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LATE HOLOCENE MIRE DEVELOPMENT OF THE LOWLAND RAISED BOGS CORS CARON AND CORS FOCHNO: A PALAEOECOLOGICAL APPROACH USING HIGH RESOLUTION MACROFOSSIL ANALYSIS

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ABSTRACT

FACULTY OF ENGINEERING, SCIENCE AND MATHEMATICS

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The main objective of this project is to examine the direction and rate of change in raised bog vegetation succession over the last 2000 years at the two lowland raised bogs Cors Caron and Cors Fochno as well as the factors which caused these changes.

From Cors Caron a significant deceleration in peat accumulation was reported in all three bogs by previous research (Morriss 2001), which appeared to be a rather unusual feature compared with other raised bogs. The vegetation of both study sites has undergone changes of varying degree including the extinction or decrease of *S. austinii* and the spread or invasion of species which usually do not occur in raised bog vegetation. The pioneering work of Godwin and Conway (1939) enables a study of the vegetation development at the Cors Caron West Bog over the past sixty five years by re-survey. In order to study the history of *S. austinii* in a wider context, an Irish raised bog (Raheenmore Bog) was selected where the species still occurs.

Macrofossil analyses were completed on multiple cores including the estimation of vegetative plant remains (Quadrat and Leaf Count Macrofossil Analysis) as well as the counting of propagules and animal remains. Horizons with significant changes in the macrofossil assemblages were radiocarbon dated to study the rate in peat accumulation. For the re-survey of the Cors Caron West Bog the vegetation cover of was recorded by establishing quadrats in representative areas and the species abundances estimated as percentage cover.

The comparison of the vegetation in 1936/37 and 2001/02 shows that there was a rapid deterioration in the peat forming vegetation on Cors Caron West Bog, leading to its currently poor condition with the species composition on the West Bog strongly suggesting that the vegetation suffers from drying out. These dry surface conditions are linked to the absence of a properly developed acrotelm over extended parts of the West Bog. An examination of the history of species which do not normally occur in raised bog habitats revealed that on Cors Caron *Molinia caerulea* and *Betula* did not appear in the macrofossil record and colonised the bog in very recent times. This could have been caused by higher water level fluctuations and increased atmospheric nitrogen deposition. On Cors Fochno *Myrica gale* was a component of the vegetation over the investigated time span and its recent increase is likely to be a result of increased water level fluctuations.

The results of the macrofossil analysis show that the significant slow down in peat accumulation on Cors Caron occurred on all three peat domes affecting the margins of the peat domes much earlier than the summits. Potential causes for this change in the accumulation rate point towards a combination of local features in the geomorphology such as changes in the river channel of the Teifi, the spatial restriction of Cors Caron by the valley sides and climatic change which could have influenced the shape of the groundwater mound in the three peat domes. The phase of slow peat accumulation ends at about similar times in most cores, suggesting that the bog responded to the last phase of the Little Ice Age (LIA) after 1800. Together with the change in the rate of peat accumulation, the vegetation also changed with species tolerating lower water levels prevalent in the peat layers of the slow accumulation and Sphagna thriving in wetter conditions, appearing after *c.* 1800. The other two study sites Cors Fochno and Raheenmore Bog differ in their history of peat formation from Cors Caron. Although there is a tendency towards drier surface conditions in both sites, there is no slow down in peat accumulation comparable to that on Cors Caron.

A comparison of the pathways of vegetation succession shows, that the succession rate on Cors Caron was much slower over the last two millennia than on Cors Fochno and Raheenmore Bog, but an acceleration in vegetation change occurs in all three sites in most recent times. The history of *S. austinii* on the investigated sites supports suggestions in the literature that *S. austinii* disappeared after the onset of wetter conditions on Cors Caron. However since it endured on other sites it could be that the genetic fitness/diversity of the species may also play an important role in the survival or disappearance of *S. austinii* in different regions.

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1. Introduction

1.1 Background and rationale

Raised bog communities are regarded as some of the very last remaining near-natural ecosystems in Britain (Godwin and Conway 1939, Lindsay 1993). In the past these systems have been exploited heavily, especially during the nineteenth and twentieth centuries. They were cut for fuel, animal bedding and, most recently, for horticultural growing media (Wheeler 1995). As much as 90% of Britain's former inventory of mires has been lost to peat extraction, forestry and land reclamation (Joosten and Clarke 2002). There are estimates that of the 67 000 ha of raised bog originally in Britain, now less than 4000 ha of primary raised bog are left (Plantlife 1992). The structurally damaged remnants of many British raised bogs display a hummocky surface topography and substantially altered plant communities, often dominated by Cyperaceae and Ericaceae, rather than a *Sphagnum* carpet, typical of the mid to late Holocene. These changes are probably caused by "*human disturbance in lowering water tables and thus encouraging cotton-sedge and heathers over bog-mosses*" Barber *et al.* (1998).

The complex of three raised peat domes at Cors Caron (Tregaron Bog; SN 685622) and the single major peat dome at Cors Fochno (Borth Bog; SN625915) have suffered from peripheral cutting and drainage over the last 150 years but the main central bodies of peat in each of these four bogs are structurally intact. There have been a number of investigations in Europe into restoring extremely damaged mires (Vermeer and Joosten 1992, Sliva *et al.* 1997). For example, 100 million guilders have been spent in the Netherlands since about 1970 on bog restoration often with little success (Joosten 1992, van der Schaaf 1999). However, less badly damaged peatlands have been given less attention.

Together the peatlands of Cors Caron and Cors Fochno represent some 17 % of the structurally intact lowland raised bogs of England and Wales (P. Jones, Countryside Council for Wales, pers. com.). In contrast to many other raised bog remnants they still show the ecological differentiation of plant communities of the crown, rand and in places lagg (Fojt 1995). But without human intervention it is doubtful that regeneration would occur spontaneously. Ombrotrophic raised bog plant communities with their special composition of species have become rare in Britain (Wheeler 1995). At Cors Caron and Cors Fochno these communities are still inhabited by bryophytes such as *Sphagnum pulchrum*, *S. austinii* and *S. fuscum*, which are regionally very rare (Averis 1999, 2000, Newton 2000). As both Welsh raised bog complexes are in closed proximity to floodplain systems (Cors Caron on the Teifi and Cors Fochno by the Dyfi estuary) they are important breeding and resting areas for birds (e.g. Slater 1972, Bölscher 1995). Furthermore, these mires support a whole range of rare animal species many of which were encountered during the fieldwork seasons of 2000-2002. These include otter (*Lutra lutra*), curlew (*Numenius arquata*), hobby (*Falco subbueto*), red kite (*Milvus milvus*), short eared owl (*Asio flammeus*), kingfisher (*Alcedo attis*), sky lark (*Alauda arvensis*) and adder (*Viper berus*). Insects of conservation importance are also found at both bogs. The nationally rare rosy marsh moth (*Coenophila subrosea*) occurs at both sites. Its caterpillar feeds usually on *Myrica gale* but the Cors Caron population relies on *Empetrum nigrum*. At Cors Fochno *M. gale* is very abundant and recent research revealed this plant as having useful pharmaceutical potential (CCW 2001).

Possessing such diversity in wildlife these mires are a major conservation resource of international significance. The great importance of both mires is reflected in their status as Natural Nature Reserves (NNR), Sites of Special Scientific Interests (SSSI's), Special Areas of Conservation (SAC's) and Ramsar sites (Stoneman and Brooks 1997, http://www.jncc.gov.uk/page-1458, Wetlands international [1],[2]).

Another aspect of raised bogs is that they represent an archive of their own history and the history of their surroundings. This gives the opportunity for research into past biodiversity, mire succession, climate change, vegetation history and also human history (Godwin 1946, Hayen 1990, Barber 1993, Barber *et al.* 1994, Hughes and Barber 2003, 2004). With the rapid disappearance of lowland raised bogs in Western Europe, the possibilities for research on them has become more restricted. As both raised mires are still relatively intact they represent valuable resources as palaeoecological archives.

Both the Cors Caron and Cors Fochno raised bogs display significantly altered vegetation communities compared to those present during the preceding 2000 years at each site. Additionally it seems that the composition of the surface vegetation especially at Cors Caron has undergone a dramatic change within at least the last sixty-five years. Godwin and Conway (1939) noted extended *Sphagnum*-rich areas and numerous pool features that appear to have largely disappeared sixty-five years on. The remaining peat forming vegetation is very vulnerable to lower, fluctuating water-levels and nitrogen deposition, which promote changes in vegetation. Those changes include colonisation by trees such as *Betula* ssp. (Fojt 1995). Along with other competitive species such as *Molinia caerulea* and *Calluna vulgaris,* trees enhance evapotranspiration and reinforce the fluctuation in water levels. These successional processes were already noticed by Godwin and Conway (1939), who investigated the vegetation of the Cors Caron West Bog in one of the first attempts in Britain to map raised bog vegetation at a large scale. The rate of twentieth century plant succession appears to have been rapid. The West Bog of Cors Caron offers a rare chance to track this change in detail because modern vegetation mapping can be compared to a vegetation survey produced by Godwin and Conway in the field seasons of 1936 and 1937. The main vegetation changes and abnormal stratigraphical features on the investigated sites are summarised as follows:

Main changes and abnormal stratigraphical features at Cors Caron (Tregaron Bog):

1) Total extinction of the former main peat forming *Sphagnum imbricatum*, ssp. *Austinii* from the whole bog complex. It is displaced mainly by *S. papillosum* (Godwin and Conway 1939).
2) General decline in *Sphagnum* cover despite high annual precipitation of av. 1300 mm for Cors Fochno (Mike Bailie, personal Communication) and av.1600 mm for Cors Caron (Paul Culyer, personal communication).
3) A relief change towards an atypical 'hummocky' bog surface with increased *Calluna vulgaris* cover and disappearance of the pool systems on the West Bog after the 1960s (aerial photographs from 1946, 1998).
4) Invasion of the bog crowns by *Betula* ssp. and *Molinia caerulea* (Godwin and Conway 1939)

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[1] http://www.wetlands.org/RDB/Ramsar_Dir/UnitedKingdom/UK001D02.htm Ramsar Sites Database
[2] http://www.wetlands.org/RDB/Ramsar_Dir/UnitedKingdom/UK057D02.htm Ramsar Sites Database

(5) A substantial late medieval slow-down phase in peat accumulation present in all three Cors Caron Bogs which is not recorded in Cumbrian bogs (Morriss 2001, Hughes *et al.* 2001).

Main vegetation changes on Borth Bog:

(1) Massive decline in the lax form of *Sphagnum austinii.* Small hummocks of the robust form of the species are still present (Newton 2000).
(2) Invasion of *Molinia caerulea* on lower cut-over parts of the bog.
(3) Invasion of *Phragmites australis* on cutover marginal parts of the ombrotrophic peat dome.
(4) Increase of *Myrica gale* onto the bog crown.
(5) Loss of most lagg areas around the bog.

The plant macrofossil diagrams produced by several other peatland researchers (e.g. Barber *et al.* 1994, Mauquoy and Barber 1999a, 1999b, McMullen *et al.* 2004) clearly demonstrate that some of the key late Holocene changes in raised bog biodiversity began substantially before the beginning of the twentieth century and may not be accounted for by peat cutting at the bog periphery, or industrial pollution, which mainly began in the nineteenth century. Previous work on the pollen record of Cors Caron by Morriss (2001) shows a significant decrease in peat accumulation rates at both, the Southeast and the West Bog over the 12 – 13th century AD. However, there is evidence that the peat overlying the dated strata must have formed from the 1800's onwards because of the presence of high quantities of pine pollen (Morriss 2001). Several possible causes for the decline in peat accumulation were discussed including uniform peat cutting or *Sphagnum* raking, marginal peat cutting, changes in the water level of the Teifi, burning and natural climatic factors. Considering that the condition of the current raised bog vegetation at Cors Caron and Cors Fochno has at least in parts changed significantly, there is now an immediate need to characterise the pathways of vegetation change and understand the principal mechanisms driving late Holocene vegetation succession on raised bogs.

1.2 Thesis aims and research questions

The overall research question for this project is: Has the direction and rate of change in raised bog vegetation succession altered over the last 2000 years at Cors Caron and Cors Fochno and if so, what factors have driven these changes? This includes to characterise and to compare the main pathways of raised bog development at Cors Caron and Cors Fochno during the late Holocene, covering approximately the last 2000 years, and to examine the possible factors driving vegetation succession throughout the observed time period. Within this overall research question specific attention is given to the following research objectives:

1) **To characterise the pathways of vegetation succession and rates of change in raised bog community development.**
2) **To examine the factors affecting peat accumulation in the investigated sites.**
3) **To examine the histories of individual species**

The research areas above encompass more detailed research questions, which are elucidated in the following paragraphs:

1) Pathways of vegetation succession and rates of change

Which vegetation types formed the bulk of late Holocene peats at the investigated sites?

How stable are vegetation communities over the last 2000 years?

When did the recent vegetation communities develop and what is the change in the succession rate over the last two millennia? At this stage the mostly palaeoecological approach applied in this project can be linked with modern vegetation mapping. The pioneering work of Godwin and Conway (1939) enables to study the vegetation development at the Cors Caron West Bog over the past sixty-five years in more detail.

How different is the 20th century vegetation succession from the late Holocene anticendants?

2) Individual species histories

What is the history of *Sphagnum imbricatum* ssp. *austinii* and possible causes of its disappearance at Cors Caron and yet presence at Cors Fochno? The comparison with an Irish site, where the species is still abundant may contribute to an understanding of the extinction process.

What are the histories of *Betula*, *Myrica gale* and *Molinia caerulea*, which are naturally sparse/absent on raised bogs but have been become problematic at the investigated sites?

With respect to the raised bog species that are present through the period under investigation – how does their pattern of occurrence change?

3) Factors affecting peat accumulation

What are the characteristics of the anomalous peat accumulation at Cors Caron in more detail and what may have caused it?

How consistent is the pattern of peat accumulation between the individual cores and sites and what accounts for this pattern?

1.3 Thesis structure

The thesis is divided into eight chapters. Chapter 1 introduces the background and rationale of this project as well as the wider and specific research questions. The chapter also presents the organisation of the thesis and explanation of terms and definitions used. Chapter 2 reviews previous research concerning succession in general and raised bog development in particular. This is followed by considerations of processes of peat formation and decomposition in order to assess the limits and potential of macrofossil analysis which is the main approach used in this project. Sources of damage to raised bogs are reviewed, followed by a discussion of bog conservation issues. In chapter 3 the study areas are introduced in detail. Information is given about their geographical background, stratigraphy, land use history, conservation status, vegetation and current status of restoration. The fourth chapter deals with the methods used in the project. Laboratory procedures incorporate macrofossil analysis, Spheroidal Carboneous Particle (SCP) analysis and radiocarbon dating

(Accelerator Mass Spectrometry – AMS). Fieldwork includes peat coring, along with peat sub-sampling and methods of vegetation surveying. The results of the palaeoecological research are presented in chapter 5. Chapter 6 deals with the results of the vegetation survey on Cors Caron West Bog. In Chapter 7 the results of chapters 5 and 6 are interpreted and discussed. Chapter 8 summarises the conclusions drawn from the research project and considers opportunities for further research.

1.4 Terminology and nomenclature

1.4.1 Introduction

This section explains the terminology and the nomenclature used in this thesis. The terms applied in scientific literature are often confusing and do not always following logic. Problems arise as many terms used in science derive from pre-scientific words. Words such as 'bog' or 'fen' cover many types of peatlands, which may cause confusion about their meaning. Additionally the use of terms differs slightly in the literature or can appear contradictory. An example is the term 'mire' (Gore 1996, Joosten and Clarke 2001). Gore (1996, p. 1) explains in his introduction that "*The term mire includes all those ecosystems described in English usage by such words as swamp, bog, fen, moor, muskeg and peatland.*" But in one of the following sections (p. 2) he elaborates: "*Swamp has a very wide range of meanings in international usage, hence its pride of place in the volume title; it can include not only mires (peat-forming) but marsh and wetland as well.*" In the end it is not clear which term includes the other, the more so as the author defines mire as a peat forming ecosystem and a swamp not necessarily peat forming.

At the end of this section follow explanations concerning the site names and finally the nomenclature that was followed for vascular plants, lichens and mosses is listed. Scientific terms, which are connected with specific topics, will be defined in the appropriate sections.

1.4.2 Terminology

Ombrotrophic implies that the water and nutrient supply derives only from precipitation (Gore 1996).

Peat is a sedentary accumulated substrate containing at least 30% organic material. Some specific mire types, which are based on mineral rich water supply may have less than 30 % organic material (Succow 1988).

The term **peatland** will be used in the sense of Joosten and Clarke (2001) as an area with or without vegetation with a naturally accumulated peat layer at the surface.

Mires are peatlands carrying peat forming vegetation and where peat is still being formed (Maltby 1997, Joosten and Clarke 2002).

The term **raised bog** refers to a bog which is dominated by ombrotrophic peat forming plant communities with its independent water table elevated above the regional ground water level (Joosten 1993).

To describe surface morphology, the term **pool** is used to define surface depressions containing open water.

The term **hollow** refers to wet vegetated depressions (filled with *Sphagnum* and vascular plants).

The terms **acrotelm** and **catotelm** were introduced by Ingram (1967) in order to found a suitable description for the so-called 'active layer' of raised bogs, identified by Ivanov (1953). Since this term defines a different feature in the scientific English terminology, Ingram coined the terms acrotelm and catotelm for the two layers of diplotelmic bogs, in order to avoid confusion. The acrotelm is defined as the upper, oxic layer of a raised bog, in which the water table fluctuations occur as well as the processes leading to peat formation such as decay and humification due to microbial activity. The acrotelm peat has a low bulk density combined with large pore spaces, which allow a large storage capacity for water. The constantly waterlogged catotelm is characterised by an anoxic environment with limited microbial activity resulting in very limited further peat decay. On the border of the acrotelm with the catotelm the macrostructure of the decaying peat collapses, leading to a high bulk density in the catotelm with small pore sizes and a limited water storage capacity.

1.4.3 Site names

The investigated sites are known under several names. On maps originating from the late 18th and early 19th century the mires are called Cors Goch or Cors Goch Lan Teifi (= *English:* The red bog on the banks of Teifi) and Gors Fochno. In many publications of the 20th century (Godwin and Mitchell 1938, Godwin and Newton 1938, Godwin and Conway 1939, Turner 1964, Moore 1963, Slater 1972) the English site names Tregaron Bog and Borth Bog were usually applied. However in more recent time there is a tendency to use the Welsh designation Cors Caron (*Welsh:* cors = *English:* bog) for Tregaron Bog and Cors Fochno for Borth Bog. Examples are publications and reports (Burton and Hodgson 1987, Barber 1993, 1994, Fojt 1995, Moore 1997, Averis 1999, 2000, Newton 2000) as well as public national and international websites (http://www.jncc.gov.uk/page-1458, Wetlands international[3],[4], CCW 2002, Wetlands International 2002a,b). Following this practice the Welsh names Cors Caron and Cors Fochno are used in this thesis.

