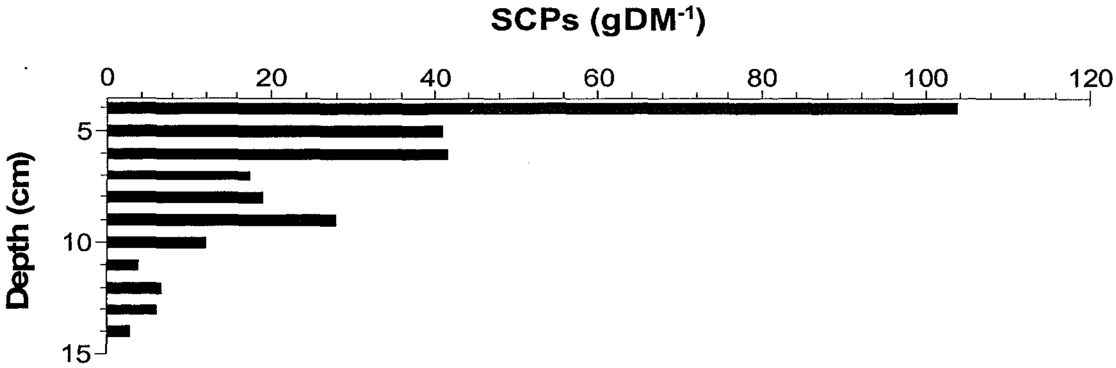
is moderately abundant. The vegetation assemblage during this zone suggests that the mire may have been in a particularly dry state.

4.2.4 Description and Interpretation of the SCP Profile

The SCP profile for MLC is presented in figure 4.8. The SCP record begins at 14-15 cm at a low level of 3 gDM^{-1} and the overall trend is for a gradual rise in the SCP profile culminating with a peak in the uppermost surface horizon of 4-5 cm at 104 gDM^{-1}. Superimposed on this are the following smaller trends: a gradual rise from the start of the SCP record to 7g DM^{-1} at 12-13 cm, dropping slightly at 11-12 cm to 4 gDM^{-1}, then rising to a small peak of 28 gDM^{-1} at 9-10 cm, between 9-7 cm falling slightly to 17 gDM^{-1}, increasing to 41 gDM^{-1} at both 6-7 cm and 5-6 cm and finally peaking at the surface horizon of 4-5 cm at 104 gDM^{-1}.

The SCP profile for MLC has very similar characteristics to MLM, which could be expected, for profiles located within the same mire only 1 km apart. The SCP profile at MLC begins at 14-15 cm so this may be interpreted as the start of the industrial revolution in the mid-19th century, perhaps earlier if local industry contributed to SCP deposition. As in MLM the rapid increases in SCPs dating the 1950-60s is unlikely to be the small and isolated peak at 8-9 cm and more likely to be represented in the rapid increase of the sub-surface horizons starting at 7cm and culminating at 4 cm. These result reveals an absence of the post-1970s SCP decline implying that the SCPs may had built up at the surface and the mire is no longer actively peat forming. Other possible explanations could be that the profile is truncated or that there have been movements within the profile. It must be considered why the same post 1970s SCP decline is also evident at MLM. Chambers & Mauquoy (1998) study on Mynydd Llangatwg found that profile MLA-S was truncated and did not experience the recent SCP decline whilst intact profile MLA-E did experience a recent SCP decline.

Fig. 4.8 Monolith MLC: SCP profile



4. Summary diagrams of MLM and MLC plant macrofossil, charcoal, pollen, humification and SCP data

Table 3 MLM Monolith

Zone	Plant Macrofossil & Charcoal	Pollen	Humification	SCPs	Interpretation
MLM-a (55-47.5 cm)	Highest frequencies of *Ericales* roots, *C.vulgaris* and *E.tetralix.* Highest charcoal frequencies in larger size classes. No *Sphagnum* except small amounts of *S.imbricatum.* U.O.M low.	Ericaceae high. *Sphagnum* moderate-low. Gramineae low. Cyperaceae v.low.	Joint driest conditions (with 2nd half MLM-b) at start of zone becoming slightly wetter towards end.		Mire in a dry condition as indicated by high Ericaceae, *Calluna* and *Erica* remains, low *Sphagnum* and the most humified conditions. Cause may be fire as indicated by high frequencies of charcoal. *S.imbricatum* now a rare taxon in contemporary mire vegetation.
MLM-b (47.5-30.5 cm)	High frequencies of *Ericales* roots and *E.tetralix.* Small amounts of *S.imbricatum*, start of zone and *S.papillosum* at end. High frequency of larger charcoal fragments mid-zone. U.O.M high.	*Sphagnum* highest frequencies, especially at start of zone. Ericaceae moderate-high. Gramineae low. Cyperaceae v.low.	Wetter at start of zone & joint driest conditions (with MLA-a 1st half) at end of zone. An isolated peak mid-zone suggesting drier conditions than previous zone.		Mire wetter at start of zone indicated by high *Sphagnum* and humification data. Drier throughout rest of zone indicated by high Ericaceae and humification data. Cause may be fire mid-zone.

MLM-c (30.5-26.5 cm)	Low *Ericales* roots, no *C.vulgaris* or *E.tetralix.* No *Sphagnum.* No charcoal. Peak in *E.vaginatum* spindles. U.O.M high.	Ericaceae moderate-high. *Sphagnum* moderate-low. Gramineae low. Cyperaceae low.	Mire becomes wetter than previous zones.		Ericaceae and *Sphagnum* co-dominant. No indications that the mire was either particularly wet or dry.
MLM-d (26.5-15.5 cm)	Low *Ericales* roots, no *C.vulgaris* or *E.tetralix.* Increase in *E.vaginatum* roots. Rise in larger charcoal fragments mid-zone. U.O.M moderate-high	Ericaceae highest frequencies. *Sphagnum* moderate-low. Gramineae moderate-low. Cyperaceae low.	Wetter conditions than previous zones followed by drier conditions after mid-zone to close but not as dry as previous zones.	Start of SCPs at top of zone (*c.*17cm) Mid-1800s	Ericaceae dominates, Gramineae increases and *Sphagnum* is low. Burning may cause these changes as indicated by a small peak in charcoal .
MLM-e (15.5-11.5 cm)	Increase in *E.vaginatum* roots and epidermis. Low *Ericales* roots, no *C.vulgaris* or *E.tetralix.* Peak in charcoal fragments especially smaller sizes. U.O.M low.	Gramineae moderate-high. Cyperaceae moderate. *Sphagnum* v.low. Ericaceae low.	Wetter mire than all previous zones.		Expansion of Gramineae and low *Sphagnum* and Ericaceae may be an initial response of fire indicated by a peak in charcoal fragments. The top of the zone dates to around the mid-1800s.
MLM-f (11.5-0 cm)	Start of *Molinia caerulea* record, v.high frequency. Start of *S.s.Cuspidata,* v.high frequency. Start of *Drepanocladus fluitans,* low frequency but high in upper-most horizon. No charcoal remains. U.O.M very low.	Gramineae highest frequencies. Cyperaceae moderate-high. *Sphagnum* v.low. Ericaceae v.low.	Wettest mire conditions of all zones.	Peak in SCPs mid-zone (*c.*7cm) or (4-0cm) 1950-60s. or peat stopped forming or profile truncated	Dominance of Gramineae and records of *Molinia caerulea* may be a result of the burning in he previous zone. Pollen evidence reveals that *Sphagnum* levels are low and that high recording in the macrofossils may be a result of increased preservation in the acrotelm.