In contrast to the single peat dome of Cors Fochno the Cors Caron complex consist now of three independent raised peat domes. According to their geographical position they are referred to as the West Bog, Northeast Bog and Southeast Bog.

1.4.4 Nomenclature

Sphagnum imbricatum is treated in the earlier literature (Godwin and Conway 1939) as a species without the later distinction in the two subspecies *austinii* and *affine* (Daniels and Eddy 1990), or species

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[3] http://www.wetlands.org/RDB/Ramsar_Dir/UnitedKingdom/UK001D02.htm Ramsar Sites Database

[4] http://www.wetlands.org/RDB/Ramsar_Dir/UnitedKingdom/UK057D02.htm Ramsar Sites Database

(Thingsgaard 2002). Stoneman *et al.* (1993) propose that the bulk of raised bog peat formed by remains of the *S. imbricatum* complex is formed by *S. austinii.* As the results of the genetical research by Thingsgaard (2002) justify the separation into two separate species, in this thesis it will be referred to *S. austinii* and *S. affine* as two species of the *S. imbricatum* complex. However, since the literature does not always differentiate between the species, in these cases it is referred to *S. imbricatum* (*cf. austinii*) when it is very likely that the mentioned species is identical with *S. austinii.*

Like the species mentioned in the previous paragraph, the sister species ***S. capillifolium*** and ***S. rubellum*** are treated by some authors as variants of one species (Daniels and Eddy 1990) or as two independent species (Fram and Frey 1992). Usually both can be easily distinguished from each other with *S. capillifolium* being more robust with a hemispherical capitulum and *S. rubellum* being more slender with a flat capitulum. The two species occur also in different habitats. *S. rubellum* prefers more oligotrophic environments whereas *S. capillifolium* is found in more minerotrophic habitats. Cronberg (1998) found that *S. rubellum* populations in Britain show the highest genetic variability, compared to populations in continental Europe. Additionally the more variable populations of *S. rubellum* are more similar to *S. capillifolium,* which may explain that the features are sometimes not clear. The author concludes that therefore: "*It is possible that the greater genetic diversity of the British populations allows S. rubellum to be morphologically more variable and to occupy a more diverse array of habitats, which may be one explanation of the different taxonomic treatments of the species complex.*" Following the findings of Cronberg in the thesis it is thus referred to *S. rubellum* and *S. capillifolium* as species.

The nomenclature followed for vascular plants is Stace (1991), for non-*Sphagnum* bryophytes Smith (1978), Hodgetts (1992) for *Cladonia* and Molberg and Holmasen (1992) for lichens. For Sphagnum the nomenclature followed Daniels and Meddy (1990) with the exception of *S. austinii* and *S. rubellum* (for justification see section 1.4.2).

2 Previous research

In the following sections literature is reviewed for topics relevant to this project. As raised bog succession is the main research objective within this project, the first section deals with the development of succession concepts, followed by a consideration of mire development pathways leading to a raised bog stage. In raised bogs the role of water is crucial, thus section 2.2 deals with hydrological properties of raised bogs as well as the mechanisms guaranteeing the maintenance of the hydrological conditions needed by the peat forming plant communities. This is followed by an overview of peat formation and interpretation of the macrofossil record. As all three study sites are affected by human impact, major sources of damage to raised bogs and the peat forming vegetation are discussed in section 2.4. Section 2.5 reviews raised bog conservation in Britain and in different European countries, because this research project aims to contribute knowledge as a base for further restoration strategies at Cors Caron and Cors Fochno. Finally, the chapter deals with the ecology of key raised bog plant species *Sphagnum imbricatum* and *Molinia caerulea* which are both matter of concern at the investigated sites.

2.1 Raised bog development

2.1.1 The concept of succession

The concept of succession was popularised by Cowles (1899) who observed a series of vegetation stages at the edges of Lake Michigan. However, Clements's (1916) regarded De Luc (1806) to be the first one using the term "*with full recognition of its developmental significance*" when describing observations on hydroseres. An even earlier succession-like idea of the origins of bogs derives from King (1685). Gorham (1953) even goes so as far to interpret King's thoughts about the origin of 'red' bogs as a clear statement of succession. These early reports suggest that the observations on peat deposits of mires have significantly contributed to the development of the concept of succession. Nonetheless, at the turn of the twentieth century succession was still seen as something exceptional (Cooper 1926).

Clements (1916) considers the vegetation unit as akin to an organism with succession being the development of this organism from infancy to maturity. Tansley (1920) adopted Clements's view of the vegetation unit. He defines "*succession, in its most general sense, is simply the gradual change which occurs in the vegetation of a given area of the earth's surface on which one plant population succeeds another*". He understands succession as colonisation of bare areas by pioneer plants and then, "*the first plant communities to appear are gradually suppressed and superseded by others which develop later, so that a series of communities is initiated, usually of progressively larger and taller plants. This succession of communities culminates in a climax community dominated usually by the tallest plants which can arrive on the area and can flourish under the particular conditions which it presents*" (Tansley 1939). However, in contrast to Clements (1916) Tansley (1939) describes different kinds of so-called 'climatic' climaxes.

Clements (1916) and Tansley (1920) view succession as a development, which always follows the same pattern towards a 'mature' community, usually Forest. Tansley (1920) considers the true 'biotic' succession as a sere where, he supposes, the plants are the main controlling factors, and regards succession induced by other factors such as animals or outside factors, as having nothing in common with true development, a view which later has become untenable (Moore 2001). However, the concept of succession was not clearly defined and a matter of controversy. For example, Cooper (1926) does not agree with Clements (1916). He points out that according to his definition of succession as "*the universal process of vegetational change*", all vegetation changes must of necessity be successional and underpins his point of view with examples. On the other hand, he questions, if vegetation changes initiated by fire or anthropogenic influence could be considered as true succession or not and refers to Clements (1916) who excluded those factors from true succession. Gleason (1927) views the definitions of Clements (1916) and Cooper (1926) as two extremes describing them as almost completely in antithesis. He assumes that the truth lies somewhere in the middle between both definitions and points out his understanding of succession as "*the replacement of one association by another*".

Cowles (1901) suggested the idea of culmination of succession in a mesophytic forest as climax, which became part of the foundation of dynamic ecology. This view was supported by Clements (1916) and Tansley (1920, 1939). Gleason (1927, p. 312) questions the concept of a climax and refers to the occurrence of reversionary successions and the fact that "*the operation of successional causes never ceases, not even on the so-called climax*". He dismisses succession as a systematic and orderly process and emphasises the complexity of successional processes depending on the behaviour of the individual plant. Gleason (1927, p. 316) also points out the role of observation in order to prove succession and suggests that the idea of a climax may derive from the fact that the changes occur so slowly that they are not observable and states: "*Our idea of finality in the climax association depends on the observation that in no discoverable successional cause is at work which may change its nature. If there are such successional causes in operation, they are so slow that their effects are not observable and not inferable, and we are prone to believe accordingly that they do not exist.*"

With the progress of the twentieth century the understanding of succession as a complex and variable process progressed. For example, Whittaker (1953, p. 44) considers succession "*not as series of distinct steps, but as a highly variable and irregular change of populations through time, lacking orderliness or uniformity in detail, though marked by certain fairly uniform over-all tendencies*". He reports that there are many studies showing the real complexity of patterning of stable vegetation. Walker (1970) demonstrates that the diversity in hydroseres alone is far greater than proposed before and concludes: "*Variety is the keynote of the hydroseral succession*" (Walker 1970, p. 137). Connell and Slatyer (1977) expand the succession concept to marine ecosystems where sessile animals play a similar role to plants in terrestrial seres. They criticise that, since many studies of succession have been carried out by persons working only on plants, possible mechanisms like the effect of grazing animals have been ignored. The authors point out that the theory of community structure was based almost entirely on competition, but suggest that in addition interactions with herbivores, predators and pathogens are of critical importance to the course of succession. However, their succession models are later the object of criticism by Picket *et al.* (1987) who claim that their review shows more mechanistic richness in these processes than allowed by the models of Connell and

Slatyer (1977). Picket *et al.* (1987, p. 347) emphasise the importance of individual replacement and the change in performance of individuals as fundamental in succession. Further, the authors stress that "*Successional processes are essentially demographic, and have complex relations to biotic and physical environments*". Walker and Chapin (1987) criticise Connell and Slatyer too, pointing out that not all studies fit neatly in these three models and that many successional processes occur simultaneously and therefore cannot always be grouped into alternative models. Connell *et al.* (1987) defend their model pointing out that their models were never designed to adequately describe successional changes and want them to be seen as representing the extremes of a continuum of effects of earlier species on later species. These more recent controversies show that even the more complex models do not fully provide a satisfying answer to all the questions behind the succession process. Although succession's existence is today generally accepted, the dispute about its underlying mechanisms is still continuing (Moore 2001).

2.1.2 Succession pathways leading to raised bog

Several pathways of succession lead to the development of raised bogs. In many cases in the British Isles the development of raised bogs followed the pathway of the classical hydrosere, where ombrotrophic raised bog succeeded minerotrophic fen. Early considerations regarded woodland as the climax stage for hydroseres (Clements 1916, Tansley 1939), but the critical review of supporting literature, carried out by Walker (1970), showed that the concept of forest as final stage in raised bog development is untenable and ombrotrophic *Sphagnum*-dominated raised bog is the climax of the succession in hydroseres under current climatic conditions. They started with the infilling of a post-glacial lake basin with gyttia (Godwin and Mitchell 1938, Winkler 1988, Hammond 1968, Moore 1997, Succow and Joosten 2000) during the early Holocene. The base of the lake sediments is often underlain with clay, which was already mentioned by King (1685). After the filling of the lake usually reedswamps develop, followed by fen. In Britain the transition from fen to ombrotrophic bog growth often took place during the early to mid Holocene (Hughes 1997, Hughes and Barber 2003). Walker (1970) suggests, that the conditions for fens to persist for a long time whilst rapidly accumulating peat must be very rare. He considered the case of Cors Caron, with its several metres of *Phragmites* peat layers, in this respect as an exception. However, it may be possible, that the river Teifi, running trough the Cors Caron mire complex brought more nutrients into the then fen, allowing the *Phragmites* reed continuous peat accumulation. Walker (1970) considers the reed swamp stage within the hydrosere as a starting point for development in different directions. Raised bog development may start then (1) directly due to invasion of the *Phragmites* fen by *Sphagnum* or (2) a carr follows the fen stage which is then invaded by *Sphagnum*. More recent research based on detailed macrofossil analysis showed that the fen vegetation was replaced by relatively dry vegetation consisting of *Eriophorum vaginatum*, *Calluna vulgaris* and *Aulacomnium palustre* and few Sphagna (Hughes 1999, 2000). This phase was a pioneer stage in which water levels were not yet stable. Hughes (2000) suggests that the macrofossil record and field stratigraphy indicate that possibly several mechanisms lead to ombrotrophy in raised mires. Almquist-Jacobson and Foster (1995) too suggest, that the accumulation of *Sphagnum* peat, indicating raised bog initiation occurred during relatively dry (or warm) phases.

Another pathway leading to raised bogs starts with minerotrophic paludification as result of rising water tables. In Britain this happened at estuarine sites for example in Cumbria and Wales (Godwin and Newton, 1938, Moore 1997), and in low lying Pleistocene sand areas in Northwest Germany (Eggelsmann 1990). With the beginning of the Atlantic period (c. 7500-5000 BP) the climate changed towards more humid conditions and triggered ombrotrophic bog growth with *Sphagnum* as the dominant peat former (Casparie and Streefkerk 1992, Petzelberger *et al.* 1999).

In Northwest Germany raised bog growth was also initially ombrotrophic over large areas on Pleistocene aeolian sand. Before the bog growth started, these areas were covered by woodland. The climate induced (ombrotrophic) paludification resulted in the death of the trees and spread of *Sphagnum*. The study by Petzelberger *et al.* (1999) showed that in large areas the ombrotrophic *Sphagnum* peat directly overlays a podsol. At the base of the peat *Betula*, *Alnus* and *Quercus* wood was often found, as well as stumps of *Quercus*. An impervious iron pan has not been found at any of the cores sampled by Petzelberger et al (1999). The average age of the bog bases decreases towards the south with increasing distance from the coast. The authors propose, that linked with the transgression of the North Sea into the present coastal area, a change in climate occurred, inducing ombrotrophic bog growth.

2.1.3 Late Holocene raised bog development

Late Holocene development of raised bogs is characterised by deposition of mainly slightly humified *Sphagnum* peat. One of the main peat formers during the late Holocene was *Sphagnum austinii*, a peat moss of the section *Sphagnum*. However, in the course of the last millennium this species declined dramatically and its present distribution is very limited (Godwin and Conway 1939, Green 1968, Overbeck 1975, Stonemann *et al.* 1993). On many sites *S. austinii* has been replaced by other *Sphagnum* species. A more detailed overview of the species is given in section 2.6.

Most raised bogs possess a mosaic of different microrelief patterns, consisting of hummocks, lawns and hollows. The observation of those patterns inspired Sernander to the concept of cyclic regeneration of bog vegetation (von Post and Sernander 1910), which was taken over by others without any critique (Cajander 1913, Clements 1916, Osvald 1923). The idea proposes that on hummocks the Sphagna are unable to thrive, die off and become replaced by non-peat-forming associations, which are in turn 'drowned' in the following stage due to the vertical growth of neighbouring bog areas. Hollows should become successively filled up and transformed to hummocks with a result of a lenticular stratigraphic pattern. However, Osvald (1923) admits, that it is difficult to track the cause for the spatially differentiated inhomogeneous vertical peat growth and criticises von Post and Sernander (1910) for providing only a very confusing overview of the course of these succession processes. He developed a diagram to illustrate the possible course of the succession at the raised bog Komosse, Sweden (see Figure 2.1).

The cyclic theory of the bog regeneration was widely accepted (Kulczynski 1949) and in the British Isles the personal contact between Osvald and Tansley as well as Godwin probably contributed to its acceptance in Britain and Ireland (Barber 1981). Tansley (1939) developed a diagram showing the lenticular pattern, allegedly formed by cyclic regeneration. Godwin and Conway (1939, p.327) tried to apply the concept to Cors Caron (Tregaron Bog), but reported that *"the cycle given above cannot be demonstrated clearly in more than a few spots, the degradation stages being particularly hard to find ..."*.

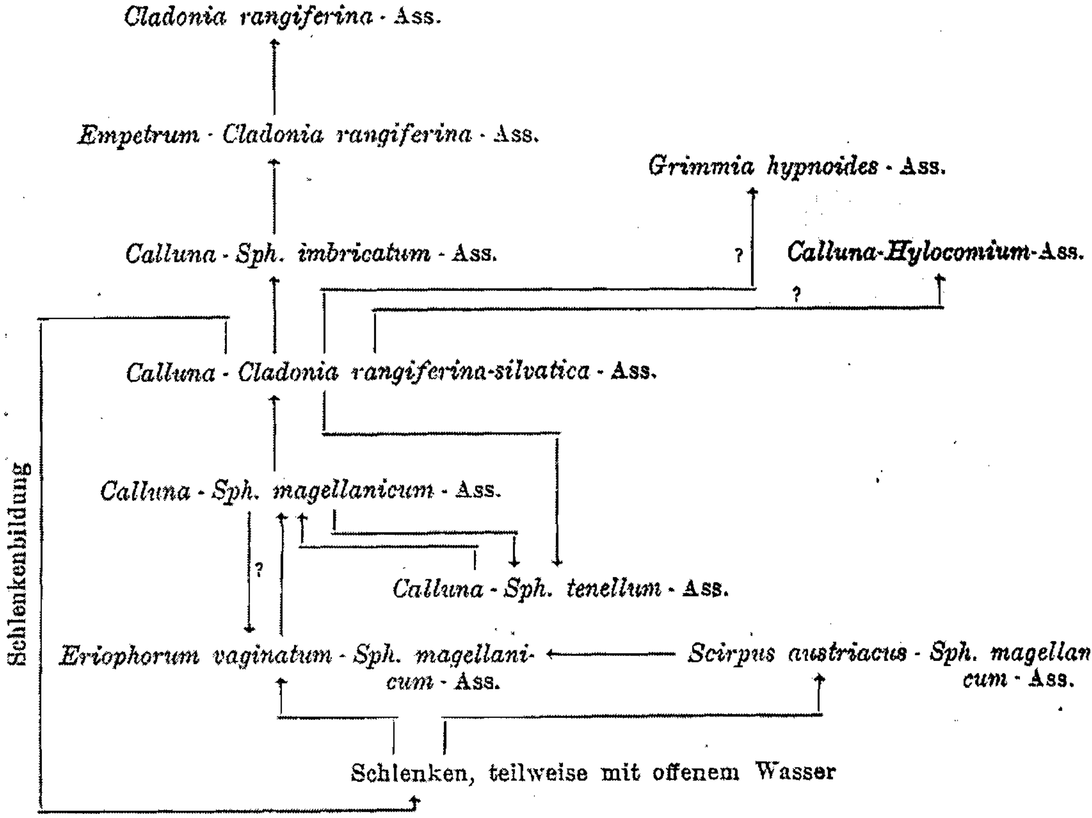

Fig. 54. Schematische Übersicht über die Sukzession in dem Regenerationskomplexe des Komosse.

Figure 2.1: Diagram of the course of cyclic regeneration by Osvald (source: Osvald 1923).

However, doubts about the theory were raised (Gorham 1957, Walker and Walker 1961, Overbeck 1975) and also the results of more recent studies (Backeus 1972, Aaby 1976, Tolonen 1980, Barber 1981, Svensson 1988) were contrary to the theory. In a review Backéus (1991) points out that Sernander never made any stratigraphic studies to underpin his theory; he was fully occupied with what he saw on the surface. Barber (1981) tested and falsified the theory using extended peat faces at Bolton Fell Moss. He concluded that there is no evidence supporting the theory of cyclic regeneration but the alteration in peat humification on the peat faces can be related to climatic changes. As a consequence of his findings Barber (1981) established the Phasic Theory of bog growth that states that raised bog growth is chiefly controlled by climate.

Within the Phasic Theory Barber (1981) also linked the occurrences of Regeneration Complexes and Recurrence Surfaces, with the Regeneration Complex succeeding stratigraphically the Recurrence Surfaces. The term Recurrence Surface was introduced by Granlund (1932) who investigated the stratigraphy of Swedish raised bogs. Recurrence surfaces are defined as the plane between slightly humified peat, sharply delimited from an underlying layer of more highly humified peat (Clymo 1991). Granlund (1932) identified five of them with the third one, RY III, being identical to the Boundary Horizon (Grenzhorizont) of Weber (1900). The highly humified peat consists mainly of the remains of *Calluna*, *Eriophorum* and rather little *Sphagnum* (Godwin and Mitchell 1938, Dickinson 1975). Initially, it was supposed that the highly humified peat was the result of secondary decay within a dry period but this assumption was later dismissed and it was acknowledged that the high degree of humification is primary (Godwin 1954). Barber (1994) points out that the theory of cyclic regeneration accepted the role of climate in the formation of recurrence surfaces. The dark humified peat was supposed to develop under relatively dry and warm conditions, whereas the succeeding, light humified peat was formed in a wetter or colder climate. Initially, it was also assumed that between the formation of the dark humified peat and the overlaying light humified peat a hiatus could have occurred but Wimble (1986) reported that there is no evidence to support this assumption. Recurrence surfaces are interpreted as a response to a changing climate (Godwin 1954, Barber 1981, 1982) and were found in raised bogs throughout Western Europe (Granlund 1932, Godwin and Mitchell 1938, Conway 1948, Overbeck 1975, Dickinson 1975). However, contrary to Granlunds assumption often they do not match chronologically among sites or even within the same bog (Godwin 1975, Overbeck 1975, Clymo 1991). Frenzel (1983) points out that several authors including von Post (1910) suggested that autogenic processes in the bogs themselves might have contributed to the formation of recurrence surfaces. Frenzel (1983, p. 56) concludes that "*recurrence surfaces may originate either from climatic triggering effects plus local conditions or from local conditions only*". Additionally he states that there are possibly long delays between the affecting climate factor and the reaction of the bog. The data of Wimble (1986) mostly support the phasic climatic theory of Barber (1981), but as the author points out, there is also some evidence which points towards local factors of influence. This is supported by Kilian *et al.* (1997) who propose that recurrence surfaces are probably related to climate pulses occurring with intervals of centuries, which a bog sometimes may have registered and sometimes not, due to local conditions and internal bog dynamics. This implies that autogenic processes may have an influence on the formation of recurrence surfaces.

Raised bogs are ombrotrophic and therefore depend solely on rainwater and dry deposition of nutrients. Thus, changes in their peat stratigraphy have been widely interpreted as being driven by climatic change (Aaby 1976, Barber 1981, Barber *et al.* 1999, Mauquoy and Barber 1999a,b, Hughes *et al.* 2000). Research based on the exploitation of ombrotrophic bogs as proxy-data sources seems to support the climatic interpretation (Barber 1982, 1993), however, there are still differences in opinion about the factors driving ombrotrophic peat growth. Almquist-Jacobson and Foster (1995) point out that, theoretical models describing raised bog hydrology and growth suggest that autogenic mechanisms are responsible for some changes in vertical accumulation and the shape of peatlands which is supported by other authors (Clymo 1978, 1992, Foster and Wright 1990, Illomets 2000). For example, Zobel (1988) considers the invasion of Sphagna as a crucial point in autogenic bog succession since they are capable of modifying the chemical properties of the habitat. Almquist-Jacobson and Foster (1995, p. 2515) conclude from their study, that "*not all aspects of mire development seem closely related to climate*".

Unfortunately, many earlier studies dealing with raised bog development often included only pollen analysis accompanied by field stratigraphy and a coarse description of some macrofossil plant remains (Godwin and Mitchell 1938, Hammond 1968, Godwin 1981, Winkler 1988). A detailed analysis of macrofossils as a source of information for the development of peatlands was rare or absent (Hughes *et al.* 1999), but has been approached more recently (Barber 1981, Haslam 1988, Hughes 1997, Hughes and Barber 2003, 2004, McMullen *et al.* 2004).

2.2 Raised bog hydrology

In contrast to minerotrophic mires, which are fed by groundwater or catchment water, raised bogs are ombrotrophic and receive their recharge solely from precipitation. Due to the hydraulic properties of the peat the water table in raised bogs is elevated above the regional groundwater level (Joosten 1993). A cross-section across a raised bog shows a characteristic 'clock-glass-like' shape with the water level always close to the surface of the bog. This suggests that a raised bog is a paradoxical system; it keeps the water table high against the forces of gravity, which is an inherently unstable condition (Ingram 1982). In order to find an explanation for the elevated ground water table, researchers suggested different hypothesises. Weber (1908) had already assumed impeded drainage as a reason. Until recently it was also assumed that capillarity maintained the high water table (**Capillary Hypothesis**) as reported by Moore and Bellamy (1974) and Gosselink and Turner (1978). However, both publications mention the capillary hypothesis only briefly and do not search for physical details behind the theory, to explain how capillarity allegedly supports a water table close to the bog surface as well as the presence of bog pools.

Ingram (1978) adopts the concept of the diplotelmic mire from Ivanov (1953) and coined the terms acrotelm and catotelm for the two layers within an intact raised bog (see Figure 2.2). The acrotelm is the upper layer where the water level oscillates and partial aeration promotes decomposition. In the acrotelm the hydraulic conductivity is highest due to the large pore size of the less or undecomposed peat. The catotelm is constantly waterlogged with further decomposition strongly inhibited due to the lack of oxygen. At the transition from the acrotelm to the catotelm the macrostructure of the dead plant matter collapses, which

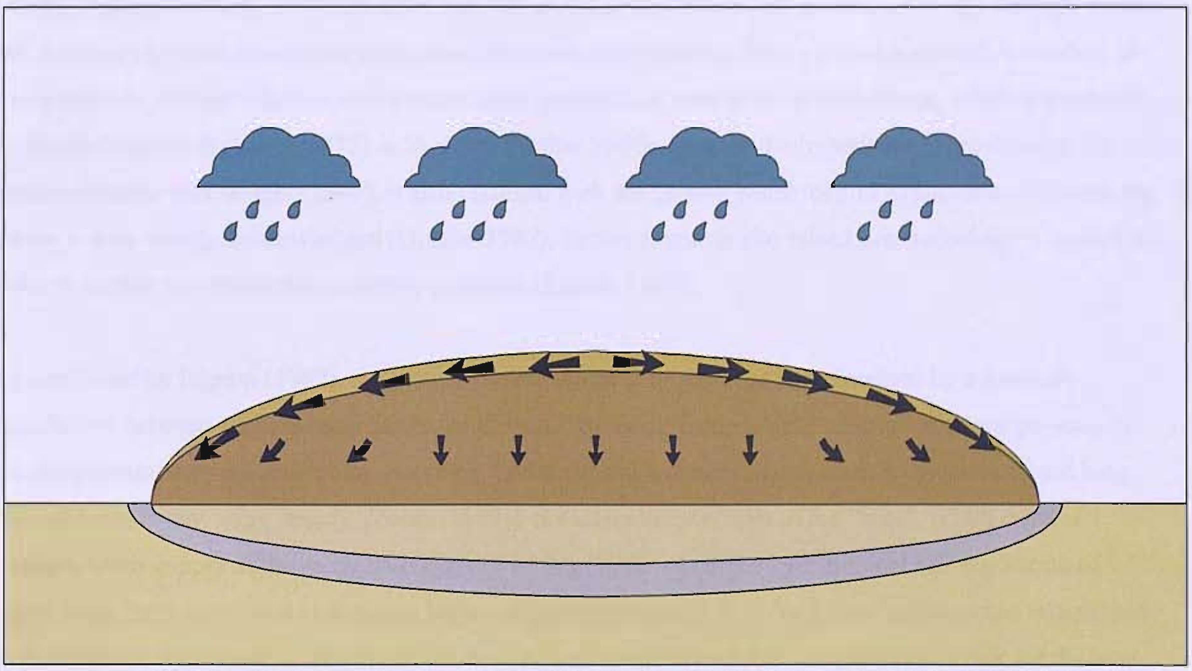

Figure 2.2: Cross-section of a raised bog sensu Ingram 1982. The arrows represent the direction and the amount of the water flow.

leads to much smaller pore spaces and a negligibly small hydraulic conductivity. Later, Ingram (1982) points out that an elevated water table can not be sustained by capillary forces and refers to Granlund (1932) who had experimentally shown that the zone of saturation from capillary forces would rise only 0.5 m, which was supported by results of Romanov (1968), who found similar maximum rises in a bog near Leningrad. Ingram (1982) argues that the pores in the uppermost layers of a raised bog are far too big to allow a capillary rise over several metres to the bog surface and concludes that the capillary hypothesis is also insufficient, because it suggests no mechanism which would explain the clock-glass bog shape, where the edges are lower than the centre. He concludes further, that the capillary hypothesis misinterprets the kind of saturation in peat deposits. In soils where saturation is sustained by capillarity, the water is tightly bound to the pores by matric forces (in hydrology this is called a negative hydraulic potential). It would imply that the water level displayed in a dip well would have to be at the same level as the lagg stream. In raised bogs this is obviously not the case, the water level normally lies almost at the bog surface or a few decimetres below it often sustaining extended pools systems. This implies that the water is not bound by matric forces (in hydrological terms; raised bogs have a positive hydraulic potential)(Ingram 1982).

As an alternative, Ingram (1982) suggests the **Ground Water Mound Hypothesis**, based on the fact that ground water mounds, named by Mariño (1974) are known in hydrology (Luthin 1966, Mariño 1975). They are maintained by a dynamic equilibrium between recharge and discharge. Ingram elucidates that in a homogenous porous medium with a simple geometry the relationship between height and width of the groundwater mound can be predicted for any combination of discharge with hydraulic conductivity, referring to Polubarinova-Kochina (1962). Ingram points out that the size and shape of raised bogs "*are controlled by soil physics and hydrology*". He tested the ground water mound hypothesis at Dun Moss and concludes that "*the similarity of the profile of an ellipse whose parameters are in reasonable accord with what is known of the hydrodynamics of the catotelm seems to support the groundwater mound hypothesis*". Finally, Ingram (1982, p. 303) concludes that "*As a conceptual model, the ground water mound hypothesis has a secure physical foundation and seems consistent with evidence from various sources.*" According to the hypothesis damper climates will support more pronounced convexity of raised bogs, which is supported by the findings of Granlund (1932) in Sweden. Further verification for the hypothesis is provided by the results of Foster and Wright (1990), which conform with the ground water mound hypothesis. Although the theory is now widely acknowledged (Ginzler 1997), further research into raised bog hydrology is needed in order to exploit the model for predictive purposes (Kneale 1987).

As concluded by Ingram (1982), the ground water mound in raised bogs is maintained by a dynamic equilibrium between recharge and discharge of water. In theory, only a small amount of recharge water is needed to maintain the equilibrium. However, under natural conditions bogs often have to withstand long periods without any water supply. Joosten (1993) considers the acrotelm as the "tool", which ensures a constant water supply to the catotelm and plays an important role in the hydrological self-regulation of raised bogs. He points out that in raised bogs a number of negative feed-back mechanisms exist which help to maintain the hydrological stability of the bog, as well as the favourable moisture conditions for the bog vegetation:

Change of the albedo due to desiccation: *Sphagnum* turns almost white when, due to high evapotranspiration, the water in the hyaline cells is replaced by air. This increases the albedo and decreases evapotranspiration.

Behaviour of the acrotelm: The acrotelm is of crucial importance for bog hydrology because its transmissivity is restricted, preventing a fast lateral discharge. The acrotelm also has a large storage capacity, which minimises the impact of evapotranspiration. In the acrotelm the bulk density increases downwards through the peat profile and the pore spaces decreases as a result of compaction (Clymo, 1978), which develops a gradient in transmissivity. If the water supply is high, the water surplus is discharged relatively slowly, laterally through the bog pore space of the acrotelm. If there is a longer period without rain, the water level drops to a level where, because of the smaller pores and the decreased conductivity, it discharges more slowly.

Bog breathing, which is the swelling and shrinking of the peat body, usually has an annual amplitude of several centimetres. This is advantageous for the bog vegetation, because it minimises the impact of water level fluctuations. Bog breathing is important in short term hydrological regulation (Baden and Eggelsmann 1964), because the swelling of the peat is also a mechanism promoting water storage (Kellner and Halldin 2002).

Intraspecific change in the morphology of the Sphagna: *Sphagnum* is able to change its growth habits according to water supply (Green 1968). At a high water level some *Sphagnum* species tend to grow in a lax form, which leads to a higher hydraulic conductivity of the bog surface and therefore an increased surface discharge. If the water supply drops, the apical growth of the Sphagna is suppressed and the plants tend to ramify. This causes a more compact peat structure with decreased hydraulic conductivity and hence the water loss decreases too.

Change in micro vegetation patterns: Changes in the water table cause changes in vegetation patterns. If, for example, the water level drops in a *S. papillosum* lawn, *S. rubellum* would spread, since it is better adapted to dry conditions. This will again, lead to a higher resistance to water flow and minimises the surface run-off, which leads to a compensating increase in the height of the water table.

Change in macro vegetation patterns: Many bogs possess concentric spatial patterns, such as pools or hummocks, which have a regulating effect. They are often arranged vertically towards the water flow. When the water flow of lateral discharge increases, more permeable elements like pools become dominant. A decrease of the discharge flow leads towards an increase of less permeable vegetation elements such as hummocks.

The ground water mound hypothesis includes the fact that in the catotelm the hydraulic conductivity is greatly reduced due to the much smaller pore size of the catotelm peat. An additional explanation for this low hydraulic conductivity is suggested by Brown *et al.* (1989) (**Methane Hypothesis**). Studies completed by Dinel *et al.* (1988) and Brown *et al.* (1989) suggested that deep layers of peatlands hold trapped pressurised methane which is evolved from decomposing peat. Methane is only partly soluble in water and the bubbles would cause reduced water flow and therefore even smaller hydraulic conductivity in the lower layers of raised bogs (Brown 1997). The studies of Brown *et al.* (1989) and Brown and Overend (1993) have proposed that the water flow though the peat body is impeded when the peat becomes super-saturated (or occluded).

Studies by Siegel and Glaser (1983), Siegel *et al.* (1995) and Glaser *et al.* (1997) indicate that mire hydrology can be more complicated and that the groundwater mound model may not apply to bogs in different climates. The authors found evidence that in peatlands in continental areas like the Glacial Lake Agassiz Peatlands, minerotrophic water wells up into the peat body of bogs during longer drought periods, enabling these peatlands to survive drought periods of several years. The study of Glaser *et al.* (1997) confirmed that in relatively arid areas such as Minnesota the development of raised bogs is linked with zones of groundwater discharge. Similar processes are reported by Sirin (1998) in Russian bogs underlain by sand. At the first glance the findings of Siegel *et al.* (1995) and Glaser *et al.* (1997) also contrast with the conclusions of Brown *et al.* (1989) and Brown and Overend (1993) mentioned before. Vertical water movement would hardly be possible if the pores are largely blocked by gas bubbles. Moore (1997) questions, if raised bogs in continental climates are generally dependent on upward movements of groundwater and if they may therefore become periodically decoupled from climatic control. This questioning is justified, especially since this hydraulic behaviour is also reported from continental Russia (Sirin, 1998). However, the hydrology of these vast mire complexes differs significantly in dependence from the underlying mineral substrate. It may therefore be unwise to generalise from those facts for all continental peatlands. Another interesting issue dicussed by Moore (1997) is if there are differences between the hydraulic conductivity of the catotelm peats in continental raised bogs and oceanic ones. The peat bodies in the Lake Agassiz Peatlands, where an upwards movement of groundwater was observed, consist partly of fen peat (Siegel 1992). Brown *et al.* (1989) assume that minerotrophic fens may have a greater methane flux than ombrotrophic bogs and the methane is more likely to be released. If methane really has an influence on the hydraulic conductivity of peats this may be an explanation for a potentially higher hydraulic conductivity in the mixed continental mires. In the case of these peatlands, mire hydrology becomes more complicated when bogs are incorporated into extensive mire complexes with changing mire types. Regarding these mires it needs to be remembered that they refer to continental areas. The sand underlying these bogs has a high hydraulic conductivity, which would allow the upward movement of water. Most Atlantic raised bogs that developed from hydroseres are underlain by lake sediments and clay, which have a very low hydraulic conductivity and would make an exchange in water extremely difficult. This may have lead researchers (Wickman 1951, Gilman 1997) to suggest the existence of impermeable bottom layers whereas others disagree (van der Schaaf 1999). Moore (1997) concludes at the end of his review: "*We can no longer assume that elevation automatically results in ombrotrophy and perhaps we need to redefine the term raised bog.*"

Although only parts of mire hydrology have been touched upon in this review, it can be concluded that it is a very complicated subject where further research is needed. The fact that it is very difficult to undertake exact measurements of water movement and hydraulic conductivity in field and laboratory experiments (Ingram 1983) makes the task even harder. The considerations by Moore (1997) indicate that shifts in the way we understand mires today are likely to occur in the future.

2.3 Peat formation and interpretation of the macrofossil record

Macrofossil analysis is the main approach in this project to investigate the development of past raised bog vegetation. To understand and to interpret macrofossil assemblages it is necessary to consider the peat forming processes and the environmental conditions which lead to the preservation of plant macrofossil assemblages.

Pollen which are found at a sample location are often transported there over considerable distances (Lang 1994). Therefore pollen-analytical investigations give a combination of information about non-wetland vegetation and local communities (those communities existing within a few metres of the sample point). By contrast, macrofossils were laid down in mires at the coring location, where they once lived, providing a detailed record of their own history (Grosse-Brauckmann 1986, Barber 1993, 1994). Transport of macrofossils over considerable distances can occur in environments like lakes and rivers by the action of water. This has to be regarded during the interpretation of macrofossil assemblages, originating from the limnic stage of mire development. Dependent on the level of preservation, many plant macrofossils often retain their diagnostic details, enabling the reconstruction of the past plant communities (Barber 1994).

2.3.1 Embedding of plant macrofossils

The acrotelm is most important for the peat forming process. It is considered to be usually less than 40 cm deep (Johnson *et al.* 1990), where the decomposition rate of the dead plant material is greatest. Here water level fluctuations take place, therefore oxygen is available and in this layer the dead plant material is transformed into peat (Grosse-Brauckmann 1990). The author emphasises that the embedding process for vascular plants and mosses into peat is very different because of their different growth modes (Figure 2.3).

Mosses grow from the tip and die towards the foot and the formation of peat starts directly underneath the living moss carpet (Grosse-Brauckmann 1990, Barber 1982). In the case of *Sphagnum,* decay begins where the incident light is not sufficient for photosynthesis, usually within a *Sphagnum* cover of about 2-4 cm deep (Clymo 1992). The lower branches of the Sphagna die due to shading from the upper branches of the moss.

Vascular plants are strictly structured into subterranean organs and organs above the surface. In peat vascular plants are mainly represented by the subterranean parts, rootlets, rhizomes, stem bases and shoots (Barber 1993). Mostly, only the epidermis and phloem remain, whereas the parenchymatic tissue is decomposed. (Grosse-Brauckmann 1972, 1990). In contrast, the aboveground litter falls onto the mire surface when the plant dies, where decay rates are most rapid and often decomposes almost entirely. Aboveground parts of plants are rarely found in peat, except luxuriantly produced seeds and fruits (Grosse-Brauckmann 1990, Barber 1993). If many parts from above the surface occur it indicates exceptional conditions for preservation. Either the litter was deposited onto the surface of very fast growing moss carpets and was enclosed and overgrown very quickly, or the litter fell into shallow water where due to a scarce supply of oxygen the conditions for preservation were more favourable.