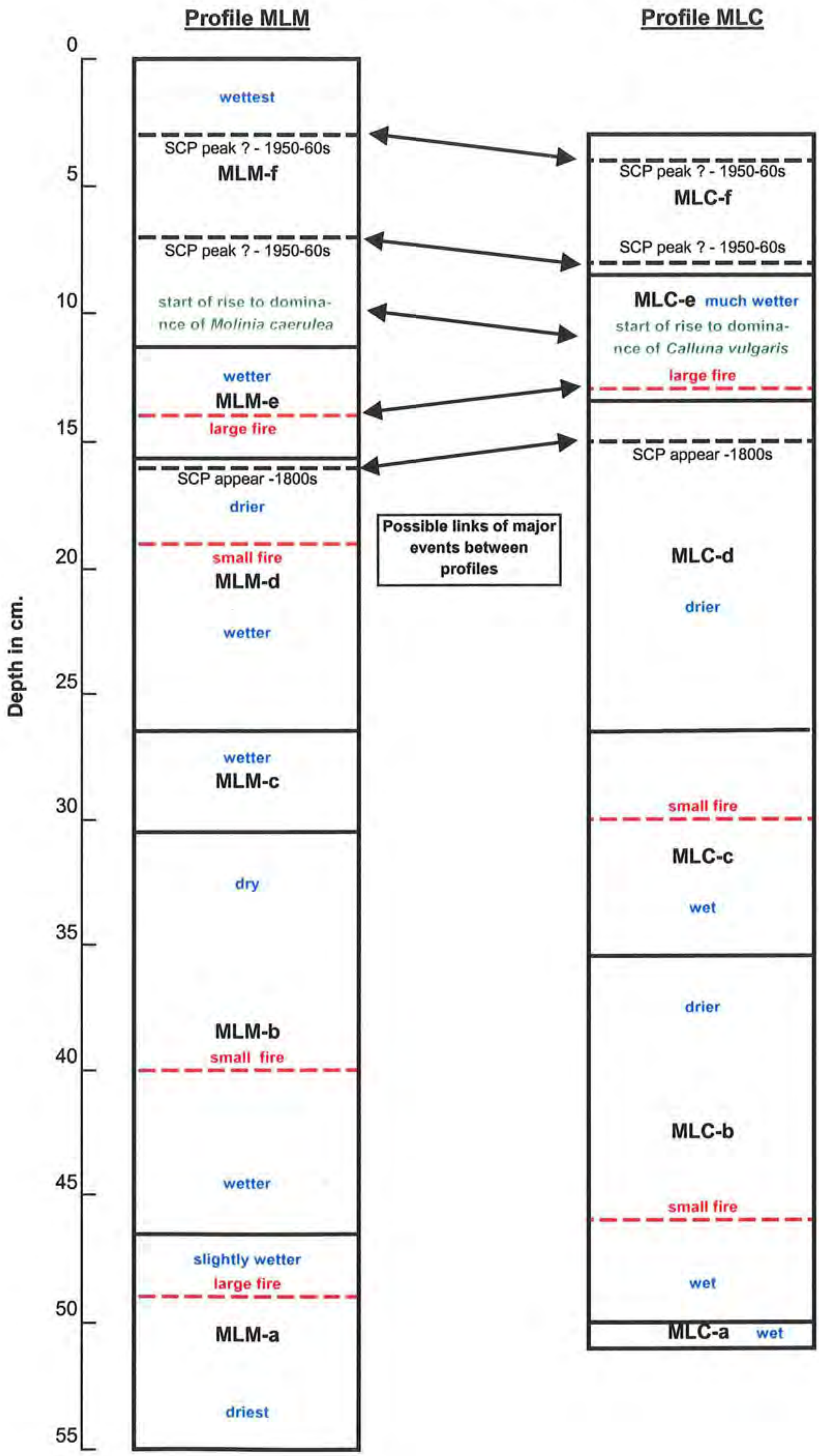
Table 4 Monolith MLC

Zone	Plant Macrofossil & Charcoal	Pollen	Humification	SCPs	Interpretation
MLC-a (51-50 cm)	Only recording of *S.imbricatum,* v.low level.	Highest *Sphagnum.* Low Gramineae & Cyperaceae. *Calluna* moderately high.	Mire getting wetter from one of the driest mire conditions.		Mire may have been in a wet condition and *S.imbricatum* now a rare taxon in contemporary mire assemblages.

MLC-b (50-35.5 cm)	Moderate levels of *Ericales* roots, *C.vulgaris* & *E.tetralix* leaves. Lowest levels of *E.vaginatum* roots. Low levels of *S.s.Cuspidata* at zone end. Low charcoal frequencies, except medium size range moderate. U.O.M v.high 1st half but low in 2nd half of zone.	*Sphagnum* very high at start and moderately high end of zone. *Calluna* moderately high. Cyperaceae low start and moderately high at end. Gramineae high mid-zone.	Mire wetter than previous zone but becoming drier in 2nd half of zone.		Pollen & humification suggest the start of the zone was wetter than the last two thirds, but U.O.M contradicts this. Of the Cyperaceae species *E.vaginatum* was present & of *Sphagnum S.s.Cuspidata* was present at the end of the zone. Pollen & macrofossils suggest *Calluna* was moderately abundant & macrofossils also reveal *E.tetralix* was present.
MLC-c (35.5-26.5 cm)	Highest *Sphagnum* records; *S.s.Actifolia* & *S.s.Cuspidata* start & *S.papillosum* end of zone. Highest frequencies of *E.tetralix.* Moderate levels of *Ericales* roots. Low *C.vulgaris* levels. Small peak in charcoal mid-zone. Low U.O.M but high at end of zone.	*Sphagnum* moderately high. *Calluna* moderate to low. Cyperaceae and Gramineae low-moderate.	Mire driest of all zones.		Although the macrofossils suggest the mire was probably v. wet from the highest *Sphagnum* remains & low U.O.M, the pollen suggests it was no more frequent than the last zone. Of the *Sphagnum* species, *S.papillosum, S.s.Acutifolia* & *S.s.Cuspidata* were present. Pollen indicates *Calluna* was at levels similar to the previous zone; however, macrofossil remains are low but high for *E.tetralix*
MLC-d (26.5-14.5 cm)	Moderate levels of *Ericales* roots, *C.vulgaris* & *E.tetralix.* Moderate levels of *E.vaginatum* roots, epidermis & spindles. No *Sphagnum.* Low charcoal records. High U.O.M.	*Calluna* moderately high but lower at end. *Sphagnum* moderately high. Cyperaceae low-moderate. Gramineae moderately high & high end zone.	Mire dry; however, slightly wetter than previous zone becoming more so at end of zone.	Start of SCPs at end of zone (*c.*15cm) dated to the mid-1800s.	*Calluna* & *Sphagnum* were co- dominant. Grasses & sedges were moderate. Pollen shows a rapid expansion of *Calluna* at 13-14 cm, a little before the mid-1800s. The mire may have become drier as indicated by U.O.M and humification.
MLC-e (14.5-8.5 cm)	Moderate *Ericales* roots. No *C.vulgaris* & *E.tetralix.* No *Sphagnum.* Highest frequency of *E.vaginatum* roots. Highest charcoal record. Low U.O.M in 1st half	*Calluna* very high. *Sphagnum* very low. Cyperaceae low. Gramineae high.	Mire rapidly become wetter than all previous zones.	Peak in SCPs at end of zone (*c.*8-9 cm) dated to the 1950-60s? <u>or</u> see MLM-f	Pollen shows the most distinctive vegetation changes of high *Calluna* & low Sphagna; however, this is not detected in the macrofossils. This coincides with a charcoal peak which may be the cause. The peak of *E.vaginatum* and Gramineae may show that these species can withstand fire or are a pioneer species. Humification and U.O.M

	and low in 2nd half of zone.				suggest the mire was very wet; however, this sudden change is more likely to be attributed to better preservation in the acrotelm.
MLC-f (8.5-4 cm)	Highest frequencies of Ericales roots, *C.vulgaris* wood, leaves, flowerheads & seeds. Highest *E.vaginatum* epidermis & moderate roots. *S.s.Cuspidata* & *S.magellanicum* at low levels. Low charcoal frequencies. Low U.O.M in 1st ½ & high in 2nd half of zone.	*Calluna* highest frequencies. *Sphagnum* lowest levels. Cyperaceae lowest levels. Gramineae moderately high.	Despite mire slightly drier at start of zone from the end of MLM-e overall this the wettest zone in the diagram.	Peak in SCPs *c.*7-surface dated to 1950-60s ? or peat stopped forming or profile truncated?	*Calluna* is most dominant in this zone. Sphagna & sedges v. low. The mire may have been particularly dry as indicated by high U.O.M after the charcoal peak. Humification results near the surface may suggest much wetter conditions or better preservation in the acrotelm.

Fig. 4.9 Summary Diagrams of Profiles MLM and MLC



CHAPTER FIVE

DISCUSSION

This chapter discusses the major vegetational shifts in both profiles MLM and MLC and in particular the behaviour of *Calluna vulgaris, Sphagnum* and *Molinia caerulea,* whilst dating and elucidating possible causal factors are explored. The findings are also put in the context of other palaeoecological research conducted at Mynydd Llangatwg and elsewhere in Wales, Britain and Europe.

5.1 Recent vegetational changes at Mynydd Llangatwg and their possible causes

5.1.1 The behaviour of *Calluna vulgaris*: MLC

At location MLC the pollen and macrofossil profiles show the rise to dominance of *Calluna vulgaris* is the major recent vegetational shift, the macrofossil evidence showing a rise in ericaceous species, particularly *Calluna vulgaris*, from 8 cm to the surface. However, the pollen data expose most clearly the rise in *Calluna vulgaris* from 13 cm to the surface, which suggest an earlier rise to dominance than indicated in the macrofossil data as the latter indicate *in situ* species growth. The pollen data may represent long-distance transportation, but, research on pollen dispersal by Evans & Moore (1986) *cit.* Moore *et al.* (1996) may suggest the earlier pollen *Calluna vulgaris* rise from 13 cm onwards may have been a local feature of location MLC. Their study on a moorland/blanket mire in north-east Britain compared the proportion of *Calluna vulgaris* pollen in surface samples to the percentage cover of the species within one metre of the sampling location. This revealed a linear relationship between *Calluna vulgaris* density and pollen sedimentation which permits the interpretation of fossil *Calluna vulgaris* assemblages in terms of the local abundance. The findings of Moore *et al.* (1996) suggest that at location MLC the rise to dominance of *Calluna vulgaris* as shown in the pollen record is a local feature and not a result of long distance transportation. Additionally, the pollen data reveals an earlier rise to dominance than the macrofossil's.

Associated with the *Calluna vulgaris* expansion is the demise of *Sphagnum* and Cyperaceae. However, the latter does increase in one sample horizon (10-11 cm) and maybe the pollen of *Eriophorum vaginatum* as the macrofossils show a corresponding increase. Gramineae pollen remains at levels that are consistent throughout the diagram and is moderately abundant, decreasing slightly to wards the surface. The mire pollen and macrofossil data suggest the vegetation community before the *Calluna vulgaris* expansion was significantly more dominant in *Sphagnum* and Cyperaceae, *Calluna vulgaris* was present but at lower levels and mainly co-dominant with *Sphagnum*. However, the latter reaches much higher frequencies in some horizons and especially at the start of the profile. Gramineae and Cyperaceae pollen fluctuate but are at similar frequencies and are moderately abundant in comparison to the other species.

The recent dominance of *Calluna vulgaris* at MLC contrasts with the majority of other published studies which have found the recent trend to be the demise of *Calluna vulgaris* with an associated rise in grasses. For example, on mires by Moore (1968), Chambers *et al.* (1979), Day (1989) *cit.* Yeo (1997), Chambers (1983), Wiltshire & Moore (1983) and Chambers & Mauquoy (1998) and on moorland, Damblon (1992) and Stevenson & Thompson (1993)as described in chapter two.

Coinciding with the onset of the *Calluna vulgaris* expansion at MLC, is a charcoal peak between 9-15 cm indicating that local fire(s) may be the causal effect of the vegetation change from a previously more *Sphagnum*- and sedge-dominated mire. Fire has been used as a management tool on moorland to regenerate *Calluna vulgaris* by keeping it young, productive and nutritious (Hobbs & Gimmingham 1987) and burning has long been employed in Wales as a management tool but also as a result of sporadic accidental burns (Yeo 1997). As Shaw *et al.* (1996) note, the effect of burning on the vegetation will depend on the initial vegetation composition, intensity and frequency of the fire, time of the burning and wetness of the substratum. Without historical evidence the cause of the fire cannot be established. Fire can rejuvenate heather as it stimulates new growth, especially in young heather; however, a very hot fire and/or heather in a degenerate phase may regenerate slower or be killed off (Shaw *et al.* 1996). Thus, if fire was the cause for the *Calluna vulgaris* expansion at location MLC then it may have been young heather in a building/mature phase of growth and/or a cooler quick-moving fire. Hobbs (1994) *cit.* Shaw *et al.* (1996) in a study on blanket bog (*Calluna-Eriophorum*) at Moor House in the Pennnines, found that frequent burning (every 10 yrs) led to a shift to *Eriophorum vaginatum,* but a longer period between fires (every 20 yrs) allowed *Calluna vulgaris* time to become co-dominant again and this may explain why there is a short lived increase in Cyperaceae, possibly indicating *Eriophorum vaginatum* the species from the macrofossils, before the rapid *Calluna vulgaris* expansion at MLC.

Earlier research by Chambers & Mauquoy (1998) at Mynydd Llangatwg also found a rise in Ericales roots and *Calluna vulgaris* in two macrofossil profiles. However, depths of change and dates differ. In profile MLA-E ericaceous remains rise from 2 cm to the surface, and were associated with the highest charcoal frequencies in the previous zone. The SCP peak at 7 cm, suggests this occurred after the 1950-60s. At MLA-S a rise in *Calluna vulgaris* from 6 cm to the surface, was associated with the highest charcoal frequencies and a SCP peak at 2 cm suggest this occurred after the mid 19^{th} century but before the 1950-60s. Both *Calluna vulgaris* expansions may have been caused by fire. This may also indicate that there was an extensive fire affecting MLC and MLA-E and MLA-S as they are only 15-20 m apart. At MLC the SCP peak is not clear, concentrations occur at 9 cm and between 7 cm to the surface, hence it is not clear which peak relates to the 1950-60s period attributed by Rose (1995). As the SCP record begins at 15 cm at MLC the *Calluna vulgaris* expansion must have occurred after the start of the mid 19^{th} century and sometime before the 1950-60s. Both of the SCP surface peaks at profiles MLM and MLC closely correlate in depth (see fig. 4.9); however, without further dating evidence and known accumulation rates it is difficult to link these with any certainty.

Grazing is often considered to lead to an increase in graminaceous species and decline in ericaceous species (see section 5.1.2). However, on blanket mires, grazing selectively which is likely to be evident at low stocking densities, can increase *Calluna vulgaris* cover and shoot production (Rawes & Williams 1973 *cit.* Shaw *et al.* 1996 and Hobbs & Gimmingham 1987). Limited grazing on blanket mires after burning retards, but does not prevent, heather regeneration and *Eriophorum vaginatum* may only temporarily dominate (Lance 1983 *cit.* Shaw *et al.* 1996). So at location MLC, light grazing may have encouraged a *Calluna vulgaris* expansion even after fire.

The risk of a fire may be increased by the peat drying out owing to climatic change. The humification data which could be taken to infer climate change in the top *c.* 16 cm of profile MLC show an overall increase to much less humified peat than the rest of the diagram which would indicate a wetter climate. However, this may simply be a change from the catotelm, which is more humified, to the less humified acrotelm, and not reflect a climate change. Hence, when examining such recent vegetational changes humification analysis as a proxy method of climate reconstruction may not be successful. The macrofossil data show some of the highest levels of unidentified organic matter in the profile between *c.* 4-7 cm and *c.* 9-11 cm. These contradict the overall trend of the humification data and suggest that the mire was dry between these periods leading to more complete decomposition. Possible causes could be the climate and/or fire drying out the peat. Maltby (1980) *cit.* Hobbs & Gimmimgham (1987) found that an increased number of bacteria on peat after fire might lead to a corresponding increase in humification. If the mire had become drier, it would favour an increase in species such as *Calluna vulgaris* and the demise of *Sphagnum.* For example, Bargett *et al.* (1995) suggested climate may lead blanket bog vegetation conversion to dry heathland vegetation. At location MLC it is possible climate may be responsible for the drier mire surface and the increase in *Calluna vulgaris* and demise of *Sphagnum.* The SCP record begins at 15 cm in profile MLC suggesting that the time of this *Calluna vulgaris* expansion was after the start of the industrial revolution, taken to be around the mid 19^{th} century.

5.1.2 The behaviour of *Molinia caerulea*: MLM

A major feature of location MLM not present at location MLC, is a relatively recent rise to dominance of the grass *Molinia caerulea* revealed in the macrofossil evidence as first appearing at 16 cm and rapidly increasing towards the surface. This is mirrored by a corresponding rise of Gramineae pollen at 16 cm which is most likely to reflect the species *Molinia caerulea* as macrofossils represent *in situ* vegetation on the mire. Blackford & Chambers (1993) note that the epidermal tissue of this species readily decomposes; however, Chambers & Mauquoy (1998) state pollen analysis does not vary between the catotelm and the acrotelm hence any major pollen analytical shift in near surface horizons would provide independent conformation of a vegetation change. Thus, *Molinia caerulea* appears to be a genuine vegetation shift on the mire at location MLM. The SCP record commences at *c.*16 cm for location MLM suggesting that this vegetational shift took place around the start of the industrial revolution in the mid-nineteenth century.

Associated with the *Molinia caerulea* onset is a short-lived small increase in *Eriophorum vaginatum* macrofossils and Cyperaceae pollen and a marked decline in Ericaceae and *Sphagnum* pollen. These changes appear to have developed from a more ericaceous dominated environment with macrofossils containing more abundant remains of Ericales roots, *Erica tetralix* and *Calluna vulgaris*. The palynological evidence also shows that the mire had been dominant in Ericaceae, before the rapid change to a dominance of Gramineae in the last two zones. There were also frequent amounts of *Sphagnum* which were most abundant in the second zone MLM-b.

The recent rise to dominance of *Molinia caerulea* is a feature of many degraded mires and Yeo (1997) reported that it was particularly a feature of mid and south Wales. A wealth of palynological evidence has shown recent rises in Gramineae and declines in *Calluna vulgaris* across Wales as described in chapter two. Whether this is the species *Molinia caerulea* in all these cases cannot be deduced owing to poor taxonomic separation, and macrofossils were not used in the published studies which can separate species.

Coinciding with the vegetation changes at location MLM was a local fire indicated by an abundance of charcoal remains identified between 12-15 cm and a smaller peak prior to this at 19-21 cm. Fire has been suggested as one cause possible for the expansion of *Molinia caerulea* by some authors. For example, Damblon (1992) found after fire on moorland the reduction in other species allows *Molinia caerulea* to flourish. In addition, *Molinia caerulea* tussocks are protected against fire. Miles (1988) *cit.* Grant *et al.* (1996) acknowledges that *Molinia caerulea* is well adapted to withstand fire and, on mixed grass and heather, burning at a frequency of greater than one in six years favours *Molinia caerulea* at the expense of heather. Hobbs & Gimmingham (1997) explain that burning can release nutrients, in the form of ash, back to the ecosystem with a possible fertilising effect, but that, greater mobility also leads to loss by leaching. Yeo (1997) states that frequent and/or severe burns typically encourage the development of species-poor swards dominated by *Molinia caerulea* or *Eriophorum vaginatum.* As Shaw *et al.* (1996) state, if the fire was very hot and/or heather is in a degenerate phase it may suppress heather regeneration by reducing *Calluna vulgaris* root stock and preventing seed bank regeneration (Stevenson & Thompson 1993) or could completely kill it off. This may have occurred at Mynydd Llangatwg. At MLM the fire may have been more intense enabling *Molinia caerulea* to flourish while at MLC, a less intense fire could have permitted the *Calluna vulgaris* expansion. In addition, if the heather was in a young growing phase at MLC and a degenerate phase at MLM this could equally permit the two different vegetation responses.

At MLM there is an small charcoal peak (19-21cm), which corresponds with the onset of the demise of *Sphagnum* macrofossils and pollen, moderate increase in Ericaceae and a small rise in Gramineae pollen which may have been the initial responses to this local fire. The larger charcoal peak preceding (12-15 cm) coincides with the rapid expansion of *Molinia caerulea*, rapid decline in Ericaceae pollen and near absence of *Sphagnum* pollen and macrofossils. These vegetation changes may be the response to more frequent burning as Hobbs (1984) *cit.* Shaw *et al.* (1996)

found that in a study on blanket bog at Moor House a short rotation burn (every 10 years) resulted in an increased dominance of *Eriophorum spp* whilst a longer rotation resulted in an a greater abundance of *Calluna vulgaris*. A similar effect was found in *Molinia caerulea* -dominated by Curall (1981) *cit.* Hobbs & Gimmingham (1987) and Grant *et al.* (1963). This may explain why at location MLC the single fire encouraged the growth of *Calluna vulgaris,* and without a further fire, *Molinia caerulea* could not become dominant. Additional evidence comes from charcoal data at Mynydd Llangatwg from Chambers & Mauquoy (1998), where at MLA-E two charcoal peaks, between 8-10 cm and 2 cm, coincide with a subsequent rise to dominance of *Molinia caerulea* in the uppermost horizons. At MLA-S only one charcoal peak, at c.2 cm, coincides with a rise to dominance of *Calluna vulgaris* and Ericales roots in the upper most horizons. These profiles are only *c.*15-20 m away from profile MLC.

Chambers & Mauquoy (1998) found at Elenydd (Drygarn Fawr) a rise of *Molinia caerulea* macrofossils in the top *c.* 10 cm that is perhaps not associated with burning. SCPs suggested this has taken place after the onset of the industrial revolution and that *Molinia caerulea* was well established before the 1950/60s. The palynological evidence also reveals a rise in *Potentilla*, which Moore *et al.* (1986) state flowers profusely after heavy grazing and Moore & Chater (1969) associated its high abundance on mire at Plynlimmon, Wales with intensive sheep grazing on the contemporary mire surface. However, at Mynydd Llangatwg profile, MLC has low records throughout for *Potentilla* pollen and it was not observed in profile MLM. This may suggest that heavy grazing was not the cause of the *Molinia caerulea* rise in MLM.