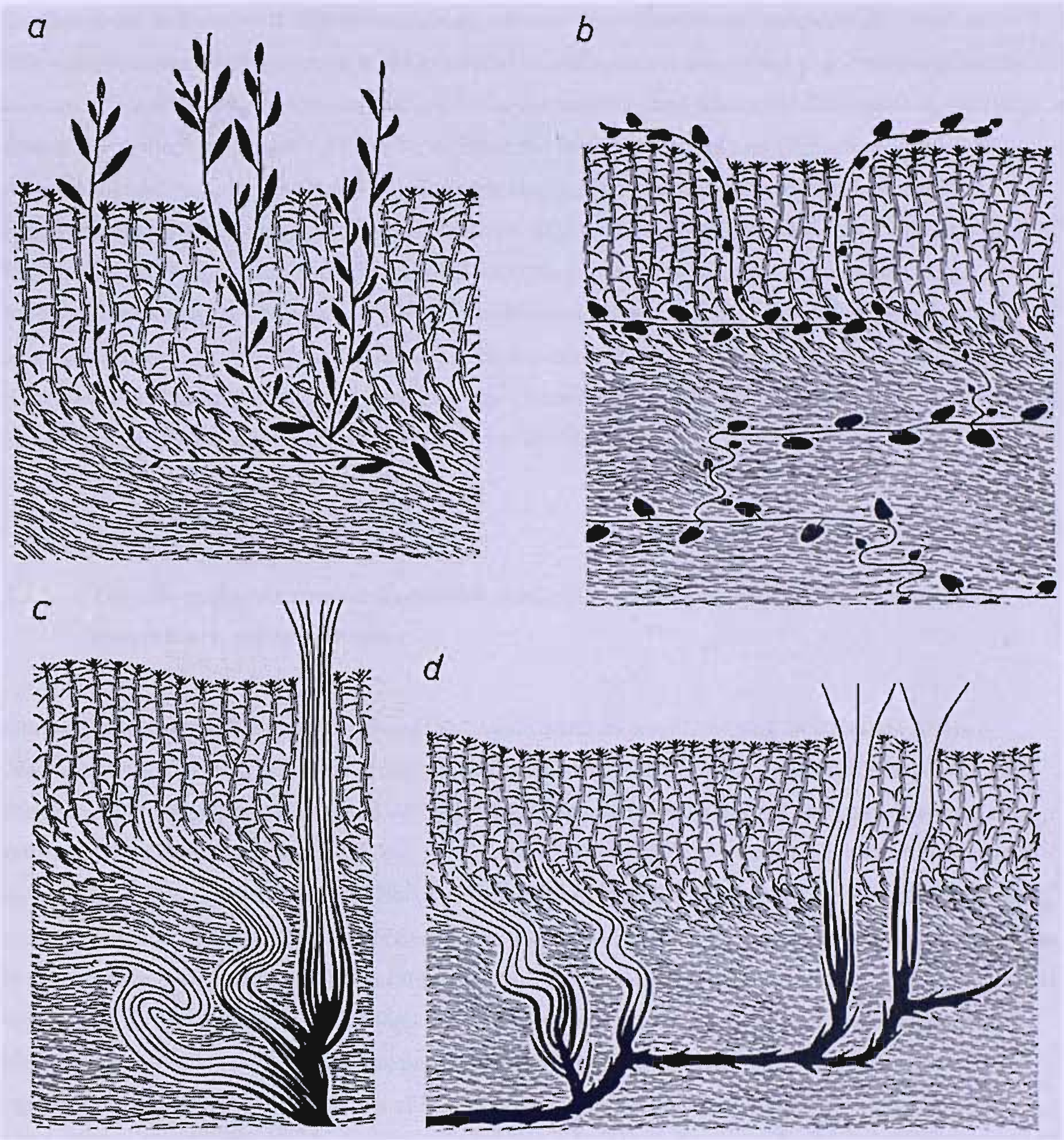

Figure 2.3: Growing mode of a *Sphagnum* carpet including a) *Andromeda polifolia*, b) *Vaccinium oxycoccus*, c) *Eriophorum vaginatum* and d) *Scheuchzeria palustris* as (source: Overbeck 1975, after Grosse-Brauckmann 1972).

2.3.2 Processes of decomposition

Decomposition is controlled by two main factors, environmental parameters and the intrinsic properties of the substrate (Coûteaux *et al.* 1995, Szumigalski and Bayley 1996), which are discussed in the following sections. The **decomposition** process consists of two components (Grosse-Brauckmann 1990), mineralisation and humification. **Mineralisation** is the process whereby organic material is turned into inorganic substances. It produces CO_2 and water within the aerated uppermost peat layer, the acrotelm. Small concentrations of inorganic salts are also released. **Humification** is the process, which turns organic material into dark brown or black coloured nitrogen-containing humic substances. This process is mostly connected with the loss of primary cell and tissue structure. Humification occurs only under aerobic conditions due to the activity of microorganisms, whereas mineralisation can also occur as a result of chemical processes. Both processes occur in parallel as peat breaks down, so that peat is characterised by a mixture of humic substances and more or less preserved primary plant structures. The degree of humification (measured on the von Post scale, H1-H10), indicates the humus content of peat (Blackford 2000). The degree of breakdown is determined within the early stages of peat formation in the acrotelm and then remains relatively stable under catotelmic conditions. Slightly humified peats contain only small amounts of humus substances whereas in strongly humified peats the humus substances are more abundant than the tissue structures (Grosse-Brauckmann 1990). In ombrotrophic bogs, the degree of decomposition of peat strata is considered to be associated with past surface wetness (Godwin and Conway 1939, Blackford and Chambers 1991) and many studies focusing on past climatic change used humification analysis (Blackford and Chambers 1991, Chambers *et al.* 1997, Langdon and Barber 2001).

2.3.3 The role of the environmental conditions affecting decomposition (pH, water saturation, temperature, soil organisms)

Grosse-Brauckmann (1986, 1990) considers that environmental conditions play an important role in decomposition. The main causes of strongly humified peat are high pH values, a greater base content and, above all, temporarily low water levels. In contrast to these conditions, a low pH and nutrient supply, and stable water tables, present in raised bogs, are unfavourable for most microorganisms, which result in little turnover and slight peat humification. However, even in less humified peat a large proportion of the initially produced organic matter disappears due to decomposition (Overbeck 1975, Grosse-Brauckmann 1990). One factor affecting decomposition is temperature (Clymo 1965, Ohlson 1987, Grosse-Brauckmann 1990). In his experiments Clymo (1965) found that the losses at Moor House (a blanket bog) were less than those at Thursley Bog (a valley bog) that may be partly related to temperature differences – the Thursley environment is 4-5 °C warmer than that of Moor House throughout the year. Presumably also the older, more strongly humified *Sphagnum* peat in most Atlantic raised bogs developed under warmer conditions of the Atlantic/Subboreal period with probably different seasonal distribution of precipitation. (Grosse-Brauckmann 1990). Clymo (1965) also emphasises the role of environmental conditions and suggests them to be primarily responsible for the low rate of loss in the case of *Sphagnum*. He supposes that breakdown rates are low and fairly uniform for all materials once they enter the zone where sulphide levels, caused by sulphur reducing micororganisms are higher. The author deduces from his results the importance of his findings for bog ecology and links them with the interpretation of recurrence surfaces and retardation layers. Although those findings derive from blanket bogs, which function differently when compared to raised bog systems, the results of Clymo's study should be at least partly applicable to raised bogs.

Soil organisms such as soil animals, bacteria and fungi are an important part of the environment influencing decomposition although the bog environment is unfavourable for most soil microbes (Zobel 1988). Fungi and aerobic bacteria are abundant in the oxygenated zone and much rarer in the anoxic zone. Anaerobic bacteria are equally abundant in both zones (Clymo 1965). Soil animals are restricted to oxygenated areas.

Coulson and Butterfield (1978, p. 649) propose: "*The animal contribution to decomposition varies much more between different plant substrates than does the microbial contribution*". The authors considered lack of an extensive fauna on blanket bogs as a possible reason for the low decomposition rate on peatlands, which is supported by the results of Ohlson (1987), who explains higher decomposition rates in a spring mire due to a relatively rich soil fauna. Coulson and Butterfield (1978, p. 649) conclude further, "*whilst the overall animal contribution to decomposition on blanket bog may be small, for some plant materials it is considerable*". The experiments show that some plant species are preferentially eaten by soil animals. As an example the relatively high loss of *Calluna vulgaris* on a blanket bog was partly caused by soil animals, whereas the contribution by animals to the decomposition of *Sphagnum recurvum* and *Eriophorum vaginatum* was negligible. The authors consider these facts of particular interest, since both these plants contribute a very high proportion of the preserved material found in peat and suppose "*that a major factor in the slow decomposition rate of peat-forming Sphagnum and Eriophorum is their unattractiveness to soil animals*" (Coulson and Butterfield 1978, p. 649). Clymo (1965) suggested that breakdown by microorganisms is probably the main cause of the loss of matter from *Sphagnum* after dying. This is supported by Dickinson and Maggs (1974), who assumed that fungi are mainly responsible for the decomposition of *Sphagnum* leaves on an ombrotrophic bog.

The acrotelm has a plentiful supply of water and oxygen – aerobic decay is dominant. Bacteria and fungi are present in the oxygenated zone (Clymo 1965) and invertebrate grazers might contribute to the breakdown of plant material too (Coulson and Butterfield 1978). At the surface the bulk density is only about 0,03 g / cm^3. The decay rate is not constant, it changes with depth and therefore also with environmental conditions. Clymo (1965, 1991) pointed out that at the surface breakdown is greatest, slowing down in the region over which the sulphide level oscillates, and is lowest below the permanently sulphidic level.

Decomposition and its rate vary with depth. In hummocks, for example, it is slow near the surface because the mosses are still alive; it then becomes rapid, and decreases again (Johnson *et al.* 1990). Apart from the change of decay rate with depth, there are differences in rate of decomposition within the various microrelief areas or microhabitats of a bog, for example, between hummocks and hollows (Johnson *et al.*, 1990). The study of Johnson *et al.* (1990) shows that the macrostructure of *Sphagnum* is more poorly preserved in hollows than *Sphagnum* in hummocks. Alternatively Farrish and Grigal (1985) found that the intrinsic rate of loss of mass from bog litter is twice as high in hummocks than in hollows. At first glance these results appear contradictory, but intrinsic loss of mass does not always imply loss of macrostructure. Johnson *et al.* (1990) summarise that preservation of *Sphagnum* macrostructure in hummocks differed significantly from that in hollows but changed in the same way with respect to the water table. Plants in both hummocks and hollows disintegrated fast and completely within the zone of water-level fluctuation. The macrostructure was more poorly preserved in hollows and the result suggests that *Sphagnum* decays more rapidly in the hollows than in hummocks. The authors regarded the age of the hollow peat not to be the primary reason for its poor preservation. They propose that *Sphagnum* decays faster in the hollows because microbial activity in this microhabitat is greater than in the hummocks and referred to (Zobel 1986) who reported higher oxygen concentrations from hollows than from hummocks. Johnson *et al.* (1990) conclude that their study clearly shows that *Sphagnum* preserves more poorly in hollows than in hummocks, but it cannot determine whether this is caused by differences in microhabitat or in decay resistance among the *Sphagnum* species. These conclusions are contradictory; on the one hand they see differences between different habitats, namely between aerated but relatively dry conditions in a hummock and wet conditions in an hollow, but they conclude that relative to the water table the macrostructure of *Sphagnum* changes in the same way.

If "*with respect to the water table*" means under the same environmental conditions, then the results of Johnson *et al.* (1990) conform to those of Clymo (1965), who found that *S. rubellum* and *S. cuspidatum* have about the same rate of loss under equal conditions. Clymo (1965) also found in his experiments that there are differences in loss rate among *Sphagnum* species. The loss rate of a species of the *S. s. Acutifolia* group and *S. cuspidatum* is twice as high as that of *S. papillosum*, which could be explained by the fact that *S. s. Acutifolia* and *S. cuspidatum* have much smaller leaves and all together a greater superficial surface in relation to their mass than Sphagna of the section *Sphagnum.* Clearly there is a much greater surface for microorganisms to attack in the smaller-leaved species.

When the plant material passes into the anoxic and waterlogged catotelm the rate of decomposition becomes much lower. Clymo (1965) reports that the major decrease in decay rate is correlated with the change from aerobic to anaerobic conditions at about the water table. The author compared the loss at the surface and at 75 cm depth and reports, "*even though fresh Sphagnum was used, the losses at 75 cm in the bog were only a small fraction of losses at the surface* " (Clymo 1965, p. 751) and that under anoxic conditions the decay rate is only a quarter of that in the oxygenated zone (in blanket and valley bogs). Johnson *et al.* (1990, p. 644) report that "*in the permanently anaerobic peat, all plants consisted of bare stems and detached leaves*" and conclude further that the macrostructural collapse, which increases bulk density, decreases the number and size of pores in the peat (Boelter 1964) and reduces its hydraulic conductivity. This eventually causes the water level to rise (Clymo 1984). Therefore the breakdown of macrostructure is of critical importance in the onset of anoxic conditions and therefore peat accumulation." Grosse-Brauckmann (1990) considers that peat accumulation is only possible if decomposition processes stop where the lowest layer of the acrotelm becomes the uppermost layer of the catotelm, combined with a continuous rise in the bog water level. This is of crucial importance for peat formation. Fungi and bacteria are much rarer in the anoxic zone but there is microbial activity (Clymo1991). One bacterial activity is the production of sulphide which is mostly H_2S. Apparently, the sulphide production is highest at about 20-40 cm below the surface at the top of the catotelm (Clymo 1991) and also the methane-producing potential is greatest at the top of the catotelm. A possible reason for the slow decay in the catotelm may be the lower microbial activity, but there is also evidence that material left for a few years is more resistant to decay. *Sphagnum* peat from 60 cm depth which was deposited in litter bags on the bog surface, decayed less rapidly than surface material (Clymo 1965).

Many experiments concerning decomposition processes have been carried out in mires and soils under varying environmental conditions (Clymo 1965, Coulson and Butterfield 1978, Ohlson 1987, Johnson *et al.* 1990, Hogg 1993, Hartmann 1998, Scheffer *et al.* 2001). It is assumed that environmental conditions in acid oligotrophic *Sphagnum* bogs tend to be similar, so some results might generally be valid, but the experiments were carried out on various mire types with different rates of accumulation, so not all the results would be applicable to raised bogs.

The currently high levels of atmospheric nitrogen deposition are of concern. Some researchers (Lee and Woodin 1988, Malmer 1988, 1990), suggested that it causes a change in the primary element limitation on plant growth in ombrotrophic bogs. This has been supported by Aerts *et al.* (1992) who have shown that in some ombrotrophic bogs, with high atmospheric nitrogen load, the productivity of Sphagna has changed from nitrogen limitation to phosphorus limitation. Aerts *et al.* (1995) report, that under phosphorus limitation within a mire the nitrogen uptake increases significantly and so does the potential decay rate under aerobic conditions. The authors conclude, that the high atmospheric nitrogen load may affect the carbon dioxide sink function of peatlands, depending on the nutrient limitation and that under phosphorus limited plant growth the net carbon accumulation will decrease.

2.3.4 The role of organo-chemical composition and physical properties of plants

Research suggests that the chemical composition and properties of fossilised material changes with depth. Plant constituents are broken down at different rates so that the material left after a few years is more resistant to decay (Clymo 1978). In a valley bog *Sphagnum* peat from 60 cm depth, which was brought to the surface decayed less rapidly than did surface material (Clymo 1965). *Sphagnum* is often the major peat component on raised bogs. Therefore, it may be worth considering what its organo-chemical properties are, which may contribute to its high percentage in peat. Since most other bog plants decompose relatively quickly, the fraction of *Sphagnum* material tends to increase with depth (van Breemen 1995).

In the acrotelm *Sphagnum* litter decomposes more slowly than most other plants in their natural habitat (Coulson and Butterfield 1978, van Breemen 1995). This is supported by other studies (Szumigalski, and Bayley 1996, Scheffer 2001), showing that *Sphagnum* litter decomposed considerably slower than *Carex* litter. He attributes this result to higher holocellulose content and the lower polymeric phenolics content of *Carex* litter when compared with *Sphagnum* litter. Van Bremen (1995) points out that the refractory nature of *Sphagnum* is thought to be mainly responsible for its slow decomposition. *Sphagnum* tissue has lignin-like properties and as a result of the strong chemical binding of carbon in *Sphagnum* polysaccharides there is a dearth of C for microbes.

Other complementary causes which may inhibit microbial decomposition on *Sphagnum* bogs are the acidic environment caused by *Sphagnum* due to its ion exchange capacity (Barber 1982, Gagnon and Glime 1992) and in addition its phenolic constituents such as the very stable *Sphagnum* acid [p-hydroxy-beta-(carboxymehtyl)-cinneamic acid] (Verhoeven and Toth 1995). Despite this the decomposition rate of different *Sphagnum* species varies considerably. Johnson *et al.* (1990) found that decay resistance of the stems decreases in the range: *S. fuscum* > *S. rubellum* > *S. balticum* in hummocks and that the macrostructure of *Sphagnum* is much more poorly preserved in hollows than in hummocks. This selective decomposition is explained by species differences, not environmental differences (Johnson and Damman 1991). The fact that in hollows the loss of macrostructure of e.g. *S. cuspidatum* and *S. tenellum* is very fast might have lead some authors to the assumption that these two species do not form peat (Godwin 1939) but macrofossil analyses in several studies have shown that both species are components of peat (e.g. Hughes *et al.* 2000, McMullen *et al.* 2004).

It has become clear that there is a correlation between chemical constituents of the plant substrates (C/N ratio, concentration of nitrogen, phosphorus and potassium) and the rate of microbial decomposition (Coulson and Butterfield 1978, Ohlson 1987, Coûteaux *et al.* 1995, Scheffer 2001). Coulson and Butterfield (1978) found that when the animal contribution was included this correlation was still valid on mineral soils, but on peat the correlation was lower. Presumably the animal decomposers on peat were not responding in the same way as the microorganisms. The authors elaborate further that on peat soils an increased nitrogen concentration resulted in an increased decay rate but phosphorus had no effect, except in the case of *Sphagnum*, where increased concentrations caused a significant decrease in the decay rate. Coulson and Butterfield (1978) conclude that the substrate is primarily responsible for determining the decomposition rate and suggest that the physical properties of an area are not the cause of blanket peat formation, but that they play a large part in determining the composition of the plant community and it is the intrinsic low decomposition rate of certain plant species forming the community which leads to peat accumulation on blanket bog. This conclusion is supported by a study of Johnson and Damman (1993), who also emphasise that intrinsic litter chemistry overrules site factors in regulating *Sphagnum* decay rates. But it contrasts with the suggestions of several other authors (Succow, 1988; Grosse-Brauckmann, 1990; Scheffer, 2001) and especially with Clymo (1965, p. 755), who did his study partly on the same bog type (blanket bog) as Coulson and Butterfield (1978) but concludes: "*it is primarily the environment which is responsible for the rate of loss*".