Despite the above evidence there may be other indicators of grazing within the floristic composition. An increase in *Molinia caerulea* and decline in *Calluna vulgaris* has also been linked to nutrient enrichment from experimental work such as that of Berendse *et al.* (1994) and Heil & Bruggink (1987) on heathland. *Molinia caerulea* is also a more tolerant species under grazing and so may become more prominent (Shaw et al. 1996). The rise to dominance of *Molinia caerulea* macrofossils in MLM is also associated with an increase of *Drepanocladus fluitans* macrofossils and this may indicate the mire was turning into a more nutrient-rich environment as Bostock (1980) *cit.* Wiltshire & Moore (1983) showed that the wet, nutrient-enriched phase at the commencement of blanket peat initiation is often characterised by a bryophyte assemblage in which *Drepanocladus* features strongly. It must also be considered that nutrient enrichment could have come from on or off site burning. Hobbs and Gimmingham (1987) suggest that nutrients from burning in the form of ash can have a fertilizing effect. However, greater mobility also leads to loss by leaching.

At Mynydd Llangatwg stocking densities are not known but grazing is current. If grazing has caused the increase of *Molinia caerulea* at location MLM it must be considered why this has not been the case at MLC which experiences a rise in *Calluna vulgaris.* Light grazing may have encouraged *Calluna vulgaris* expansion at MLC but, if so, such light grazing would not have encouraged *Molinia caerulea* at MLM. Its expansion is often linked to high stocking rates (Thompson *et al.* 1995), but some authors, such as Hughes *et al.* (1973), Bargett *et al.* (1995) and Yeo (1997) suggest on blanket bog low gazing densities may induces floralistic changes. However, grazing may have been taking place and the cause of two different outcomes as Aerts *et al.* (1990) found from experimental research on heathlands that *Calluna vulgaris* could out-compete *Molinia caerulea*, if *Calluna vulgaris* was sufficiently tall to start with. This may have occurred if the *Calluna vulgaris* was taller at location MLC than MLM. In addition, Shaw *et al.* (1996) noted that the effects of raised mire nutrient status from grazing, which gives grasses a competitive advantage, were likely to be localised.

Another source of nutrients at MLM could be from atmospheric deposition of nitrogen. Since the 1950s sulphur levels have fallen and current concerns are focused on high levels of atmospheric nitrogen deposition (Yeo 1997). Some research such as Roelefs (1986) and Pitcairn *et al.* (1995) claims that this atmospheric nitrogen has encouraged grasses such as *Molinia caerulea* and a corresponding decline in heather. Chambers *et al.* (1979) investigated upland peats dominated by *Molinia caerulea* from two localities in S.Wales, close to the industrial valleys and tentatively postulated that the increased acid deposition after the onset of the industrial revolution may have contributed to the loss of heather and increase in grasses as surface deposits were heavily contaminated with soot. However, Stevenson & Thompson (1993) consider that this may have missed earlier reductions in *Calluna vulgaris* and incorrectly attributed the onset, rather than the exacerbation of the decline to atmospheric pollution. At Mynydd Llangatwg atmospheric nitrogen deposition would affect vegetation across the whole mire. As two different responses occur it seem unlikely that atmospheric nitrogen is a cause of the vegetation changes, unless as described in section 5.1.1, the heather was sufficiently tall at MLC and not at MLM as to have increasing *Calluna vulgaris* in the former and increasing *Molinia caerulea* in the latter.

A slightly warmer climate was a tentative explanation made by Yeo (1997) for the spread of *Molinia caerulea* in South Wales uplands in comparison to North Wales. However, the humification data from location MLM and MLC have very high light transmission values suggesting the mire was particularly wet associated with a possible deterioration in climate. However, the data in the upper horizons simply represent the change from the catotelm to acrotelm. Climate would also affect the whole mire and as there is only a rise to dominance of *Molinia caerulea* in one profile this causes seems unlikely. In addition, other authors such as Bargett *et al.* (1995) suggest a warmer climate may cause blanket bog vegetation to convert to heathland vegetation.

5.1.3 The behaviour of *Sphagnum*: MLM and MLC

At location MLM the macrofossil data suggest a relatively recent rise to dominance of *Sphagnum* section *Cuspidata* from *c.* 12 cm to the surface. In contrast the palynological evidence suggests that *Sphagnum* levels were at their lowest throughout the upper most two zones (i.e. the top *c.* 16 cm of the profile). As Chambers & Mauquoy (1998) noted, macrofossils in near-surface horizons may be less humified and so will be more easily recognisable than they would be once they had passed into the catotelm. This can lead to particular taxa having recordable relatively fresh macrofossils in the near-surface horizons, but the same macrofossil types would not be so easily recognisable at depth.. So, a vegetational shift towards the surface might be indicated by the macrofossil data, when in fact none had occurred. Comparison with the palynological data, for which the preservation of most pollen types is likely to be similar in both the acrotelm and catotelm with relatively little differential destruction between pollen types in acidic mires (Chambers & Mauquoy 1998) verifies the macrofossils have exaggerated the increase in of *Sphagnum* section *Cuspidatum* at location MLM. Light transmission values from the humification data, from *c.* 16 cm to the surface, confirm that this is the less humified acrotelm.

At location MLM the mire had been more dominant in both *Sphagnum* and *Ericaceae* prior to the rapid increase of *Gramineae* and demise of *Sphagnum* from *c.* 16 cm. It is only through the palynological evidence that it becomes apparent that *Sphagnum* had once been more frequently abundant as the macrofossils in the catotelm have not been preserved well. At location MLC the palynological evidence also shows a rapid decline in *Sphagnum* from *c.* 13 cm, the mire had previously been more dominant in *Sphagnum*, with moderate amounts of Ericaceae. As at MLM the plant macrofossils did not reveal this presumably as the peat is too highly humified.

The relatively recent demise of *Sphagnum* at both MLM and MLC is a floristic change similar to those of Yeo's (1997) findings of modified blanket mire throughout Wales and other authors as described in chapter two. Chambers & Mauquoy (1998) found a demise of Sphagnum macrofossils at one Mynydd Llangatwg profile, MLA-E but at MLA-S, this was not found as the profile contained a hiatus where more recent material had slumped onto an eroded front. They also found a decline in Sphagnum pollen and macrofossils at Hirwaun Common and Elenydd (Drygarn Fawr). However, these data may not be truly representative as there are no palynological data to verify the changes.

Associated with the rapid demise of *Sphagnum* from *c.* 15 cm at both locations in this study are charcoal peaks, between 12-15 cm at MLM and between 9-15 cm at MLC. The onset of burning may therefore be responsible for this vegetation change. There are also charcoal peaks at MLM between 19-21 cm and 48-54 cm; which are also associated with a decline in *Sphagnum*. As Shaw *et al.* (1996) acknowledge, fire can sometimes be beneficial (e.g. rejuvenation of heather) but at other times detrimental such as the destruction of *Sphagnum* hummocks, particularly where the fire is uncontrolled. Yeo (1997) states frequent and/or severe burning, especially in combination with high stocking densities, damages *Sphagnum* carpets and dries out blanket peat. Shaw *et al.* (1996) suggest there are many Welsh examples of grazing and burning on blanket mire and the loss of Sphagna.

At both MLM and MLC the macrofossils reveal that the mire supported some *Sphagnum papillosum*, also found in Chambers & Mauquoy (1998) MLA-E profile at Mynydd Llangatwg, before the charcoal peaks after which *Sphagnum* section *Cuspidata* remains are detected. This species change may be a result of fire killing off *Sphagnum papillosum* whilst Sphagnum section *Cuspidata* may have survived as it is found in wetter conditions especially in pools. However, grazing may also have caused this via trampling. Shaw *et al.* (1996) note that *Sphagnum* microtopography change is particularly susceptible under grazing due to the reduction in hummock forming species such as *Sphagnum papillosum.* Other studies such as Chapman & Rose (1991) *cit.* Shaw *et al.* (1996) on Coom Rigg Moss, northern England, suggest a lack of low-level grazing and autumn burning may have contributed to the decline of *Sphagnum* abundance, perhaps through the accumulation of standing dead material from grass and sedge species.

If the climate had become drier this may have led to a decline in *Sphagnum.* For example, Tallis (1995) found at Berwyn, Wales, a documented dry phase corresponded with a demise in *Sphagnum.* At Mynydd Llangatwg the humification data suggest wetter mire conditions at both MLM and MLC in the top *c.* 15cm. However, as mentioned in section 5.1.1 and 5.1.2, this is thought to represent the change from acrotelm to catotelm and not be a proxy record of climate change.

A number of studies have focused on acid deposition and its effects on *Sphagnum* in blanket mires. For example, Ferguson & Lee (1983) and Lee *et al.* (1988) from research in the Pennines, suggest nitrogen does not always have a fertilising effect on plants, and this is particularly true for bryophytes. Press *et al.* (1986) and Woodin *et al.* (1991) *cit.* Woodin & Farmer (1993) suggested that only a relatively small increase in nitrogen deposition reduces the growth of *Sphagnum cuspidatum* and hence this may be sufficient to bring about significant changes in North Wales. Mires in South Wales may be more greatly affected than North Wales as they have been potentially more polluted due to their close proximity to large urban and industrial centres, the southern Pennines, and especially since the mid nineteenth century and the onset of the industrial revolution. At location MLM and MLC, if grazing and/or atmospheric deposition had caused elevated nutrient levels the low levels of nitrate sensitive Sphagnum section *cuspidata* found may be a response to this and possibly could occur at higher frequencies without nitrate enrichment. However, equally possible is that its presence indicates that the site is now less polluted than it ever has been. As the macrofossils contain little detail of quantity or actual species the *Sphagnum* spores, which indicate that it was generally more prevalent further down the profiles, cannot reveal how much Sphagnum section *Cuspidata* there was previously.

Small amounts of Sphagnum *.imbricatum* are detected at the bottom of both MLM and MLC profiles. This taxon is now rare across Wales and is now confined to three Welsh sites: Borth Bog, a raised bog nr. Trawsfynydd, blanket bog on Mingeint (Yeo pers.com. *cit.* Chambers *et al.* 1998) and Berwyn (Bostock 1980). Mauquoy & Barber (1999) mention that the disappearance of its fossil remains from British and Irish peats is dramatic and well documented (e.g. Green (1968), Barber (1981), Van Geel and Middledorp (1988) and Stoneman (1993). Possible causes have included climate change, drainage, burning, grazing and atmospheric pollution. Mauquoy & Barber (1999) conclude from their study that pinning down the cause is difficult, but suggest that it may be due to climate deterioration and competitive interactions between species. Chambers & Mauquoy's (1998) Mynydd Llangatwg MLA-S profile has an abundance of *Sphagnum imbricatum* remains until *c.* 14 cm; however, the demise was discovered not to be recent as the profile contained a hiatus, where more recent *Calluna vulgaris* peat had slumped down probably due to erosion onto the *Sphagnum imbricatum* peat. *Sphagnum imbricatum* is detected at *c.* 50 cm in profiles MLM and MLC. The above findings of Chambers & Mauquoy (1998) may suggest that the species was once more abundant in the mire vegetation assemblage.

At location MLC *Sphagnum magellanicum* macrofossils are recorded in the uppermost horizon. The presence of this species is interesting as it was now thought to be absent from South Wales, with the nearest record at Cors Caron (David Stephens, pers. com.).

The SCP evidence dates the *Sphagnum* decline at MLM and MLC to around the mid 19th century and the onset of the industrial revolution. This may support the theory that pollution caused the decline in *Sphagnum*

5.1.4 Summary

At Mynydd Llangatwg two distinct vegetation changes have taken place - a rise to dominance of *Molinia caerulea* at profile MLM and a rise to dominance of *Calluna vulgaris* at MLC. Both profiles have also experienced a decline in *Sphagnum*. At both profiles, the depth of changes are similar and both date to the mid-nineteenth century at the onset of the industrial revolution. The vegetation changes both appear to have come from a vegetation assemblage co-dominant in *Ericaceae* and *Sphagnum* with moderate amounts of Gramineae and Cyperaceae. Both vegetation changes are strongly associated with burning which may have played a crucial role in the vegetational changes. Grazing may also have been a contributing factor, and grazing and burning may have had combined effects. There is no conclusive evidence that atmospheric pollution or climate change initiated the principal vegetation changes.

Ratcliffe's (1959) detailed study of the Carneddau, North Wales reported that in *Molinia caerulea* flush bogs *Calluna vulgaris* grows plentifully in some patches of Molinietum, but where the water table is high and more stagnant, there are small pockets of bog in which *Molinia caerulea* shares dominance with Sphagna. On blanket bogs wetter peats consistently contain ericaceous remains particularly of *Calluna vulgaris* and the wettest natural type is *Sphagnum* dominant with much *Calluna vulgaris*. This example may go some way to explaining how two areas *c.* 1 km apart have shown such marked but different vegetation changes on blanket mire at Mynydd Llangatwg.

5.1.5 Evaluation of the Palaeoecological and Palaeoenvironmental Techniques

The reconstruction of the vegetational history at Mynydd Llangatwg using plant macrofossil analysis was successful. The results revealed the recent rise to dominance of *Molinia caerulea* at MLM and *Calluna vulgaris* at MLC, and the demise of *Sphagnum* in both profiles. In addition, the data was provided useful species inferences about conditions on the mire. For example, the association of *Drepanocladus fluitans* alongside the *Molinia caerulea* rise in the upper horizons was an indicator of possible nutrient enrichment. The macrofossil's provided a priori evidence of a significant recent vegetational shift at both sites. However, plant macrofossils in the near-surface horizons (the acrotelm) are generally less humified and so will be more easily recognisable than they would be once they had passed into the catotelm (Chambers & Mauquoy 1998). Therefore, the vegetational shifts towards the surface might be exaggerated by plant macrofossil analysis and/or indicate towards a recent vegetational shift when in fact none had occurred. Blackford & Chambers (1993) found this was particularly the case for graminaceous species such as *Molinia caerulea*. These concerns were clearly dispelled by the adoption of pollen analysis. The major pollen analytical shifts in the near surface horizons provided independent conformation of the recent vegetation changes. Pollen analysis also revealed that the *Sphagnum* had once been much more prevalent on the mire surface whilst the macrofossil records were very sparse. Pollen analysis despite being at a somewhat generalised taxonomic level, has the following advantages; the level of taxonomic separation achieved is the same throughout a profile, the preservation of most pollen types is similar in both the acrotelm and catotelm and there is relatively little differential destruction between pollen types in mires (Chambers & Mauquoy 1998).

The charcoal analysis was able to provide a record of local fire history by the adoption of particle size classification and was linked as a possible cause of the vegetation changes at Mynydd Llangatwg. Elucidating climate change as a possible cause of vegetation change through peat humification analysis was unsuccessful. The particularly high percentage light transmission values that occurred alongside the major vegetational shifts reflect simply reflect the change from the acrotelm to catotelm. The combination of peat humification (percentage light transmission) and the unidentified organic matter (UOM) peat component from plant macrofossil analysis revealed spurious results. The two are intrinsically linked; a high UOM value indicates higher decomposition which should be reflected by a low percentage light transmission as more humic and fluvic acids (being brown in colour) are produced at a higher rate of decomposition. The opposite should be true of low UOM and high percentage light transmission values where there is less decomposition. However, both records oscillated considerably and overall corresponding trends were not always evident. A possible cause is that inorganic mineral material incorporated in the peat can distort the humification results (Chambers & Blackford 1993)

Spheroidal carbonaceous particle analysis as a dating tool revealed to be problematic in this study, most notable is the lack of an SCP decline in the upper horizons in both profiles that Rose (1995) attributed to the 1970s. These results may imply that SCPs had built up at the surface as the mire is no longer actively peat forming as Rose (1995) noted that with very low sediment accumulation rates the generalised features of the 'idealised' SCP curve may not be evident. Another possible explanation is that the profile is truncated. Chambers & Mauquoy (1998) study on Mynydd Llangatwg found that profile MLA-S was truncated and also did not experience the recent SCP decline whilst the intact profile MLA-E had experienced a recent SCP decline. However, the MLA-S macrofossil profile exhibited indications that it may contain a hiatus even before confirmation from radiocarbon dating as abundant *Sphagnum* remains, and in particular the now rare species *Sphagnum imbricatum,* were found. In MLM and MLC there are no indications in the macrofossil or pollen record to suggest the profiles are truncated. Rosen (1998) found at Llanllwch Bog South Wales the SCP profile did not experience a recent decline and that perhaps this had been caused by local industrial output expanding steadily during the early twentieth century. In the absence of local sources, pollutants will derive from the wider region (Rosen 1998). At Mynydd Llangatwg the mire is influenced by the wider region of the Lower Swansea Valley (see section 2.2.3), therefore, it seems most likely that the absence of a recent SCP decline has been caused by the accumulation rate of the mire slowing in recent times allowing SCPs to build up on the surface.

5.1.6 Contributions to the Palaeoenvironmental and Palaeoecological History of South Wales' Blanket Mires

Many previous palaeoecological and palaeoenvironmental reconstruction's have not used a multidisciplinary approach in assessing the recent vegetational changes and their possible causes on Welsh blanket mires. For example, Ratcliffe (1959), Turner (1964), Moore (1968), Chambers *et al.* (1979) and Chambers (1983) used palynological evidence to reveal the recent rise to dominance of Gramineae and decline in Sphagnum and Ericaceae. Turner (1964) used historical grazing records and Chambers (1979) examined soot particles in their attempts to elucidate possible causes of these vegetation changes.
Rosen (1998) adopted a multidisciplinary approach in her investigation of the impact of industrial activity of the vegetation of South Wales. Her study highlighted that a multidisciplinary approach was an important progression in understanding the recent vegetational changes. However, this study was concerned with vegetation from the wider region and not local mire vegetation.

The pilot project of Chambers & Mauquoy (1998) was one of the first studies to adopt a multidisciplinary approach in their preliminary interpretation of recent human impact on Welsh blanket mire vegetation and assessment of palaeoecological techniques. Despite adopting a number of methodologies to elucidate possible causes of vegetation change the research highlighted a number of areas that needed further investigation. These included the use of pollen and macrofossil analyses in combination, techniques to examine the influence of climate on the mire and a contiguous count of charcoal so as not to miss important fire events.

The adoption of multidisciplinary approach to the palaeoecological and palaeoenvironmental reconstruction in this study was thought to an important progression in the application of palaeoecological and palaeoenvironmental techniques and in the understanding of the factors involved in recent vegetation changes on blanket mires in South Wales.

5.1.7 Contribution of the Results to the Conservation Management at Mynydd Llangatwg

Burning and in particular the frequency of burning may have played a crucial role in the vegetational changes. The rise to dominance of *Molinia caerulea* and demise of *Sphagnum* and ericaceous species at MLM may have been caused by two burning episodes in quite close succession. The rise to dominance of *Calluna vulgaris* and demise of *Sphagnum* at MLC may have been caused by a single burning event (Grant *et al.* 1963, Curall (1981) *cit.* Hobbs & Gimmingham 1987).

Shaw *et al.* (1997) reviewed the burning recommendations for blanket mire and these are described as follows. The Nature Conservation Council (NCC) (1989), Rodwell (1998), MAFF (1992), Tir Cymen (CCW) (1992), Phillips *et al.* (1993) and Thompson *et al.* (1995) all recommended that blanket mire should not be burned. Coulson *et al.* (1992) recommended that blanket bog should be burnt on a long cycle or not at all and Phillips *et al.* (1993) states if at all, blanket bogs should not be burned on intervals less than 15-20 year's. The Scottish Natural Heritage (*cit.* Shaw *et al.* 1997) suggest burning should be restricted to December to March, heather must cover 70% of the ground and there must be a minimum burning rotation of 12 years. It is therefore recommended at Mynydd Llangatwg that the mire should not be burned or that there should be a long rotation period to attempt preventing the spread of *Molinia caerulea*.