2.3.5 Interpretation of macrofossil assemblages

If macrofossil analysis is chosen as the main approach to investigate past vegetation biodiversity, there needs to be a consideration of the extent to which the macrofossils are representative of the past vegetation communities. If current plant communities are investigated, the usual approach of vegetation survey includes only the aboveground relations of species. However, the subterranean biomass relations between different species or plant groups such as bryophytes and vascular plants can be completely different from the aboveground biomass relations as shown by Wallen (1986).

The approach of macrofossil analysis can only assess remains that have been preserved, which usually include a considerable fraction of subterranean plant organs. As previously mentioned, different embedding processes between mosses and vascular plants (Grosse-Brauckmann 1990) indicate that the presence of plant macrofossils in peat may not be a reflection of the former species abundance (Barber 1993, van Breemen 1995). This was already noticed by Weber (1902), who reported that the remains of *Calluna vulgaris* in hummocks disappear almost entirely with time contrary to those of *Sphagnum*. Whole ranges of plant species, which are common within the mire surface vegetation, are scarcely found (e.g. in a charred stage) or absent as macrofossils. These include lichens, fungi and Hepaticaceae, except *Kurzia pauciflora*, and few other species (Grosse-Brauckmann 1990). Also, the tissues of some vascular plants seem to decompose quickly, such as *Drosera* species (McMullen *et al.* 2004).

It needs to be considered that the presence or absence of plant macrofossils seems to vary between different regions. Overbeck (1975) reports that *Narthecium ossifragum* is able to form several decimetre thick peat layers, known from western Scandinavia, whereas in Lower Saxony and Schleswig-Holstein, Germany, *Narthecium ossifragum* peat has only been observed at the bog surface. In Britain it is considered as not being preserved in peat (McMullen 2000). However, if the species forms peat, it displaces the formerly present peat with its dense system of rhizomes and roots, being over-represented in contrast to the displaced plant material, which is usually *Sphagnum* peat.

Clymo (1965) proposes that some bog plants grow in positions which will lead to their preferential preservation and gives as an example *Eriophorum angustifolium.* This is supported by the results of (Boggie et al. 1958), who found that the rhizomes and roots of several Cyperaceae (*Eriophorum angustifolium, E. vaginatum* and *Scirpus caespitosus*) grow several decimetres below the bog surface in an environment promoting their preservation, whereas other bog plants such as Ericaceae and *Narthecium ossifragum* are surface-rooting which exposes their remains to decomposition for a longer period. The result would be an overrepresentation of the remains of deep-rooting plants, whereas the surface-rooters may be absent or underrepresented. Great variability is also apparent among the species represented by seeds or other remains as shown by Greatrex (1983).

Another example of considerable selectivity in decomposition among species is given by the results of Coulson and Butterfield (1978). In their experiment, losses of mass from *Calluna vulgaris* shoot tips were 43 %, *Rubus chamaemorus* leaves 27 %, *Eriophorum vaginatum* leaves 1 % and *Sphagnum recurvum* plants less than 1 %. Considering that aboveground parts of plants are scarcely present in peat it is surprising that for many studies (Coulson and Butterfield 1978, Ohlson 1987, Verhoeven and Arts 1992, Szumigalski and Bayley 1996, Scheffer et al. 2001) aboveground litter of vascular plants was used, instead of subterranean parts (Hartmann 1998).

It can be concluded that decomposition among species is selective and that the subfossil assemblages reflect only the immediate vicinity of the core location. These factors restrict the usefulness of plant macrofossils as indicators for past bog vegetation in the same way as pollen percentages may not represent the local presence of a species (Greatrex 1983, Clymo 1991). However, despite this shortcoming plant macrofossils are considered to be useful as a relative measure for of the previous vegetation communities (Barber 1993). Further research is needed in order to determine the ratio of volume percentage and real presence of plant macrofossils.

2.4 Sources of damage to bog systems

2.4.1 Impact of drainage

Water is of crucial importance for bog ecosystems. The peat body of a raised bog consists of up to 97% pore space, which is almost filled with water (Eggelsmann 1990a). Thus drainage is the most important and most destructive source of damage to raised bogs. Drainage is a pre-condition of almost every kind of commercial use of bogs (Succow 1990). The attitude to drainage throughout centuries was to eliminate surface water in order to improve land for agriculture, often under the necessity for survival (Newson 1992). In more recent times drainage has been applied to enhance timber yields in forestry, particularly in Britain and Finland. Newson (1992) points out that there is much research support for drainage but monitoring of the drainage process and its off-site impacts has been only sporadic.

The impact of drainage is most pronounced close to ditches (Ingram 1992). Here the water table gradient is steepest and the acrotelm becomes more sharply drained and its mechanical support weakened (subsidence). The catotelm peat undergoes irreversible physical alteration. This involves shrinking, cracking and as a result of this disintegrated peat slumps towards the ditches. Ingram reports, that as a consequence of this development the competitive balance within the bog vegetation becomes disturbed and the main peat-forming bryophytes suppressed by dwarf-shrubs. The same effect also occurs on bogs which are marginally cut (Bragg 1995). Subsidence is a result of prolonged drainage (Eggelsmann 1990b). The process of subsidence is explained in detail by Van der Schaaf (1999): if a bog is drained, water is extracted from the peat, which causes a reduction in pore pressure. As a result the peat matrix responds by collapsing to some extent, which causes surface subsidence. The withdrawal of water also diminishes the buoyancy of the peat and increases; therefore, the pressure of the upper peat layers on the lower peat layers. In deep bogs all peat layers suffer from subsidence (Eggelsmann 1990b). Van der Schaaf (1999) considers subsidence induced by drainage to be considerable and a fast process. He points out that according to Van der Molen (1975) drainage may cause an initial subsidence of 0.5 to 1.0 m in ten years in thick peat layers. Eggelsmann (1990b) and also Succow (1990) reported that subsidence values are in the order of 25–35 % of the original peat thickness. Drainage associated with peat extraction also threatens uncut bog remnants and the regeneration of abandoned and flooded peat workings (Heathwaite 1995). This impact is clearly shown in the LiDAR digital image in Figure 2.4 where a ditch cuts through and along a primary bog remnant at Wedholme Flow, Cumbria. The margins of the uncut bog remnant along the ditches and towards the peat mining area have collapsed producing a pronounced relief. The orange and yellow coloured areas on the LiDAR image represent uncut peat surface. At the margins of this area the areas of shadow indicate zones of dewatering and collapse.

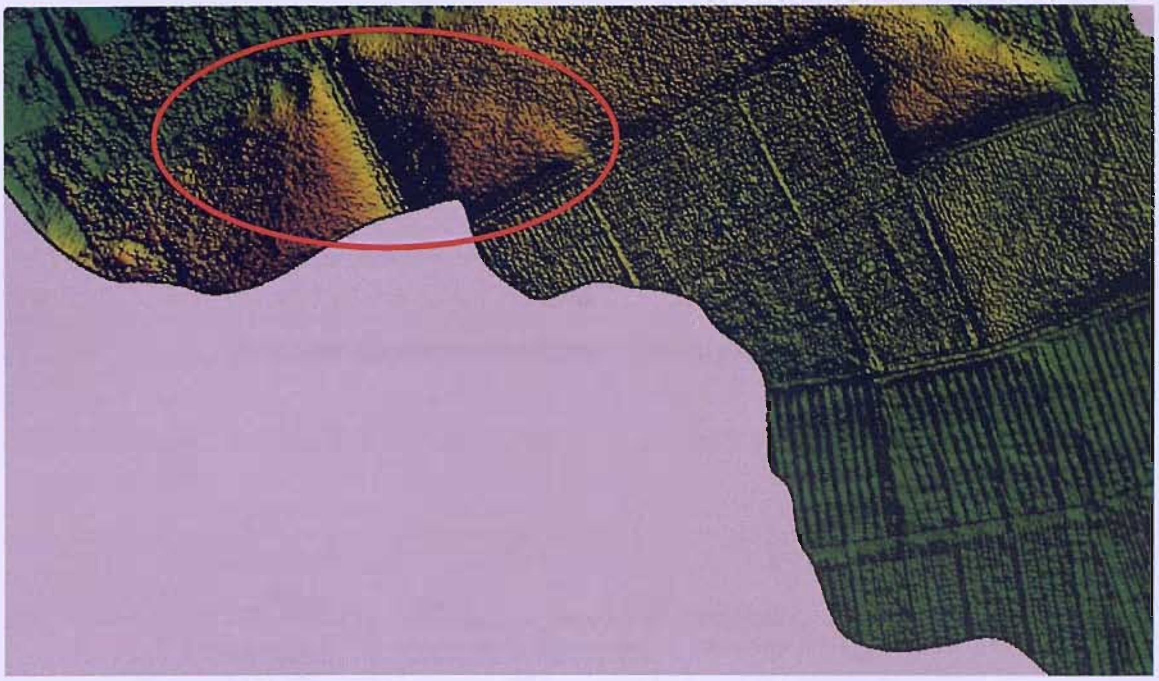

Figure 2.4: Partial LiDAR digital image of Wedholme Flow, Cumbria (copyright by NERC).

Van der Schaaf (1999, p. 23) concludes: "*Subsidence may therefore considerably change the cross-section of the bog surface in one or two decades. This in itself must have an influence on the hydrology of the bog system, because of the changes of the hydraulic gradient and of the surface slope that results from it*". The author also considers the impact of subsidence along bog margins due to turf cutting. Van der Schaaf (2000, p. 262) reports that along face banks, which are several decades old, subsidence can expand far into the bog. "*Effects on surface slope and vegetation over distances of 50 to several hundred m were observed on Clara Bog and Rahemore Bog in the Irish Midlands.*" The cause is probably a change in acrotelm properties. Induced by the increased surface slope, the acrotelm transmissivity decreases considerably and with it, its regulating effect on discharge. As a consequence the surface dries out, causing the subsidence to expand towards the central parts of a bog. The author reports that in Clara Bog, subsidence occurred over 1 km, caused by a road built in 1840. Van der Schaaf (2000) concludes that subsidence is very relevant, from the point of view of bog protection. Even if re-wetting of the affected peat body occurs, subsidence is only partly reversible (Succow and Joosten 2001). This is supported by Ingram (1992) and Bragg (1995), who concluded that disturbance in one part of the bog system affects the water table everywhere else due to the physics which are the basis for the hydraulic equilibrium in a raised bog, so that the whole bog has to be considered as a single hydrological unit.

As drainage on mires continues or becomes reinforced, formerly inhibited nutrient cycles become mobilised due to accelerated microbial activity, which controls the mass balance between litter input and decomposition losses through carbon mineralization (Maltby 1992). Nitrogen is released due to microbial nitrification. Ombrotrophic raised bogs are especially characterised by mobilisation of phosphorus. If the water table of drained bogs remains 0.5 m below the bog surface, the lower and fluctuating water regime encourages vegetation changes such as colonisation by *Molinia caerulea* and trees (*Betula pubescens*, *Pinus sylvestris*) and enhanced evapotranspiration (Schouwenaars 1992, Beets 1992, Fojt 1995). This development is also reflected by the colonisation of Cors Caron by *Molinia caerulea* and *Betula* and was already noticeable in the 1930's (Godwin and Conway 1939). From ombrotrophic bogs in sub-continental areas the development towards *Pleurozium-Betula* woodland is reported by Succow and Jeschke (1990):

Calluna vulgaris heathland (beginning of negative water balance),

↓

Sphagnum-Betula woodland (water table in summer 0.3-0.4 m below surface)

↓

Pleurozium-Betula woodland (water table in summer > 0.5 m below surface)

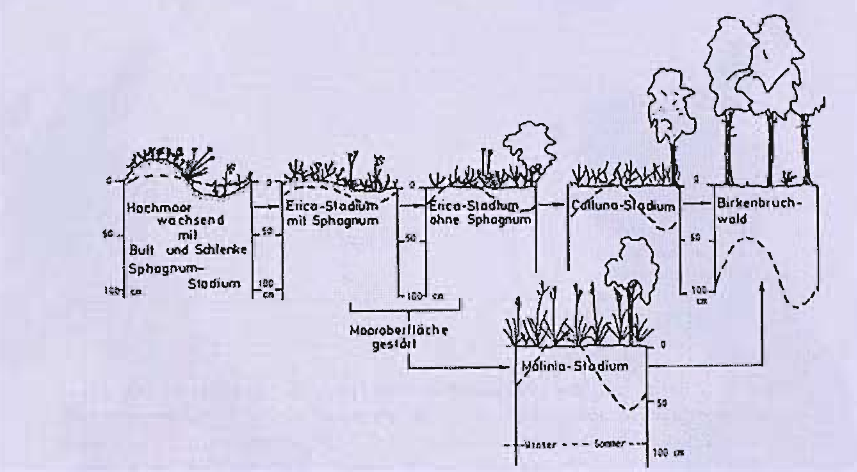

Figure 2.5: Succession on drained bogs in Northwest Germany, after Eggelsmann (1990d).

Schouwenaars (1992) points out that when, after excavation of raised bogs, a strongly humified peat soil becomes colonised by *M. caerulea*, the re-establishment of *Sphagnum* vegetation is almost impossible. The small pore size of the highly humified raised bog peat results in little water storage capacity. Therefore the there water tables will be lower, but highly fluctuating. Together with high evapotranspiration rates this environment favours species like *M. caerulea*. To support *Sphagnum* growth, the peat needs to possess a large water storage capacity as present in a well functioning acrotelm.

Other processes which are often associated with drainage like slow oxidation and burning contribute to subsidence in raised bogs. Eggelsmann (1990b) reports a surface loss of 2-4 cm for each time German and Dutch bogs were burnt for the cultivation of buckwheat. Ingram and Bragg (1984) consider frequent burning as very destructive to the *Sphagnum* carpet and the acrotelm. Burning is also reported from both Cors Caron (CCW aerial photograph 1998) and Cors Fochno (Slater 1972).

2.4.2 The influence of increased airborne nitrogen deposition on ombrogenous bog ecosystems

Within the last two centuries, and especially in recent decades, the amount of atmospheric nitrogen deposition throughout the whole of Europe has significantly increased (Salmon *et al.* 1978, Brimblecomb and Stedman 1982, Press *et al.* 1986, Aerts 1992, Tomasson *et al.* 2000). At the beginning of the 20th century the input of atmospheric nitrogen deposition was 1-5 kg/ha/yr. and increased up to a present amount of 20-60 kg/ha/year in non-forest ecosystems in Central-Western Europe (Bobbink and Heil 1993, cited in Tomasson *et al.* 2000). This increase is a feature of both rural areas as well as major industrial regions (Press *et al.*, 1986). Gaseous ammonium is released into the atmosphere from agricultural and industrial sources (Baxter *et al.* 1992, Pitcairn *et al.* 1995). Figure 2.6 gives an overview of the amount of two different forms of nitrogen pollution within the UK.

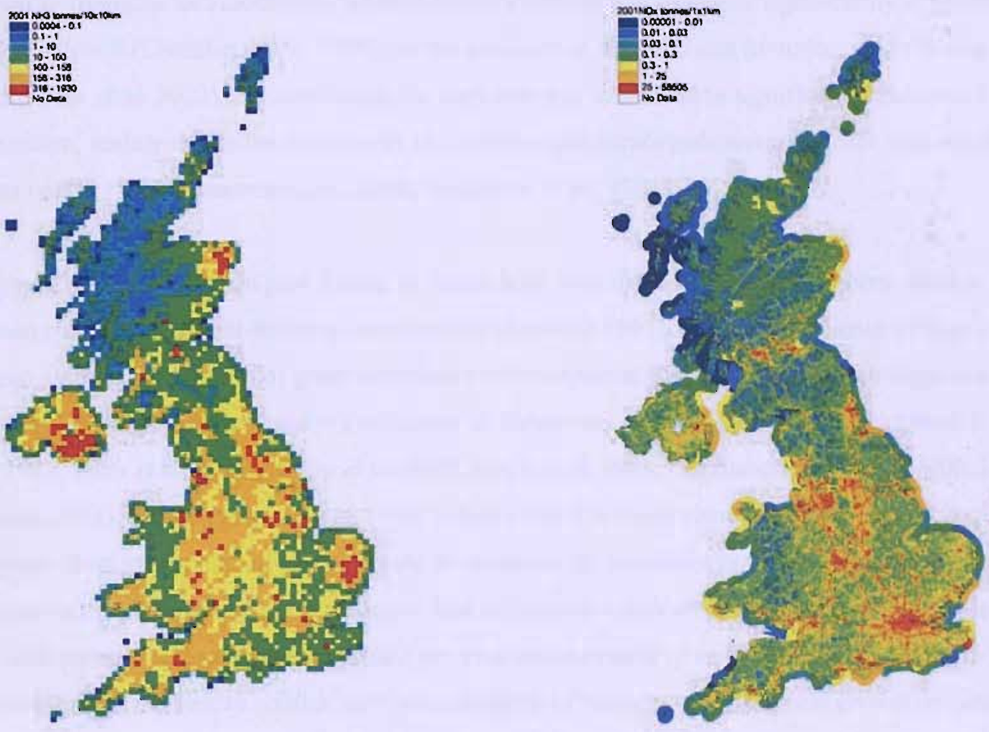

Figure 2.6: Emission of Ammonia (left) and Nitrogen Oxides as NO2 (right) in the UK 2001 (Source: National Atmospheric Emission Inventory: http://www.naei.org.uk/mapping/mapping_2001.php).

In Britain the atmospheric nitrogen supply contributes approximately one third of the acidity measured in precipitation (Barret *et al.* 1983). However, more recently it is reported for Wales, that nitrogen deposition contributes 60% of the total acidifying input (Reynolds *et al.* 1999). Bobbink *et al.* (1998) report that the availability of nutrients is an important factor, which determines the species composition of vegetation, since nitrogen is the limiting nutrient for plant growth in many sensitive ecosystems. Most of the species of such habitats are adapted to nutrient poor conditions and can only compete successfully on soils with low nitrogen levels (Chapin 1980). Therefore, the effects of increasing nitrogen deposition include the loss of buffer capacity, lower pH and increased leaching of base cations (Bobbink *et al.* 1998). Since a high proportion of species from natural and semi-natural vegetation are adapted to low nitrogen supply (Ellenberg Jr. 1988) an increase in nitrogen deposition will cause a drastic loss of diversity because of competitive exclusion (Al-Mufti *et al.* 1977, Wedin and Tilman 1997).

Ombrotrophic bogs receive all of their mineral nutrients from atmospheric deposition (Aerts *et al.* 1992, Aerts *et al.* 2001) and are traditionally considered as nitrogen limited (Lee *et al.* 1983, Tomasson *et al.*

2000). Thus, they are some of the most sensitive ecosystems to nitrogen enrichment (Barber 1993, Bobbink *et al.* 1998, Tomasson *et al.* 2001). The empirical critical load of nitrogen for ombrotrophic bogs has been set at 5-10 kg/ha/year (Bobbink and Roelofs 1995, Tomassen *et al.* 2003). However, in the mid-nineties the total in organic nitrogen deposition in Wales was 20-25 kg/ha/year, significantly above this critical load. Several authors (Press *et al.* 1986, Aerts *et al.* 1992, Aerts *et al.* 2001) suggest, that one effect of an increase in atmospheric nitrate deposition could be potential stimulation of plant growth and productivity which may be manifest itself in a differential species response in sensitive ecosystems. These changes have been reported from heaths and moorlands where *Molinia caerulea* has increased significantly at the expense of *Calluna vulgaris* (Chambers *et al.* 1999), or the decrease of *Racomitrium lanuginosum* in Welsh upland heaths (Jones *et al.* 2002). In raised bogs, the high nitrogen loads lead to significant alterations in species composition, mainly due to the increase in *M. caerulea* and *Betula pubescens* together with other nitrophilic species (Aerts 1994, Tomassen *et al.*, 2000; Tomassen *et al.*, 2003)

Sphagnum has been the main peat former in raised bogs over the mid and late Holocene (Barber 1993) and is the main component in peat-forming communities (Rodwell 1991). Thus, the influence of high atmospheric nitrogen loads on Sphagna is of great importance with respect to the role of *Sphagnum*-bogs as carbon sinks. One result of a high nitrogen load is a reduction of *Sphagnum* growth as shown by many studies (Ferguson *et al.* 1984, Press et al. 1986, Baxter *et al.* 1992, Hogg *et al.* 1995, Gunnarson and Rydin 2000, Limpens and Berendse 2003). However, Aerts *et al.* (1992) shows that this is not always the case. In their experiment *Sphagnum* from an unpolluted site increased its productivity fourfold after addition of inorganic nitrogen, and even on the polluted site the fertilisation had no adverse effect on *Sphagnum*. The authors conclude, "*that high atmospheric nitrogen deposition per se is not the cause of reduced Sphagnum growth*". They point out that "*in the British studies, detrimental effects of nitrogen on Sphagnum growth occurred at concentrations >20 mg N/g* " (Aerts *et al.* 1992, p. 137). These concentrations are higher than in the study from Aerts *et al.* (1992), but the authors assume that the critical concentration may be present after several years of fertilisation. Another aspect, pointed out by Aerts *et al.* (1992) is, that in the British studies (Ferguson *et al.*, 1984) the iron concentration on polluted areas has reached a level where iron has a toxic effect on *Sphagnum*, and this toxicity probably contributes to the reduction of *Sphagnum* growth. Woodin and Lee (1987) found that at high rates of nitrogen supply *Sphagnum* carpets lose their ability to retain all the nitrogen deposited on them. Since in their experiment the nitrogen saturation was not reached, Aerts *et al.* (1992) deduce that a considerable proportion of the nitrogen is lost from the *Sphagnum* due to leaching and could be taken up by vascular plants or microorganisms. This is contrary to the results of Tomassen *et al.* (2000), who found that during the first growing season of their experiment all the nitrogen was taken up by *Sphagnum* due to the formation of free amino acids. After saturation they report a markedly positive correlation between the relative length increase of *Betula* and the nitrogen deposition rate in a Dutch bog. Aerts *et al.* (1992) conclude, that their results show that the growth response of *Sphagnum* species to inorganic nitrogen supply depends on the initial nitrogen and phosphorus concentrations of the plant material, and that the N:P ratio of plant material is a good indicator of primary element limitation.

An additional effect of airborne nitrogen could be increased susceptibility of plant species to secondary stress factors such as pathogens, frost and drought (Bobbink *et al.* 1998). These assumptions are supported by a study by Power *et al.* (1998), who investigated the effects of nitrogen addition on stress sensitivity of

Calluna vulgaris, common on raised bogs. These authors found that larval growth rates and adult weights of Heather beetles *(Lochmaea suturalis)* were significantly higher when insects were reared on plants that had received additional nitrogen. They concluded that the relationship between enhanced nitrogen deposition and increased insect performance was likend with the potential for substantially increased insect damage if deposition rates reach a critical load. As a result litter production was almost double the amount produced in high N plots, in controls. If this happens on raised bogs with a slightly relatively dry and a high *Calluna* cover, such as Cors Caron, the *Sphagnum* below the *Calluna* would probably be adversely affected by shading caused by higher amounts of litter, since *Sphagnum* is sensitive to light levels (Hayward and Clymo 1983).

In addition to the detrimental effects on *Sphagnum*, the atmospheric nitrogen fertilisation seems to enhance the growth of nitrophile vascular plant species. Heijmans *et al.* (2000) showed that the increased abundance of vascular plants due to increased N deposition adversely affected *Sphagnum* growth despite increased *Sphagnum* height. The latter had detrimental effects on the species *Drosera rotundifolia* and *Vaccinium oxycoccus*. Tomasson *et al.* (2003) showed that the elevated nitrogen load causes the encroachment of nitrogen-dependent fast growing grasses like *Molinia caerulea* and trees like *Betula pubescens* in ombrotrophic vegetation. Nitrogen eutrophication has been observed in Danish and Dutch ombrotrophic bogs and, for example, a Danish field survey showed a decline of ombrotrophic vegetation and an increase of more nitrophile grass species such as *M. caerulea* and *Deschampsia flexuosa* and trees (*Betula pubescens*) in areas with ammonium deposition loads higher than 10-15 kg/ha / year (Aaby 1994). Barkman (1992), reports that invasion of Birch has been observed in Dutch bogs and that recent nitrogen pollution has probably made them able to invade wet, undisturbed bogs. In their study Tomasson *et al.* (2000) found a significant positive correlation between the relative length increase of *Betula* and the nitrogen deposition rate, whereas in contrast to this, no correlation was found for *M. caerulea*. The authors conclude that the effects of nitrogen on the growth of this species are not yet clear but in previous studies nitrogen addition showed growth stimulation in *M. caerulea* (Roelofs 1986). The authors expect the effect of nitrogen on *Molinia caerulea* to become clearer after a longer research period and suggest that at higher nitrogen loads *Sphagnum* may not be able to assimilate all of the extra nitrogen in future, which will lead to higher nitrogen availability in the rooting zone of higher plants. Another aspect is that in bogs that are subjects to high nitrogen loads over a long period the N: P ratio will become so high that a shift from nitrogen to phosphorus as the limiting element will occur (Aerts *et al.* 1992). The authors referred to Lee and Woodin (1988) and Malmer (1988, 1990), who suggested that high atmospheric nitrogen deposition causes a change in the primary element limitation on plant growth in ombrotrophic bogs. In their study Aerts *et al.* (1992) demonstrated that on some ombrotrophic bogs, where the atmospheric nitrogen deposition is relatively high, the productivity of Sphagna changes from being nitrogen limited to phosphorus limited, as a result of dilution of phosphorus in *Sphagnum* tissue (Aerts *et al.*, 2001). Aerts *et al.* (1995) found that under phosphorus limitation no significant increase of net carbon fixation occurred upon enhanced nitrogen supply. The nitrogen uptake increased substantially and the potential decay rate under aerobic conditions increased significantly, which was not the case in nitrogen-limited peatlands. This is supported by Lee and Caporn (1998) who found that nitrogen fertilization had a sustained stimulation effect of nitrogen mineralization in grassland soils. Aerts *et al.* (1995) conclude that the atmospheric nitrogen deposition may affect the carbon dioxide sink function of peatlands but the effect is dependent on the nature of nutrient limitation, under phosphorus limited plant growth the net carbon accumulation will decrease. However, another negative aspect of phosphorus limitation is that *M. caerulea*, probably the most invasive species, is able to grow well under phosphorus-limitation (Kirkham 2001, Tomassen *et al.* 2003), which may be one of the reasons for its recent spread. However, since low decomposition rates of organic matter, rather than high productivity, are considered as the major cause of carbon accumulation in peatlands (Coulson and Butterfield 1978, Clymo 1965, 1984, Aerts *et al.* 1992, Aerts *et al.* 2001), this process could seriously effect the carbon balance of ombrotrophic bogs. Aerts *et al.* (1992) conclude that finally it may turn these carbon-accumulating systems into carbon-emitting systems. This could be forced by the fact, that when nitrogen deposition increases, the growth of *Sphagnum* might decrease and with it the 'sink' for atmospheric elements (Lee and Woodin 1988, cited in Tomasson *et al.* 2000). The enhanced availability of nitrogen in the rhizosphere will stimulate the growth of nitrophile vascular plants such as *Betula* and *Molinia* on bogs, which will increase the interception of water and input of dry deposition (Tomassen and Roelofs submitted, cited in Tomasson *et al.* 2000). At the same time desiccation and nitrogen eutrophication will force the growth of *Molinia* and *Betula* and hamper the growth of *Sphagnum* species. As the earth has a relatively large peat cover this change might affect the global carbon budget; if true, this would be a rather serious indirect effect of increased atmospheric nitrogen deposition (Aerts *et al.* 1992).

Several studies have shown that *Sphagnum* has high nitrogen uptake rates from its surrounding environment, and acts therefore as a 'sink' for airborne nitrogen deposition (Press *et al.* 1986, Jauhiainen *et al.* 1998a, Aerts *et al.* 2001) and makes nitrogen unavailable for the roots of vascular plants (Tomassen *et al.* 2000). Since the *Sphagnum* leaves are only one cell thick, and the plant is able to absorb nutrients with its whole surface, Sphagna capture atmospheric nitrogen supply very quickly from the water held by capillary forces around the chlorophyllous cells and from the hyaline cells (Clymo and Hayward 1982, Lee and Woodin 1988, Malmer *et al.* 1994). Additionally, and in contrast to many vascular plants, *Sphagna* do not have a long lag phase in activation of nitrate reductase and are therefore capable of assimilating even short NO_3^- pulses (Woodin *et al.* 1985) It is suggested by Lamers *et al.* (2000) that *Sphagnum* species can therefore be used as biological indicators to define nitrogen deposition based on their tissue nitrogen concentrations. Jauhiainen *et al.* (1998a, p. 287) found in their study that "*hummock species, which occur in high densities and have high potential N-uptake rates on a dry mass basis, were the most effective species in retaining available nitrogen*" and explained this result by the higher cation exchange capacities of these Sphagna (*S. rubellum* and *S. fuscum*).

2.5 Bog conservation and restoration

2.5.1 Introduction

Peatlands have been used by humans for several millennia. However, within the last two centuries large scale exploitation of peatlands has reached a scale, which brings raised bogs especially, in many countries to the verge of extinction (Cross 1990, 1992). The commissioner's report of Plantlife (1992) informs that about 6000 ha of natural raised bog is left in the UK, representing only 6 % of the original area, 94% has been destroyed or damaged by human activities. This is illustrated by Figure 2.7, which shows the amount of original Late-Holocene raised bog surface on the right and what is left on the left side of the diagram.

Throughout Western Europe the situation is similar. Grünig (1994) reports that in Switzerland up to 90 % of the original mire surface has been destroyed by human impact in the last few decades. In the Netherlands only small remains of bogs are left and all the present bog reserves are in a degenerated state (Vermeer and Joosten 1992). Table 2.1 gives further information about the loss of mire area in different European countries with former extensive mire habitats.

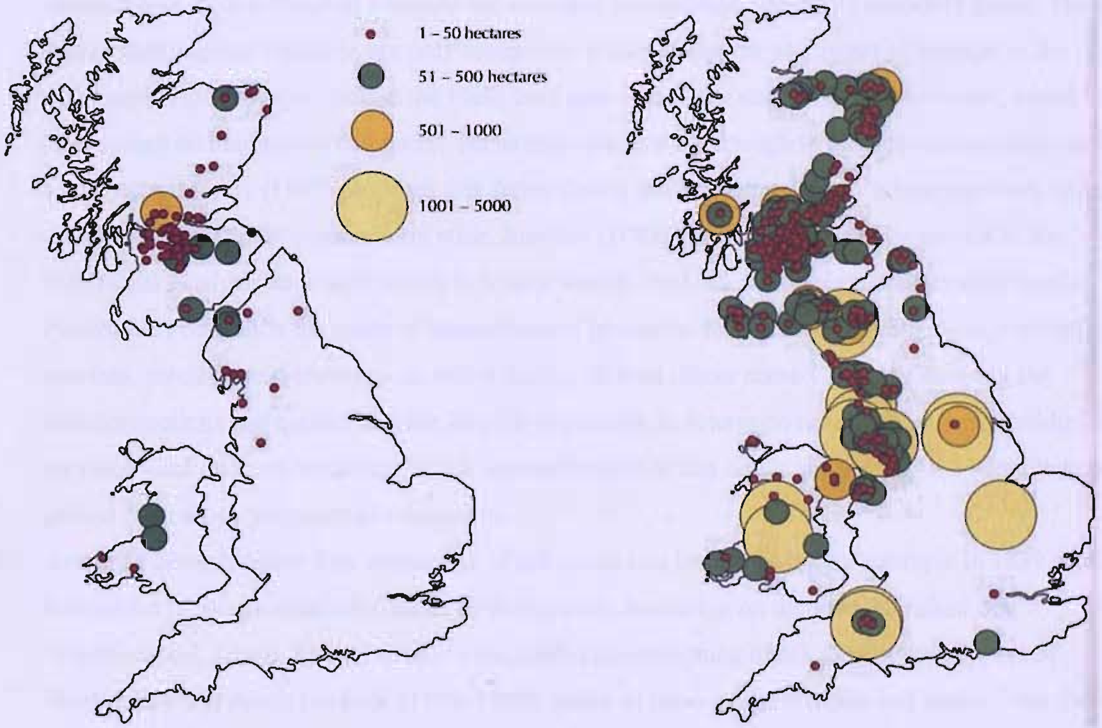

Figure 2.7: The loss of raised bogs in Britain (source: CCW 1995).

Lindsay (1992,1993) points out "*the mood of antipathy and neglect which has prevailed towards peatlands for the past 500 years cannot be altered in just a few months or years*". The author criticises that there have been a range of missed opportunities. Peatlands were much underrepresented in television documentaries and popular as well as scientific literature. However, more recently the attitude towards peatlands seems to have changed from viewing them as midge-infested wastelands, only useful for digging peat, to the recognition of their ecological and aesthetic values (Faulkner *et al.* 1992). The alarming loss of peatland habitat has resulted in increasing activities in conservation and restoration over the last few decades.

Table 2.1: Loss of mire area in European countries that possessed a high coverage of mires in the past (source: Joosten and Clarke, 2002).

	Former mire area [km²]	Present mire area [km²]
Ireland	14 000	2100
Britain	18 000	1800
Netherlands	15 000	150
Germany	15 000	150

The motives for peatland conservation and restoration are wide ranging:

1) Conservation motives which aim to protect the functions and processes as well as biodiversity of mires: Maltby (1997) and Immirzi (1997) point out, that goods (e.g. wild berries, medical plants, peat archive) and services (water filtration, flood prevention, wildlife sheltering), provided by mires are difficult to account for in monetary terms, whereas peat mining, agriculture and forestry generate tradable commodities. It is difficult to translate the scientific and heritage value into monetary terms. The value of peatland support functions are only recognised if they disappear as a result of damage to the ecosystem. Both authors criticise the traditional approach in the conservation movement, which emphasises on uniqueness and rarity. These attributes are not enough to promote conservation and its acceptance. Maltby (1997) proposes that future policy must be supported by a new approach which extends the traditional conservation ethic. Immirzi (1997) suggests as such an extension to the Functional Analysis approach, which is widely used in the USA to underpin conservation needs. Functional Analysis is the study of interactions of processes and functions within mires yielding services, products and attributes on which society at least places some value. By studying the interconnections and quantifying the flows it is possible to determine natural functions providing useful services, such as flood buffering, which summed together, can be far greater than the benefits to be gained from many proposed developments.
2) Aesthetic consideration: The impression of the raised bog landscape led for example in 1889 to the foundation of an association of artists in Worpswede, bordering on the lowland raised bog 'Teufelsmoor', Lower Saxony (http://www.beribo.de/entstehung.html). One of the painters of Worpswede was Fritz Overbeck (1869–1909), father of the wetland scientist and author Fritz Overbeck.
3) Information motives: Mires preserve their own history in the peat as well as the history of the wider region and the climate (Barber 1993, Coles 1997, Whitehouse *et al.* 1997). They also contain an archive of human history and are important for archaeology (Hayen 1990, Buckland 1993). Wetlands in general, and raised bogs in particular, often harbour spectacular archaeological finds. Organic artefacts are so well preserved that traces of their processing or use can be easily recognised providing much more precise information than findings from many dry soils (Godwin 1946, Hayen 1992, Coles 1997). For example Lemanaghan, Co. Offaly possesses one of the highest known densities of archaeological sites in Europe, contrasting with the common assumption of bogs being an empty wilderness without human presence (Crushell, Foss and Dwyer 2001). In contrast to the ecosystem, which can recover somewhat

after damaging impact the archive can not. Once it is destroyed it is lost forever (Coles 1997, Whitehouse 1997).

4) Human well-being motive (which also includes economic considerations): One important use of living bogs, especially in boreal zones, is the collection of a range of edible wild berries such as cranberry (*Vaccinium oxycoccus, V. macrocarpon*) and cloudberry (*Rubus chamaemorus*). In Estonia two bogs alone give half of the annual Estonian cranberry harvest, 1.5 and 1 million tons respectively (Paal *et al.* 1997). This shows clearly that mires also have great commercial importance and not only as functioning ecosystems, providing substantial income, food and vitamins for the local population. Other plant species inhabiting wetlands have importance in medical research like *Myrica gale* on Cors Fochno[5] [6] and *Drosera* species in Estonia (Paal *et al.* 1997).

2.5.2 Raised bog conservation in Britain and other European countries

Raised bog conservation started in Britain in the last few decades. The destruction of, for example, the Thorne and Hatfield Moors caused particular concern because they represented the last raised bogs of Eastern England (Stoneman 1997b). It was realised that raised bogs were under particular threat (Faulkner *et al.* 1992, Lindsay 1993). An example of early conservation initiatives in Britain is Woodwalton Fen, which was one of the first National Nature Reserves (NNR) in Britain. It was acquired by the Society for the Promotion of Nature Reserves in 1919 and became a NNR in 1945 (Wheeler 1995). Cors Caron, one of the two main study sites of this project in Ceredigion, Wales became a National Nature Reserve in 1955 (CCW 1995), at a time when the commercial peat extraction at many other raised bogs had just started.