The two marked but different vegetational changes at Mynydd Llangatwg could have been caused by grazing as under nutrient enrichment *Calluna vulgaris* may be able to out-compete *Molinia caerulea* if the *Calluna vulgaris* is sufficiently tall to start with (Aerts *et al.* 1990). Shaw *et al.* (1997) reviewed the grazing recommendations for blanket mire and their review is described as follows. Rodwell (1998) recommends 0.25 – 0.37 ewes ha^{-1}, preferably in summer only, lower stocking rates would be required. Tir Cymen (CCW) recommends <0.5 – 1 ewes ha^{-1} and that stock should be removed between October and March. At Mynydd Llangatwg it is recommended that stocking densities should be limited to levels similar to those outlined in the above literature.

The role of atmospheric pollution and climate change in the vegetational changes at Mynydd Llangatwg did not draw any firm conclusions. Since neither can be controlled by site conservation management, recommendations are not given here. Further research is required to ascertain their influences (see section 6.4)

CHAPTER SIX
CONCLUSIONS

6.1 Vegetation Changes

- At Mynydd Llangatwg two peat profiles *c.* 1 km apart reveal marked but different vegetational changes, most notably a rise to dominance of *Molinia caerulea* at profile MLM and a rise to dominance of *Calluna vulgaris* at MLC. Both profiles have also experienced a decline in *Sphagnum*.

- From the SCP profiles the approximate date of these changes can be established. At MLM the shift to dominance of *Molinia caerulea* from *c.* 16 cm coincides with the onset of the SCP record and hence can be dated to a time of around the mid 19th century and the onset of the industrial revolution (Rose 1995) or possibly earlier due to the influence of industry in the Lower Swansea Valley (Rosen 1998). Dating of the MLC profile suggests that the *Calluna vulgaris* expansion took place sometime before the onset of the industrial revolution as the SCP record begins at *c.* 15 cm and the *Calluna vulgaris* expansion at *c.* 13 cm.

- The vegetation changes both appear to have come from a vegetation assemblage co-dominant in Ericaceae and *Sphagnum* with moderate amounts of Gramineae and Cyperaceae.

6.2 Cause(s) of Vegetation Changes

6.2.1 Burning

- Burning and in particular the frequency of burning at Mynydd Llangatwg seems to be the most likely cause of the vegetational changes.

- At location MLC one major local burning episode is associated with the expansion of *Calluna vulgaris* and demise of *Sphagnum.* It is known that fire can rejuvenate heather and can destroy *Sphagnum* (Shaw *et al.* 1996).

- At location MLM the rise to dominance of *Molinia caerulea* and the decline of ericaceous species and *Sphagnum* is associated with two major local burning episodes. The first is associated with the onset of the demise of *Sphagnum*, moderate increase in Ericaceae and a small rise in Gramineae and may represent the initial response. The second major local fire coincides with the rapid expansion of *Molinia caerulea*, rapid decline in Ericaceae and near absence of *Sphagnum*.

- Results from Mynydd Llangatwg by Chambers & Mauquoy (1998) also support of the theory that the frequency of burning may be a causal factor in the vegetational changes.

6.2.2 Grazing

- From this study the role of grazing as a causal factor in the vegetational changes is not clear. It must be considered why two marked but different vegetational responses occurred. It is suggested that low gazing densities on blanket bog may induce the expansion of *Molinia caerulea* (Yeo, 1997; Bargett *et al.,* 1995; Hughes *et al.,* 1973) which may be the case at location MLM. At location MLC the rise to dominance of *Calluna vulgaris* could also be a response to grazing as (Aerts *et al.* 1990) suggested under nutrient enrichment this species may be able to out-compete *Molinia caerulea*, if *Calluna vulgaris* is sufficiently tall to start with.

- Other possible indicators of grazing included localised nutrient enrichment evident from the species *Drepanocladus fluitans* alongside the *Molinia caerulea* expansion (Bostock 1980 *cit.* Wiltshire & Moore 1983) and the demise of the hummock-forming *Sphagnum* species *Sphagnum papillosum* in both profiles which is particularly susceptible to trampling (Chapman & Rose 1991 *cit.* Shaw *et al.* 1996).

6.2.3 Atmospheric Pollution

- At MLM the onset of the SCP record occurs around the time of the rise to dominance of *Molinia caerulea* and the demise of *Sphagnum* and at MLC the *Calluna vulgaris* expansion took place some time before sometime before the onset of the SCP record. Atmospheric pollution may therefore have involved in the principal vegetational changes, but not the initiation at MLC and possibly not at MLC. Therefore no firm conclusions can be drawn from this study.

6.2.4 Climate Change

- The use of humification to examine the possible influence of climate on the major vegetational shifts was found to be of limited value in this study and no firm conclusions have been drawn. In the upper horizons of the profiles where the most significant vegetation changes take place the humification values are thought to simply represent a change from the catotelm, which is more humified, to the less humified acrotelm.

6.2.5 Summary

- Examination of the evidence in this study strongly indicates that burning, and in particular the frequency of burning may have played a crucial role in the vegetational changes at Mynydd Llangatwg. Grazing may have also been a contributing factor, and grazing and burning may have had combined effects. There is no conclusive evidence for climate change or atmospheric pollution initiating the principal vegetation changes at Mynydd Llangatwg and these would require further examination before firm conclusions of their effects on the vegetation changes could be drawn (see section 6.4).

6.3 Conservation Management at Mynydd Llangatwg

- To promote the growth of *Calluna vulgaris* and *Sphagnum,* discourage the spread of *Molinia caerulea* and to avoid further damage to *Sphagnum* the following conservation management recommendations are made for blanket mire at Mynydd Llangatwg base on the literature described in section 5.1.7. Burning should be avoided or conducted using a long rotation period of around 15-20 years or more. Stocking densities should be limited to around 0.25 ewe's ha^{-1} to a maximum of 1 ewe's ha^{-1}.

6.4 Recommendations for Further Research

- As humification analysis proved to problematic in detecting a climate signal in near-surface horizons other techniques should be considered. Testate amoebae (Protazoa: Rhizopoda) have the potential to provide improved quantative estimates of water-table depths and soil moisture, as these are the two most important environmental variables related to their distribution. Woodland *et al.* (1998) reviewed their use in Holocene peatlands and developed a modern training set which offers a new technique for reconstructing surface wetness changes on British mires and provides data in terms of a meaningful environmental parameter.

- Documentary records of grazing stocking rates, breeds and time of year would be invaluable if available. The use of non-pollen microfossils could be used as indicators of grazing. Blackford (1990) describes that a number of *Cerophora* fungal remains are associated with dung decomposition.

- Rosen (1998) and Rosen & Dumayne-Peaty (2001) used chemical analysis and magnetic mineral analyses to determine the past heavy metal and historical magnetic deposition in their assessment of the recent industrial impact on the South Wales landscape. Such techniques could be used in conjunction with SCP analysis to fully reconstruct the pollution history.

- To improve on the chronological sequence of the vegetation changes ^{210}Pb dating could be considered. Rosen & Dumayne-Peaty (2001) noted that despite difficulties associated with this method in dating recent peat sediments the CRS (constant rate of supply) dating model can be considered to be reliable as in their study it closely corresponded with the documented historical events.

REFERENCES

- **Aaby, B.** (1976) Cyclic climatic variations in climate over the last 5,500 years reflected in raised bogs. *Nature*, **263**, 281-4.
- **Aaby, B. & Tauber, H.** (1975) Rates of peat formation in relation to degree of peat humification and local environment, as shown by studies of a raised bog in Denmark. *Boreas*, **4**, 1-17.
- **Aerts, R., Berendse, F., De Caluwe, H. & Schmitz, M.** (1990) Competition in heathland along an experimental gradient of nutrient availability. *Oikos*, **57**, 310-318.
- **Anderson, P. & Yalden, D.W.** (1981) Increased sheep numbers and the loss of heather moorland in the Peak District, England. *Biological Conservation*, **20**, 195-213.
- **Ardron, P., Gilbert, O. & Rotherham, I.** (1997) Factors determining contemporary upland landscapes: a re-evaluation of the importance of peat-cutting and associated drainage, and the implications for mire restoration and remediation. *Blanket Mire Degradation: Causes, Consequences and Challenges (*eds. J.H. Tallis, R. Meade & P.D. Hulme), pp. 38-41. Macaulay Land Use Research Institute (for British Ecological Society), Aberdeen, UK
- **Barber, K.E.** (1976) History of vegetation. In: *Methods in Plant Ecology* (ed. S.B. Chapman): Blackwell Scientific Publications, Oxford, 5-83.
- **Barber, K.E.** (1981) *Peat Stratigraphy and Climatic Change: a Palaeoecological Test of the Theory of Cyclic Peat Bog Regeneration.* Rotterdam, Balkema.
- **Barber, K.E.** (1993) Peatlands as scientific archives of past biodiversity. *Biodiversity & Conservation,* **2**, 474-489.
- **Barber, K.E., Chambers, F.M., Maddy, D., Stoneman, R. and Brew, J.S.** (1994) A sensitive high resolution record of late Holocene climate change from a raised bog in northern England. *The Holocene*, **4**, 198-205.
- **Barber, K.E., Dumayne-Peaty, L., Hughes, P.D.M., Mauquoy, D. and Scaife, R.G.** (1998) Replicability and variability of the recent macrofossil and proxy-climate record from raised bogs: field stratigraphy and macrofossil data Bolton Fell Moss and Walton Moss, Cumbria, UK. *Journal of Quaternary Science*, **15**, 515-528.
- **Barber, K.E., Battarbee, R.W., Brookes,S.J., Eglinton, G., Haworth, E.Y., Oldfield, F., Stevenson, A.C., Thompson, R., Appleby, P., Austin, W.N., Cameron, N., Ficken, K.J., Golding, P., Harkness, D.D., Holmes, J., Hutchinson, R., Lishman, P.J., Maddy, D., Pinder, L.C.V., Rose, N., & Stoneman, R.** (1999) Proxy records of climate change in the UK over the last two millennia: documented change and sedimentary records from lakes and bogs. *Journal of the Geological Society of London*, **156**, 369-205.
- **Bargett, R.D., Marsden, J.H. & Howard, D.C.** (1995) The extent and condition of heather on moorland in the uplands of England and Wales. *Biological Conservation*, **71**, 155-161.