The destruction of peatland sites in the UK led in the 1980's to the formation of the Peatlands Consortium. In 1987 the 'Peat Campaign' was proposed by the Yorkshire Wildlife Trust, RSNC and Friends of the Earth and finally launched in 1990, aiming to protect all UK peatlands of conservation importance (Barkham 1993, Scottish Wildlife Trust 1993). Barkman (1993) reported that the 'Peat Campaign' strategy, concentrating on the commercial extraction of peat from lowland raised bogs had great achievements after only 3 years. Public and political awareness increased and substantial areas of conservation value were brought under conservation management. The introduction of the National Bog Day in August 1992 attracted much attention by the media and publicised the peat issue very effectively (Scottish Wildlife Trust 1993). A big achievement is that now most garden centres offer peat-free compost products and some large suppliers such as B&Q committed themselves to offer entirely peat-free compost products for amateur gardeners[3]. In February 2002 the government committed to buy the peat extraction rights of the peat extraction company Scotts in return stopping its operations on key sites on Wedholme Flow and the Humberland Peatlands (http://www.news.bbc.co.uk/1/hi/sci/tech/1843299.stm).

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[5] http://www.ccw.gov.uk/News/index.cfm?Action=Press&ID=50

[6] http://www.ccw.gov.uk/News/index.cfm?Action=News&NewsArticleID=19

In Ireland the cooperation between conservationists and the peat producer Bord na Móna resulted in the handing over of Raheenmore Bog and Pollardstown Fen in 1970 for conservation, followed by Clara Bog, Mongan Bog, Redwood Bog and All Saints Bog (McNally 1997). However, the situation is extremely difficult since one bog is often owned by many people, who wish to continue with peat excavation. Often it is the case that one person is the owner of the land, but another person owns the right for peat extraction. This makes it impossible to start restoration activities, on parts of bogs, which are already owned by the DUCAS Heritage service (Jim Ryan, 2001, personal communication). In 1990 Watts (1990) complained that peatland conservation had little support at national political levels and emphasised that "*it is necessary to persuade leaders of public opinion and legislators that effective peatland conservation cannot be delayed any longer*" (Watts 1990, p. 199). The Irish Peatland Conservation Council, formed in 1982, aims to conserve a representative sample of living intact Irish bogs and peatlands. It supports purchasing of bog nature reserves, restoration management of damaged bogs and providing training on bogs for the public to promote a positive public attitude towards peatlands (http://www.ipcc.ie/aboutIPCC.html) by launching the 'Save the Bogs Campaign' [7].

Nature protection in the Netherlands started as a matter of private enterprise around the turn of the century. (Vermeer and Joosten 1992). It began in 1905 with the foundation of the society 'Natuurmonumenten' which bought the Naardermeer area in 1906, becoming the first fen nature reserve in the Netherlands. Further purchases followed, which made Natuurmonumenten the largest private landowner in the Netherlands with more than 60, 000 ha. in over 159 nature reserves (Vermeer and Joosten 1992). The initiatives of non-governmental organisations have drawn support within the last three decades, when the government also started to buy peatland for conservation. The Dutch government has spent more than 100 million Dutch guilders since 1970 on bog conversation, restoration and management (van der Schaaf 1999).

Carl Albert Weber recognised the ecological and scientific importance of undisturbed bogs in Germany and demanded their protection in 1901(Eggelsmann 1990d). However, as Van der Schaaf (1999) points out, Weber's proposals were too radical to be accepted at this time and the bog areas he had in mind for protection were too attractive for exploitation. Initiatives started significantly later, for example with the foundation of the organisation 'Bund für Natur- und Umweltschutz Deutschland' (BUND), in 1975, which aimed to the purchase and manage endangered sensitive areas (which include peatlands) alongside many other campaigns (http://www.bund.net/).

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[7] http://www.peatlandsni.gov.uk/education/campaign.htm

2.6 Key plant species of the study sites

2.6.1 *Sphagnum austinii*

Sphagnum austinii is considered to be the main peat former throughout most of the mid- to late Holocene (Barber 1993). It is a major peat component of many raised and blanket bogs throughout Britain (Green 1968), including Cors Caron (Godwin and Conway 1939). However, this species has disappeared from bogs over a large part of its former range in the British Isles and its present occurrence is mainly restricted to high hummocks (Green 1968, Stoneman *et al.* 1993, Dierßen 1996).

The *S. imbricatum* complex is divided into two different sub-species, *S. austinii* and *S. affine* (Green 1968, Daniels and Eddy 1990, Dierßen 1996). Flatberg (1984) distinguished them as two different species, which was later supported in a revision by Hill (1988) and recent genetic research by Thingsgaard (2002). Ecologically, the species occur in different habitats. *S. affine* grows in a more mesotrophic habitat whereas *S. austinii* is viewed as an ombrotrophic species (Hill 1988). Thus, Stoneman *et al.* (1993) suppose, that it is likely that any *S. imbricatum*, found on ombrotrophic mires to be *S. austinii.* Tallis (1961) found in experiments that *S. imbricatum* can grow in two different forms, lax in wet habitats and the compact form occurs under dryer conditions forming hummocks. A review of the species used for the experiment, by Hill (1988) showed that all the plants used in Tallis experiment were *S. austinii.* The species became the major peat former on Cors Caron at approximately 4600 BP and on Cors Fochno at 3300 BP (Hughes 1997). Godwin and Conway (1939), who recorded the vegetation of the Cors Caron West Bog in the summers 1936/37, emphasised that despite a prolonged search no *S. imbricatum (S. austinii)* was ever found among the living bog vegetation on the entire bog. On Cors Fochno the *S. austinii* still occurs still on the top of several hummocks (Slater 1972, Newton 2000).

The causes of *S. austinii's* widespread disappearance are still unclear. The study of Green (1968) showed that *S. imbricatum* can tolerate desiccation better than other Sphagna and deduces that dryness could not be the cause for its disappearance. But the author noticed that its growth rates are slower than those of other *Sphagnum* species, even if it grows under wet conditions. He points out that factors other than hydrology may have an influence such as supply of minerals and emphasises that the current distribution of *S. imbricatum (S. austinii)* is significantly oceanic supposing that this species receives a better supply of minerals due to high precipitation in areas close to the sea. Stoneman *et al.* (1993) found evidence from macrofossil diagrams that the species was associated as with *Sphagnum* sect. *Cuspidata*, indicating that this peat was formed in a lawn rather than on hummocks found at present. The authors reported that the decline of *S. imbricatum (S. austinii)* is linked with the increase of *S. magellanicum* within lawns and suggest that *S. magellanicum* has outcompeted *S. imbricatum* (*S. austinii*) confining it to hummock tops. This is supported by Mauquoy and Barber (1999a) who found that the decline of *S. austinii* was associated with evidence for climatic change towards wetter conditions. Another important fact is that populations of *S. austinii* in Europe are genetically depleted (Thingsgaard 2002). Thingsgaard points out that the genetic structure in rare decreasing species or marginal populations may be very important as a determining factor with respect to eventual extinction.

2.6.2 *Molinia caerulea*

Godwin and Conway (1939) report the presence of *Molinia caerulea* at the centre of Cors Caron West Bog, where it is still present today. The authors record *Molinia* to be dominant there, accompanied by frequent *Betula pubescens*. An investigation of the peat beneath the *Molinia* showed fresh *Sphagnum imbricatum* peat, indicating that this Molinietum must have developed very recently before Godwin's investigation on Cors Caron. *M. caerulea* causes big problems in many ombrotrophic bogs with a disturbed hydrology (Tomassen *et al.* 2003).

In contrast to other grasses *Molinia* possesses some special properties (Jefferies 1915), which make it very successful and competitive. Its basal internodes, which can be found as macrofossils (Grosse-Brauckmann, 1972), contain food reserves and its upper parts retain chorophyll throughout the winter. This enables the plant to continue with photosynthesis after shedding its leaves. The leaf has stomata on both sides, a comparatively large surface, and its structure is stabilised by abundant stereomes. These features are, according to Jefferies (1915), characteristic of grasses from seashores, which expose a large leaf-surface in situations where wind pressure can be high. The mechanically resistant leaves, which possess all the advantages of rapid transpiration, alongside the support of the food stores and a very efficient root system, make *Molinia caerulea* a very successful competitor.

The species occurs particularly on sites with groundwater movement, aerated soil and an enriched nutrient supply (Jefferies 1915, Rutter 1955), but it is adapted to nitrogen-poor conditions (Ellenberg 1992). According to Taylor *et al.* (2001) the species has a bimodal pH distribution and is divided into two different populations, one on calcareous soil, and the other always on at least seasonally wet acid ground. Both populations are suggested to belong to *M. caerulea* ssp. *caerulea* (Salim *et al.* 1995). In a study by Loach (1968a), the addition of phosphorus combined with other elements, caused a large increase in growth. Sheikh (1969b) also reported a positive response to additional supply of nutrients.

The National Vegetation Classification gives an overview of the plant communities in which *M. caerulea* is present (Rodwell 1991), but the question arises as to whether the species originally occurred in all these communities? The data collection for the National Vegetation Classification started in 1976. At this time several decades of atmospheric pollution might have altered the composition of these communities.

According to Taylor *et al.* (2001) *M. caerulea* is tolerant of burning and grazing, but in contrast to that some studies report a decline of this grass due to mowing or controlled grazing by cattle (Wittig and Hellberg 1999). Chambers *et al.* (1999) point out that *M. caerulea* has increased significantly in environmentally sensitive areas throughout western Europe, at the expenses of mire, moor and heath. The displacement of typical bog species by *Molinia caerulea* on disturbed mires is also reported from Belgium (Damblon 1992, Frankard and Hindrykx 1998), the Netherlands (Tomassen *et al.* 2000) and Germany (Wittig and Hellberg 1999).

2.7 Summary

Succession in the earlier literature (Clements 1916, Tansley 1939) was assumed to culminate in a climax stage of forest (Cowles 1901). However, during the twentieth century the understanding of succession progressed. For example, Walker (1970) demonstrated that the successional diversity alone in hydroseres is far greater than previously proposed. The hydrosere is one possible pathway leading to raised bog in Britain. Others started with a fen stage succeeded by raised bog (Casparie and Streefkerk 1992) or ombrothrophic peat grow followed directly a woodland stage (Petzelberger *et al.* 1999). Late Holocene raised bog development is characterised by the deposition of slightly humified *Sphagnum* peat, with *S. imbricatum* as one of the main peat formers. The mosaic of different microrelief patterns that occurs on most raised bogs inspired scientists (von Post and Sernander 1910, Osvald 1923) to the '**Theory of Cyclic Regeneration**'. The theory was later criticised (Walker and Walker 1961) and finally dismissed by Barber (1981) proposing that raised bog development is chiefly controlled by climate. This is linked with the occurrence of 'Recurrence Surfaces', which were supposed to be caused by climate change (Godwin and Conway 1939, Barber 1982). Other authors (e.g. Frenzel 1983) suggest that autogenic succession too may have contributed to the formation of Recurrence Surfaces. The scientific debate about the influence of allogenic and autogenic factors, driving raised bog development still continues (Foster and Wright 1990, Clymo 1992, Illomets 2000).

Raised bogs are ombrotrophic and characterised by an elevated groundwater table. The peat body supports a so-called 'ground water mound' against gravity forces. One hypothesis, proposed to explain this paradox such was the Capillary Hypothesis (Moore and Bellamy 1974, Gosselink and Turner 1978) However, Ingram (1982) argues that it does not explain the hydrological properties of raised bogs and suggested the Ground Water Mound Hypothesis, which is now widely accepted (Ginzler 1997). In order to maintain the dynamic equilibrium between discharge and recharge, raised bogs possess self-regulation mechanisms, which enable them to withstand long periods without water supply (Joosten 1993). However, the studies by Siegel and Glaser (1983), Siegel *et al.* (1995) and Glaser *et al.* (1997) show, that mire hydrology is a very complicated subject where further research is needed to fully understand the dynamics of mire complexes.

When applying plant macrofossil analysis, the processes of peat formation and decomposition have to be considered since they define the limits and potentials of the analysis. The decay and preservation of plant matter is determined by the environment as well as by the organo-chemical composition of the plant remains from vascular plants. Mostly the below-ground parts are preserved from vascular plants, whereas *Sphagnum* is preserved in its entirely due to its growth mechanism. This has implications for the interpretation of macrofossil assemblages since they are only representative for the area of the core location and may not reflect analysis of the former composition of plant species. However, despite the shortcomings of plant macrofossil, assemblages are useful as a relative measure of the previous vegetation communities (Barber 1993).

The most important sources of damage to remaining raised bogs are drainage and high amounts of airborne nitrogen deposition. Since undisturbed raised peat bodies consist up to 97 % of water (Eggelsmann 1990a), drainage is the most destructive source of damage, leading to irreversible physical alteration such as subsidence (Van der Schaaf, Bragg 1995). This can cause a loss of 25-35 % of the original peat thickness (Succow 1990). In the long term, the physical process is followed by ecological alteration resulting in the loss of peat forming vegetation. These ecological changes are also reinforced by high atmospheric nitrogen deposition, which are currently much higher than the critical load for ombrotrophic bogs. Since nitrogen is the limiting nutrient in these habitats, high nitrogen input supports the invasion of species like *Molinia caerulea* as reported from the Netherlands (Tomassen *et al.* 2000).

During the last two centuries, raised bogs were the object of large-scale exploitation, which brought them in many countries to the verge of extinction in many countries (Cross 1990). More recently, the attitude towards peatlands has changed and the alarming loss of peatland habitat has resulted in conservation and restoration activities. The motives for conservation include aesthetic views and information interests as well as economical motives. Natural bogs may provide substantial income and food for local population (Paal *et al.* 1997). Raised bog conservation in Europe started in the early twentieth century, but at a significant scale within the last few decades. Examples are the 'Peat Campaign', proposed by NGO's in the UK or the ' Save the bogs Campaign' of the IPCC in Ireland, trying to promote a positive public attitude towards peatlands.

There are two key plant species, which are important on the investigated sites, *Sphagnum imbricatum* (*austinii*) and *Molinia caerulea. Sphagnum austinii* was the main peat former in the study sites but its recent distribution pattern differs. It has disappeared from Cors Caron, but is still present on hummocks on Cors Fochno and on hummocks as well as in lawns at Raheenmore Bog. *Molinia caerulea* is also present on all three sites but its encroachment on the mire expanse, and cut-over parts of Cors Caron is of particular concern. The physical properties of the species enable it to compete successfully with the peat-forming vegetation at sites where the hydrological balance is disturbed.

3 Selection and introduction of the investigated sites

3.1 Site selection

In Wales no raised bogs remain in a virtually intact condition. Many are badly damaged or cut over, such as Rhos Goch Common (Bartley 1960) and do not retain late Holocene peat records. Cors Caron and Cors Fochno are not only the largest raised bogs in Wales, but are also the most structurally intact in terms of the mire expanse. Therefore there is great interest from the government nature conservation body (Countryside Council for Wales) in restoring the functionality of these peatlands and gathering information about their late Holocene succession. Additionally Cors Caron was the first raised bog to be the focus of a major ecological study in Britain in 1936/37 (Godwin and Conway 1939),which makes it ideal for the current project. This was also the basis for investigating whether if the contemporary vegetationcover over the last 100 years as degraded as during the formation of the Retardation Layer, which was first described by Godwin and Mitchell (1938).

The structural integrity of the major peat bodies is vital for investigations of late Holocene raised bog development. At cut-over bogs such as Wedholme Flow or Rhos Goch Common, the 'archive' of the upper peat layers is largely or even completely lost. Both chosen study areas suffer from marginal domestic peat cutting, but their central peat bodies are structurally intact, which makes them very suitable for palaeoecological research. The early to mid-Holocene mire development of Cors Caron and Cors Fochno, involving the transition from the fen- to the ombrotrophic bog stage, has been investigated by Hughes (1997).

An important aspect of the choice of these peatlands was that the late Holocene palaeoecological record may help to understand the extinction patterns of *Sphagnum austinii.* This species was the main peat former in Atlantic raised bogs from the mid-to late-Holocene until several centuries ago, and vanished from many raised bogs in western Europe after the medieval climatic optimum (Green 1968, Barber 1982, Hill 1988, Stoneman *et al.* 1993, Mauquoy and Barber 1999a). *Sphagnum austinii* is extinct at Cors Caron but fresh, unhumified peat, formed by this species, lies immediately beneath the surface of all three bogs of the Cors Caron complex (Godwin and Conway 1939). A recent palynological study on pollen at Cors Caron (Morriss 2001) revealed a substantial medieval slow-down in the peat accumulation rate at the West Bog and the Southeast Bog. The macrofossil analysis for this study was carried out on the same profiles as the pollen analysis from Morriss (2001), which gave the opportunity to use the same chronology. The first results of this study showed that these uppermost *Sphagnum austinii* peat layers are of medieval age. This is in agreement with the findings of several other researchers at other British sites (e.g. Barber *et al.* 1994, Mauquoy and Barber 1999a, 1999b), which demonstrate that some of the key changes in late Holocene raised bog succession began substantially before the beginning of the Industrial Revolution. Therefore they may not be accounted for by recent marginal peat cutting or industrial pollution. At Cors Fochno hummocks of the compact variant of *Sphagnum austinii* still occur very locally (Newton 2000). The macrofossil analysis of multiple cores from this site should provide information about the late Holocene record of *S. austinii* at locations where it survived and where it has been displaced by other *Sphagnum* species.

To provide a control site for studying the decline of *S. austinii*, the macrofossil record of Cors Caron and Cors Fochno have been compared with an additional undisturbed site in Ireland, where *Sphagnum austinii* is still relatively abundant (Hill 1988). This Irish site should possess a considerable amount of *Sphagnum austinii* in its living surface vegetation cover to be suitable as a comparison site. It was hoped that the comparison of the macrofossil records of all three sites would give information about possible differences in succession processes in the bogs where *S. austinii* has declined and bogs where it continues to thrive. Potential Irish sites considered were Ballynahone Bog (Co. Londonderry, Northern Ireland and Mongan Bog, Clara Bog and Raheenmore Bog (Co. Offaly, Republic of Ireland). During a raised bog study tour in 2001, Clara Bog and Raheenmore Bog in Offaly were described as possibly the least disturbed classical raised bogs in the country (Jim Ryan, Dúchas Heritage Service, pers. communication), so the selection concentrated on these two sites. Unfortunately it seems that no entirely pristine raised bog is left in Ireland, which once had more than 17 % of its surface covered with peatlands (Foss *et al.* 2001). Clara Bog and Raheenmore Bog are both marginally cut. Clara Bog possesses a regular pattern of drainage channels (which are now blocked) and it has been strongly affected by a road crossing the central peat dome. Although Raheenmore Bog also suffers from marginal cutting it is less affected and *Sphagnum austinii* still occurs as a component of the vegetation cover[8]. As Raheenmore Bog most fulfilled the necessary conditions it was therefore chosen as the comparison site. An overview of the location of all three study sites is shown in Figure 4.1.

Table 3.1: Selection of the Irish site.