- **Berendse, F., Schmitz, M. & de Visser, W.** (1994) Experimental manipulation of succession in heathland ecosystems. *Oecologia*, **100**, 38-44.
- **Berendse, F. & Aerts, R** (1984) Competition between *Erica tetralix* L. and *Molinia caerulea* (L.) Moench as affected by the availability of nutrients, *Acta OEcologica*, **100**, 38-44.
- **Birks H.J.B. & Birks H.H.** (1980) *Quaternary Palaeoecology*. Edward Arnold, London, UK.
- **Birks, H.J.B.** (1996) Contributions of Quaternary palaeoecology to nature conservation. *Journal of Vegetation Science*, **7**, 89-98.
- **Blackford, J.J.** (1990) Blanket Mires and Climatic Change; a Palaeoecological Study Based on Peat Humification and Plant Macrofossil Analyses. *Unpublished Ph.D. Thesis, University of Keele*, UK.
- **Blackford, J.J. & Chambers, F.M.** (1991) Blanket peat humification: evidence for a Dark Age (1400 BP) climatic deterioration in the British Isles. *The Holocene*, **1**, 63-67.
- **Blackford, J.J. & Chambers, F.M.** (1993) Determining the degree of peat decomposition in peat-based palaeoclimatic studies. *International Peat Journal*, **5**, 7-24.
- **Brookes, S. & Stoneman, R.** (1997) *Conserving Bogs: The Management Handbook.* (eds. S. Brookes, P. Immirizi, L. Parkyn, A. Sommerville & R. Stoneman) The Stationary Office, Edinburgh, UK.
- **Burglund, B.E.** (1986) *Handbook of Holocene Palaeoecology and Palaeohydrology*. J. Wiley, Chichester.
- **Burglund, B.E. & Ralska-Jesiewiczowa, M.** (1956) Pollen analysis and pollen diagrams. *Handbook of Holocene Palaeoecology and Palaeohydrology*. (eds. Burglund, B.E.), pp. 455-497. J. Wiley, Chichester.
- **Chambers, F.M.** (1982) Two radiocarbon-dated pollen diagrams from high-altitude blanket peats in South Wales. *Journal of Ecology*, **70**, 445-459.
- **Chambers, F.M.** (1983) Three radiocarbon-dated pollen diagrams from upland peats north-west of Merthyr Tydfil, South Wales. *Journal of Ecology*, **71**, 475-487.
- **Chambers, F.M., Dresser, P.Q. & Smith, A.G.** (1979) Radiocarbon dating evidence on the impact of atmospheric pollution on upland peats. *Nature*, **282**, 829-831.
- **Chambers, F.M., Barber, K.E., Maddy, D. & Brew, J.** (1997) A 5500-year proxy-climate and vegetation record from blanket mire at Talla Moss, Borders, Scotland. *The Holocene*, **7**, 391-399.
- **Chambers, F.M. & Mauquoy, D.** (1998) *Recent Human Impact on Welsh Blanket Bogs.* Report commissioned by CCW from CECQR, GEMRU, University of Gloucestershire.
- **Chambers, F.M., Mauquoy, D. & Todd, P.A.** (1999) Recent rise to dominance of *Molinia caerulea* in environmentally sensitive areas: new perspectives from palaeoecological data. *Journal of Applied Ecology*, **36**, 719-733.

- **Chambers, F.M., Mauquoy, D., Pearson, F.R.A., Daniell, J.R.G., Gent, A. & Cook, C.** (2001) *Recent vegetational change in Welsh Blanket mires: a palaeoecological appraisal.* Report commissioned by CCW from CECQR, GEMRU, University of Gloucestershire.
- **Clapham, A.R., Tutin, T.G. and Moore, D.M.** (1978) *Flora of the British Isles, 3rd edn.* Cambridge: Cambridge University Press.
- **Clarke, M.J.,** (1988) Past and Present Mire Communities of the New Forest and their Conservation. *Unpublished Ph.D. Thesis, University of Southampton, UK.*
- **Clymo, R.S.** (1984) The limits to peat bog growth. *Philosophical Transactions of the Royal Society, London B*, **327**, 331-338.
- **Coulson, J.C. & Butterfield, J.** (1978) An investigation of the biotic factors determining the rates of plant decomposition on blanket bog. *Journal of Ecology*, **66**, 631-650.
- **Coupar, A., Immirizi P. & Reid,** E. (1997) The nature and extent of degradation in Scottish Blanket Mires. *Blanket Mire Degradation: Causes, Consequences and Challenges (*eds. J.H. Tallis, R. Meade & P.D. Hulme), pp. 90-100. Macaulay Land Use Research Institute (for British Ecological Society), Aberdeen, UK.
- **Damblon, F.** (1992) Palaeobotanical evidence *Eriophorum* and *Molinia* tussocks as a means of reconstructing recent history of disturbed mires in the Haute-Ardenne, Belgium. *Review of Palaeobotany and Palynology*, **75**, 273-288.
- **Daniels, R.E. and Eddy, A.** (1990) *A Handbook of European Sphagna*. Swindon: Natural Environment Research Council.
- **Day, A. (1989)** *Upland Vegetation Survey 1979-1989; Background, Methodology and Summary of Data Collected*. Bangor: Nature Conservancy Council.
- **Faegri, K. & Iversen J.** (1989) *Textbook of Pollen Analysis*, 4th edn. (eds K. Faegri, P.E. Kaland & K. Krzywinski). Wiley, Chichester, UK.
- **Ferguson, P. & Lee, J.A.** (1983) Past and present sulphur pollution in the Southern Pennines. *Atmospheric Environment*, **17**, 1131-1137.
- **Fritz, S.C., Kreiser, A.M., Appleby, P.G. & Battarbee, R.W.** (1990) Recent acidification of upland lakes in North Wales: Palaeoliminological evidence. *Acid Waters in Wales* (ed. Edwards, R.W., Gee, A.S. & Stoner, J.H.). Kluwer Academic Publishers, The Netherlands.
- **Gimmingham, C.H. & de Smidt, J.T.** (1983) Heaths as natural and semi-natural vegetation. *Man's Impact on Vegetation* (ed. W. Holzner, M.J.A. Werger and I. Ikusima), pp. 185-199.
- **Grant, S.A., Hunter, R.F. & Cross, C.** (1963) The effects of muirburning *Molinia*-dominated communities. *Journal of the British grassland Society*, **18**, 249-257.
- **Grant, S.A., Bolton, G.R. & Torvell, L.** (1985) The responses of blanket bog vegetation to controlled grazing by hill sheep. *Journal of Applied Ecology*, **22**, 739-751.

- **Grant, S.A., Torvell, L., Common, T.G., Sim, E.M. & Small, J.L.** (1996) Controlled grazing studies on *Molinia* grassland: effects of different seasonal patterns and levels of defoliation on *Molinia* growth and responses of swards to controlled grazing by cattle. *Journal of Applied Ecology*, **33**, 1267-1280.
- **Green, B.H.** (1968) Factors influencing the spatial and temporal distribution of *Sphagnum imbricatum* Hornsch. ex Russ. In the British Isles. *Journal of Ecology*, **56**, 47-58.
- **Griffin, J.J. & Goldberg, E.D.** (1981) Sphericity as a characteristic of solids from fossil fuel burning in Lake Michigan sediments. *Geochimica et Cosmochimica Acta*, **45**, 763-769.
- **Grimm, E.** (1991) TILIA and TILIAGRAPH. Illinois State Museum, Illinois.
- **Gross-Braukmann, G.** (1996) Analysis of vegetative plant macrofossils. *Handbook of Holocene Palaeoecology and Palaeohydrology*. (eds. Burglund, B.E.), pp. 591-608. J. Wiley, Chichester.
- **Hall, S.A.** (1981) Deteriorated pollen grains and the interpretation of Quaternary pollen diagrams. *Review of palaeobotany and Palynology*, **32**, 193-206.
- **Haslam, C.J.** (1987) Late Holocene Peat Stratigraphy and Climate Change - a Macrofossil Investigation from Raised Mires of Western Europe. *Unpublished Ph.D. Thesis, University of Southampton, UK.*
- **Havinga, A.J.** (1964) Investigation into the differential corrosion susceptibility of pollen and spores, *Pollen et Spores*, **6**, 621-635.
- **Havinga, A.J.** (1967) Palynology and pollen preservation. *Review of palaeobotany and Palynology*, **2**, 81-98.
- **Havinga, A.J.** (1984) A 20-year experimental investigation into the differential corrosion susceptibility of pollen and spores in various soil types, *Pollen et Spores*, **26**, 541-557.
- **Heil, G.W. & Diemont, W.M.** (1983) Raised nutrient levels change heathland into grassland. *Vegetatio*, **53**, 113-120.
- **Heil, G.W. & Bruggink, M.** (1987) Competition between *Calluna vulgaris* (L.) Hull and *Molinia caerulea* (L.) Moench, *Oecologia*, **73**, 105-107.
- **Hobbs, R.J. & Gimmingham, C.H.** (1987) Vegetation, fire and herbivore interactions in heathland. *Advances in Ecological Research*, **16**, 87-173.
- **Hughes, R.E., Dale, J., Williams, I.E. & Rees, D.I.** (1973) Studies in sheep populations and environment in the mountains of north-west Wales. I. The status of the sheep in the mountains of north Wales since mediaeval times. *Journal of Applies Ecology*, **10**, 113-132.
- **Immirizi, C.P & Maltby, E.** (1992) *The Global Status of Peatlands and their Role in Carbon Cycling*. A report for the Friend of the Earth by the Wetlands Ecosystem Research Group, Department of Geography, University of Exeter. Friends of the Earth, London.

- **Jones, R., Chambers, F.M. & Benson-Evans, K.** (1991) Heavy metals (Cu and Zn) in recent sediments of Llangorse Lake, Wales: non-ferrous smelting, Napoleon and the price of wheat - a palaeoecological study. *Hydrobiologia,* **214**, 149-154.
- **Keen, R.** (1995) The archaeology of industrial Wales. *Industrial Archaeology Review*, **18**, 63-82.
- **Lee, J.A., Tallis, J.H. & Woodin, S.J.** (1988) Acidic deposition and British upland vegetation. In: *Ecological Change in the Uplands* (ed. M.B. Usher & D.B.A. Thompson), pp.151-162. Blackwell Scientific Publications, Oxford.
- **Lee, J.A., Caporn, S.J.M. & Read, D.J.** (1992) Effects of increasing nitrogen deposition and acidification on heathlands. In: *Acidification Research: Evaluation and Policy Applications* (ed. T. Schneider), pp. 97-106. Elsevier Science Publishers, The Netherlands.
- **Lindsay, R.** (1995) *The Ecology, Classification and Conservation of Ombrotrophic Mires.* Scottish Natural Heritage, Perth, UK.
- **Lindsay, R.A. & Immirzi, C.P.** (1996) *An Inventory of Lowland Raised Bogs in Great Britain.* Edinburgh: Scottish Natural Heritage.
- **Mallik, A.U., Gimmingham, C.H. & Rahman, A.A.** (1984) Ecological effects of heather burning. I. Water infiltration, moisture retention and porosity of surface soil. *Journal of Ecology*, **72**, 767-776.
- **Mauquoy, D.** (1997) Testing the sensitivity of the palaeoclimatic signal from ombrotrophic peat stratigraphy. *Unpublished Ph.D. Thesis, University of Southampton, UK.*
- **Mauquoy, D. & Barber, K.E.** (1999) A replicated 3000 yr proxy-climate record from Coom Rigg Moss and Felecia Moss, the Border Mires, northern England. *The Holocene*, **14**, 263-275.
- **Mc Tiernan, K.B., Garnett, M.H., Mauyuoy, D., Ineson, P. & Couteaux, M.M.** (1998) Use of near-infrared reflectance spectroscopy (NIRS) in palaeoecological studies of peat, *The Holocene*, **8**, 729-740.
- **MacDonald, G.M., Larsen, C.P.S., Szeicz, J.M. & Moser, K.A.** (1991) The reconstruction of Boreal Forest fire history from lake sediments: a comparison of pollen, sedimentological and geochemical indices. *Quaternary Science Reviews*, **10**, 53-71.
- **Moore, P.D.** (1968) Human influences upon vegetational history in north Cardiganshire. *Nature,* **217**, 1006-1009.
- **Moore, P.D., & Chater, E.H.** (1969) The changing vegetation of west-central Wales in the light of human history. *Journal of Ecology*, **57**, 361-379.
- **Moore, P.D., Evans, A.T. & Chater, M.** (1986) Palynological and stratagraphic evidence for hydrological changes in mires associated with human activity. In: *Anthropogenic Indicators in Pollen Diagrams* (ed. Behre, K.E.). Rotterdam: Balkeman.
- **Moore, P.D., Webb, J.A. & Collinson, M.** (1991) *Pollen analysis (2nd ed.).* Blackwell Scientific Publications, Oxford.

- **Pitcairn, C.E.R., Fowler, D. & Grace, J.** (1995) Deposition of fixed atmospheric nitrogen and foliar nitrogen content of bryophytes and *Calluna vulgaris* (L.) Hull, *Environmental Pollution*, **88**, 193-205.
- **Press, M.C., Woodin, S.J. & Lee, J.A.** (1986) The potential importance of an increased atmospheric nitrogen supply to the growth of ombrotrophic *Sphagnum* species. *New Phytologist*, **103**, 45-55.
- **Ratcliffe, D.A.** (1959) The vegetation of the Carneddau, North Wales. I. Grasslands, heaths and bogs. *Journal of Ecology*, **47**, 371-413.
- **Renberg, I. & Wik, M.** (1985) Carbonaceous particles in lake sediments - pollutants from fossil fuel combustion. *Ambio*, **14**, 161-163.
- **Roelofs, J.G.M.** (1986) The effect of airborne sulphur and nitrogen on aquatic and terrestrial heathland vegetation, *Experientia*, **42**, 372-377.
- **Rose, N.L.** (1990) A method for the extraction of carbonaceous particles from lake sediment. *Journal of Paleoliminology*, **3**, 45-53.
- **Rose, N.L.** (1994) A note on further refinements to a procedure for the extraction of carbonaceous fly-ash particles from sediments. *Journal of Paleoliminlogy*, **11**, 201-204.
- **Rose, N.L, Harlock, S., Appleby, P.G. & Battarbee, R.W.** (1995) Dating of recent lake sediments in the United Kingdom and Ireland using spheroidal carbonaceous particle (SCP) concentration profiles. *The Holocene*, **5**, 328-335.
- **Rose, N.L. & Juggins, S.** (1994) A spatial relationship between carbonaceous particles in lake sediments and sulphur deposition. *Atmospheric Environment*, **28 (2)**, 177-183.
- **Rosen, D.Z.** (1998) Recent Palaeoecolgy and Industrial Impact on the South Wales Landscape. Volume 1. *Ph.D. Thesis, University of Swansea.*
- **Rosen, R.Z. & Dumayne-Peaty, L.** (2001) Human impact on the vegetation of South Wales during late historical times: palynological and palaeoenvironmental results from Crymlyn Bog NNR, West Glamorgan, Wales, UK. *The Holocene*, **11 (1)**, pp. 11-23.
- **Rudeforth, C.C., Hartnup, R., Lea, J.W., Thompson, T.R.E. & Wright, P.S.** (1984) *Soils and their Use in Wales*. Soil Survey of England & Wales, Bulletin No. 11, Harpenden.
- **Shaw, S.C., Wheeler, B.D., Kirby, P., Philipson, P. & Edmunds, R.** (1996) *Literature Review of the Historical Effects of Burning and Grazing of Blanket Bog and Upland Wet Heath.* English Nature, Peterborough, UK.
- **Shaw, S., Wheeler, B. & Backshall, J.** (1997) Review of the effects of burning and grazing on blanket bogs: conservation issues and conflicts. *Blanket Mire Degradation: Causes, Consequences and Challenges (*eds. J.H. Tallis, R. Meade & P.D. Hulme), pp. 174-182. Macaulay Land Use Research Institute (for British Ecological Society), Aberdeen, UK.
- **Smith, A.J.E.** (1978) *The Moss and Flora of Britain and Ireland.* Cambridge: Cambridge University Press.

- **Stevenson, A.C. & Thompson, D.B.A.** (1993) Long-term changes in the extent of heather dominated moorland in upland Britain and Ireland: palaeoecological evidence for the importance of grazing. *The Holocene,* **3**, 70-76.
- **Stoneman, R.E.** (1993) Late Holocene Peat Stratigraphy and Climate: Extending and Refining the Model. *PhD. Thesis, University of Southampton, UK.*
- **Straker, V. & Crabtree, K.** (1995) Palaeoenvironmental studies on Exmoor: past research and future potential. *The Changing Face of Exmoor* (ed. H. Binding), pp. 43-51. Exmoor Books, Tiverton, UK.
- **Tallis, J.H** (1975) Tree remains in southern Pennine blanket peats. *Nature*, **256**, 482-484.
- **Tallis, J.H** (1995) Climate and erosion signals in British blanket peats: the significance of *Racomitrium lanuginosum* remains, *Journal of Ecology*, **83**, 1021-1030.
- **Tallis, J.H.** (1997) The Southern Pennine experience: an overview of blanket mire degradation. In Tallis, J.R., Meade, R. & Hulme, P.D. (eds) *Blanket mire degradation: causes, consequences and challenges*. Aberdeen: Macaulay Land Use Research Institute (for BES), 7-15.
- **Taylor, J.A. & Tucker, R.B.** (1968) The peat deposits of Wales: an inventory and interoperation. In: *Proceedings of the 3rd International Peat Congress* (ed. C. Lafleur & J. Butler), pp. 163-173.
- **Thompson, D.B.A., MacDonald, A.J., Marsden, J.H. & Galbraith, C.A.** (1995) Upland heather moorland in Great Britain: a review of international importance, vegetation change and some objectives for nature conservation. *Biological Conservation*, 71, 163-178.
- **Todd, P.A.** (1995) The MAFF *Molinia* Study. *The Heather Trust Annual Report* (1995) (eds. J. Kippen & A. Watson), pp. 41-44. Heather Trust, Kippen, UK.
- **Turner, J.** (1964) The anthropogenic factor in vegetational history. I. Tregaron and Whixall Mosses. *New Phytologist*, **63**, 73-90.
- **Van Geel, B. & Middledorp, A.A.** (1988) Vegetational history of Carbury bog (co. Kildare, Ireland) during the last 850 years and a test of the temperature indicator value of $^2H/^1H$ measurements of peat samples in relation to historical sources and meterological data. *New Phytologist*, **109**, 377-92.
- **Wein, R.W., Burzynski, M.P., Sreeinsva, B.A. & Tolonen, K.** (1987) Bog profile evidence of fire and vegetation dynamics since 3000 years BP in the Acadian Forest. Canadian *Journal of Botany*, **65**, 1180-1186.
- **Welch, D.** (1984) Studies in the grazing of heather moorland in north-east Scotland. II. Response of heather. *Journal of Applied Ecology*, **21**, 197-207.
- **Welch, D.** (1986) Studies in the grazing of heather moorland in north-east Scotland. V. Trends in *Nardus stricta* and other unpalatable graminoids. *Journal of Applied Ecology*, **23**, 1047-1058.
- **Wiltshire, P.E.J. & Moore, P.D.** (1983) Palaeovegetation and palaeohydrology in upland Britain. *Backround to Palaeohydrology* (ed. K.J. Gregory), pp. 433-451. John Wiley & Sons, Chichester, UK.

- **Woodin, S.J. & Farmer, A.M.** (1993) Impacts of sulphur and nitrogen deposition on sites and species of nature conservation importance in Great Britain. *Biological Conservation*, 63, 23-30.
- **Yeo, M.** (1997) Blanket mire degradation in Wales. *Blanket Mire Degradation: Causes, Consequences and Challenges (*eds. J.H. Tallis, R. Meade & P.D. Hulme), pp. 101-115. Macaulay Land Use Research Institute (for British Ecological Society), Aberdeen, UK