Potential Irish Sites + Grid reference	Area [ha]	Comments on eligibility	Selection status
Clara Bog (N 250 300; 665)	460	Marginally cut; has an extensive drainage pattern (now blocked); no *Sphagnum austinii*	Eliminated
Raheenmore Bog (N 440 320; 190)	162	Marginal cut but in good condition; *Sphagnum austinii* still present	**Selected**
Mongan Bog (N 030 306; 136)	127	Partly exploited but largely undisturbed, very wet due to its unusual surrounding topography [9]; no *Sphagnum austinii*	Eliminated
Ballynahone Bog (H 860 980)	243	Affected by marginal cutting; half of the bog has an extensive drainage pattern (now blocked); no *Sphagnum austinii*	Eliminated

3.2 Cors Caron (Tregaron Bog), Ceredigion, West Wales (Grid Reference: SN 685622)

Cors Caron, also known as Tregaron Bog, is situated near Tregaron village in the Teifi valley in Ceredigion, west Wales (Figure 3.1). The bog complex developed from a late glacial lake, which was formed behind an end-moraine (Godwin and Conway 1939). It is an extensive lowland raised bog complex of 816 ha,

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[8] http://www.duchas.ie/ie/LSCannaLCSannaLONanna/LSCLCSEolas/UibhShaile/d5864.ie.v1.0.t4.html

[9] http://www.duchas.ie/en/SACsSPAs/SACSPASiteInformation/Offaly/d5872.en.v1.0.t4.html

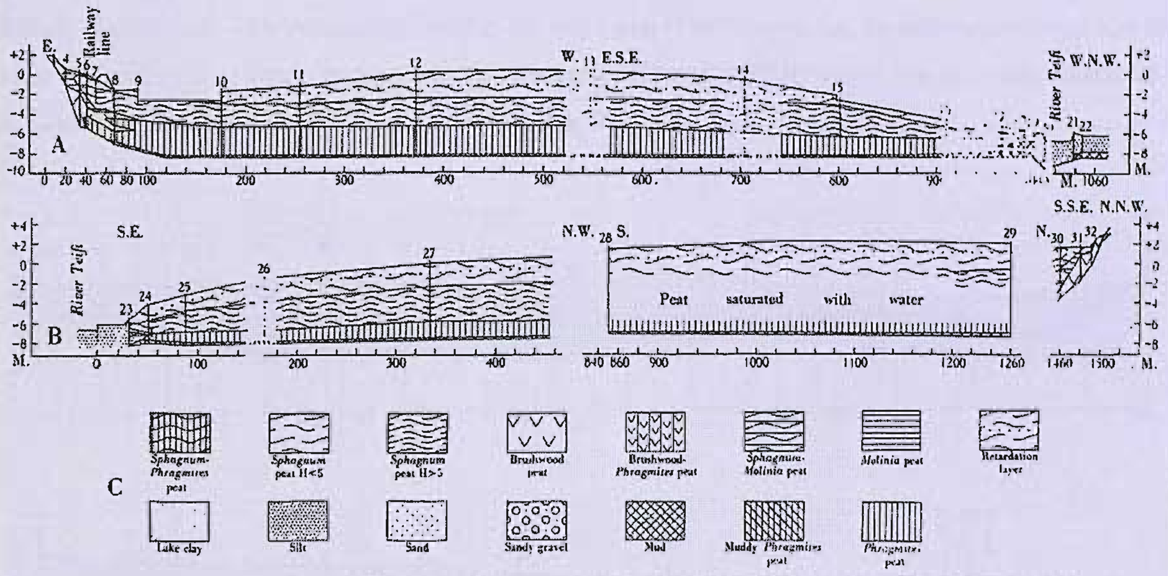
consisting of three hydrologically independent peat domes (see Figures 3.1 and 3.2). All three bogs suffer from marginal peat cutting at different scales. There may have been three further raised peat domes, which are destroyed now due to peat extraction for domestic fuel (CCW 1994). The least disturbed bog is the West Bog, stretching 2 km parallel to the river Teifi on its western bank. At the eastern side of the Teifi are the Northeast Bog and the Southeast Bog, separated by a mineral ridge. These two bogs are more affected by peripheral peat cutting (see Figure 3.2), but the central peat domes of all three bogs are still structurally intact. Peat cutting occurred only for domestic purposes and ceased in 1960 (CCW 1995).

Cors Caron became a National Nature Reserve (NNR) in 1955 (CCW 1995) and is managed by the Countryside Council for Wales (CCW). It is further designated as a Ramsar site, Site of Special Scientific Interest (SSSI), Special Area of conservation (SAC) and NCR Grade 1 (Stoneman and Brooks 1997, http://www.wetlands.org/RDB/Ramsar_Dir/UnitedKingdom/UK057D02.htm). The wetland complex supports rare plants such as *Sphagnum pulchrum* and a range of rare animals species like adder (*Vipera berus*), otter (*Lutra lutra*), red kite (*Milvus milvus*), kingfisher (*Alcedo attis*), hobby (*Falco subbueto*), curlew (*Numenius arquata*), short-eared owl (*Asio flammeus*) and the rosy marsh moth (*Eugraphe subrosea).* Most of these animals were encountered during the fieldwork on Cors Caron. The former richness of wildlife was also vividly described by Evans (1950). At the end of his paper (p. 101) the author makes an unusual statement for the time: " *'Corsydd' play an important part in the human and animal divisions of nature, providing fuel and heat for mankind, protection and sustenance for fowl, fish, and wild creatures. The secret of the Teify's renown for salmon and trout lies in the feeding supplies carried down its whole length from Tregaron bog. Though the 'corsydd' appear useless wastes, they contain a wealth of goodness which some day will be scientifically tapped for the benefit of man and beast.* "

The stratigraphy of the Cors Caron West Bog and Southeast Bog was first comprehensively investigated and published by Godwin and Mitchell (1938) and is shown in Figure 3.3. The transition from the limnic stage towards *Phragmites* peat was dated to 9750 ± 220 BP by Hibbert and Switsur (1976) and the Fen-Bog-Transition (FBT) transition at about 6530 ± 110 BP. A comprehensive study of the FBT was carried out by Hughes (1997) and the results published in Hughes *et al.* (2001) and Hughes and Barber (2003). Worth mentioning is the occurrence of a so called 'Retardation Layer' in the peat close to the surface, which was noted by Godwin and Mitchell (1938). This layer was well developed at the centre of all three domes and disappeared at the margins. The authors reported that, when exposed to drying this peat contracted much more than the surrounding fresh Sphagnum peat. Radiocarbon dating of this Retardation layer in the Southeast and West Bog (Turner 1964, Morriss 2001) shows that peat accumulation was very slow during a period of several hundred years.

Page 44 missing

Management to reduce the impact of peat cutting started in 1988 (Stoneman and Brooks 1997). Since then, 4,000 m of pressure bund and 300 peat dams were constructed in order to prevent loss of water. Behind many of these dams, bodies of standing water have formed, which support renewed colonisation by *Sphagnum cuspidatum*. The management success is regularly monitored. Permanent vegetation quadrats were installed to record botanical changes and the hydrology in the uncut areas is monitored with R 16 water level recorders and lysimeters. Data are collected twice a month.



Text-fig. 2. A. Stratigraphy of the S.E. bog from hill-side to the Teifi. B. Stratigraphy of the W. bog. C. Symbols for peat types employed in this and the other figures.

Figure 3.3: Stratigraphy of the Cors Caron West Bog and Southeast Bog (source: Godwin and Mitchell 1938)

3.3 Cors Fochno (Borth Bog), Ceredigion, West Wales (Grid Reference: SN625915)

Cors Fochno (Figures 3.4 and 3.5) is situated on a coastal plain south of the Dyfi estuary, 10 km north of Aberystwyth. The surrounding hills consist of slaty rock with grits and mudstones and belong to the Ordovician and lower part of the Silurian system (Shi and Lamb 1991). The raised bog Cors Fochno is part of a larger wetland complex also involving the estuary of the Dyfi. The area of the NNR Cors Fochno comprises 653 ha. After 1813 marginal peat cutting started on an extensive scale in connection with trials to enclose and to reclaim the area. At the same time, ancient ditches were widened and in 1822 the course of the river Lerry altered (Colyer 1977). Although the scale of damage to the raised peat body is quite extensive, the centre of the raised bog remains structurally intact. It is reported that the bog surface has previously been burnt many times (Slater 1972, Chambers 1997) and Evans (1950) comments that peat-cutting combined with periodical burning has spoiled much of the natural vegetation. However the current bog vegetation is in good condition contrary to that on Cors Caron. The site is managed by the CCW and

An overview of the stratigraphy of Cors Fochno is shown in Figure 3.6. The bedrock beneath Cors Fochno is overlain by 50-75 m of deep estuaric sediments (Shi and Lamb 1991). At the base of the peat deposits there is a layer of blue clay or silt containing foraminifera (Godwin and Newton 1938, Shi and Lamb 1991). This clay is overlain by *Phragmites* peat, which was succeeded by a woodland stage. Shi and Lamp (1991) report that fenwood forests were widespread through the whole estuary around 6000 BP. On the beach at Borth and Ynyslas, the remains of this woodland are visible at low tide. A publication by Godwin and Newton (1938) based on the notes from F.N. Campbell James gives a more detailed overview of the development of the woodland stage. In the paper it is demonstrated that the stratigraphy of the submerged coastal forest and beneath Cors Fochno were remarkably similar. Shi and Lamb (1991) prove that the submerged forest and the forest bed under Cors Fochno are in continuity. Between 6280 and 5990 BP raised bog initiation succeeded the woodland stage (Hughes 1997, Hughes and Schulz 2001).

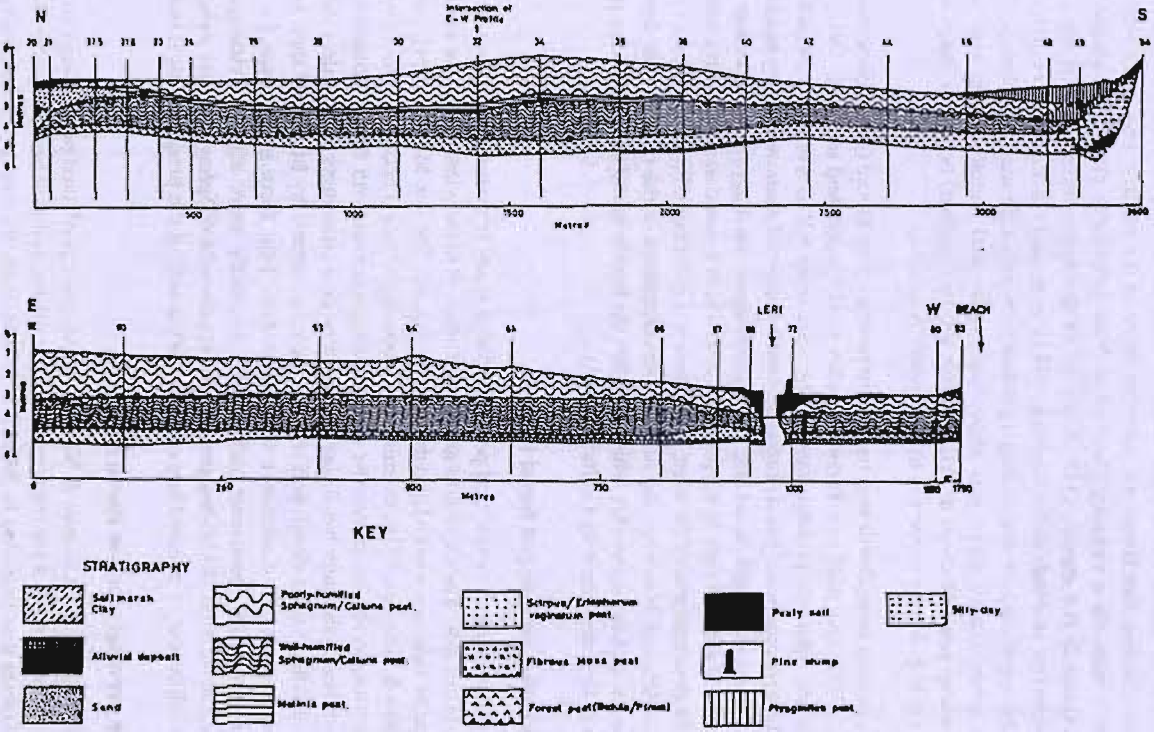


Figure 3.6: Stratigraphy of Cors Fochno (source: Williams Parry and Parker 1939, in Slater 1972)

In the past the vegetation of Cors Fochno was affected by repeated burning as reported by Evans (1950) and Slater (1972). However, after restoration management much of the peat-forming vegetation, also in the cut-over parts, has recovered (Mike Bailie, personal communication.) and it consists currently of fairly wet and *Sphagnum*-rich communities. In contrast to Cors Caron, *Myrica gale* is very common on the mire expanse and also on the marginal areas, becoming much taller than on the bog centre, where it remains of dwarf shrub size. However on the mire expanse the species becomes a potential competitor for the hummock forming and rare Sphagna *S. austinii* and *S. fuscum*. A survey in 2000 revealed that several hummocks consisting of those species still persist (Newton 2000).

3.4 Raheenmore Bog, Co. Offaly, Ireland (Irish Grid reference: N 440 320)

Raheenmore Bog is situated in the north Irish Midlands, (County Offaly) about 11 km northeast of the town of Tullamore. It is a classic example of an Irish Midland raised bog, characteristically dome-shaped and with typical raised bog vegetation. With a maximum depth of 15 m Raheenmore Bog is exceptionally deep. The site was purchased by Bord na Móna in 1970 and subsequently donated to the National Parks and Wildlife Service[11]. The area of the nature reserve of Raheenmore Bog comprises 162 ha[12], but the actual bog comprises about 130 ha (Van der Schaaf 1999). A map of the area is shown in Figure 3.7. The bog is still largely intact but suffers from marginal peat cutting and drainage ditches cut between 1950 and 1970. As a result the formerly present bog pools have dried out and the peat body has undergone degeneration and subsidence (Stoneman and Brooks 1997, Van der Schaaf 1999). The central peat dome is still structurally intact, but the former lagg is completely destroyed by drainage (Van der Schaaf 1999).

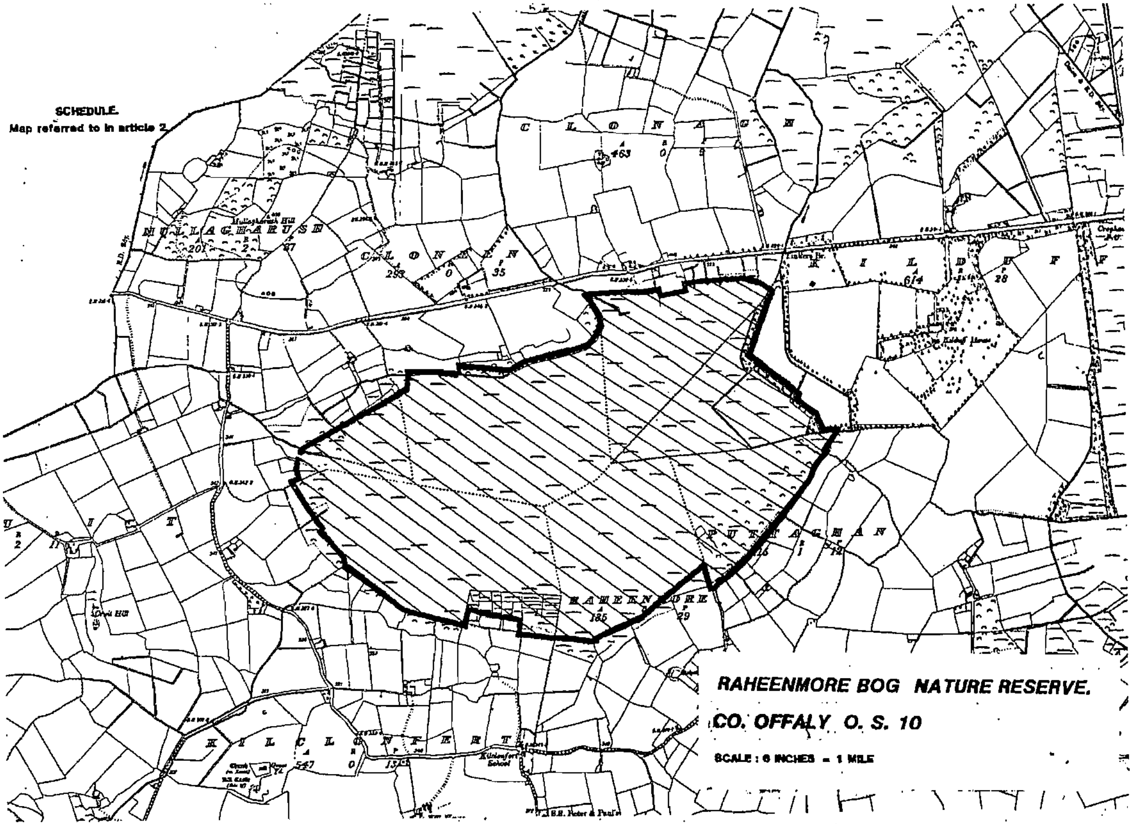


Figure 3.7: Map of Raheenmore Bog (source: http://193.120.124.98/ZZSI280Y1987.html)

Despite this, Raheenmore Bog still exhibits a microrelief of *Sphagnum* hummocks and *Sphagnum* carpets and hosts a range of rare *Sphagnum* species including *S. austinii* in hummock and lawn form as well as *S. fuscum.* In the hollows *Drosera anglica* can still be found[13]. In 1959 *Scheuchzeria palustris*, found on its only Irish site in a nearby bog, was transplanted to Raheenmore Bog. However, it has not been recorded

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[11] http://www.bnm.ie/group/conservation_and_afteruse/conservationinaction/raheenmore.htm

[12] http://www.wetlands.org/RDB/Ramsar_Dir/Ireland/ie014D02.htm

[13] http://82.112.120.223/en/NatureConservation/SitesdesignatedforNatureConservation/NATURA2000sitesSACsSPAs/SpecialAreasofConservationSACs/SACSiteInformation/Offaly/d5864.en.v2.0.t4.html

recently and may be extinct now. Amongst rare animals hosted by the site are the curlew (*Numenius arquata*), red grouse (*Lagopus lagopus*), snipe (*Gallinago gallinago*), sky lark (*Arlauda arvensis*) and the large heath butterfly (*Coenonympha tullia*). Raheenmore has a status as a NNR, Area of Scientific Interest (ASI), National Heritage Area (NHA), and Biogenetic Reserve (BGR according to the Bern Convention). It is further designated as a Ramsar site, Recorded Monument (RM), and Special Area of Conservation (SAC) (Foss 2001). The average annual precipitation in the Irish Midlands is between 800 and 1000 mm.

The bog developed in a glacial basin that is related to the land ice sheet that covered a large part of Ireland during the Midlandian. The retreating ice field formed a deep basin, which was subsequently filled with melt water. The organic deposits are underlain by gritty clay on glacial till. Then, after a limnic stage, fen peat developed containing *Phragmites*, *Alnus and Betula* remains overlain by ombrotrophic peat (Figure 3.8). Raheenmore Bog is typically dome-shaped and slightly asymmetric. It rises between 3 and 7 m above the surrounding land (Figure 3.9). And the maximum peat depth reaches 15 m.

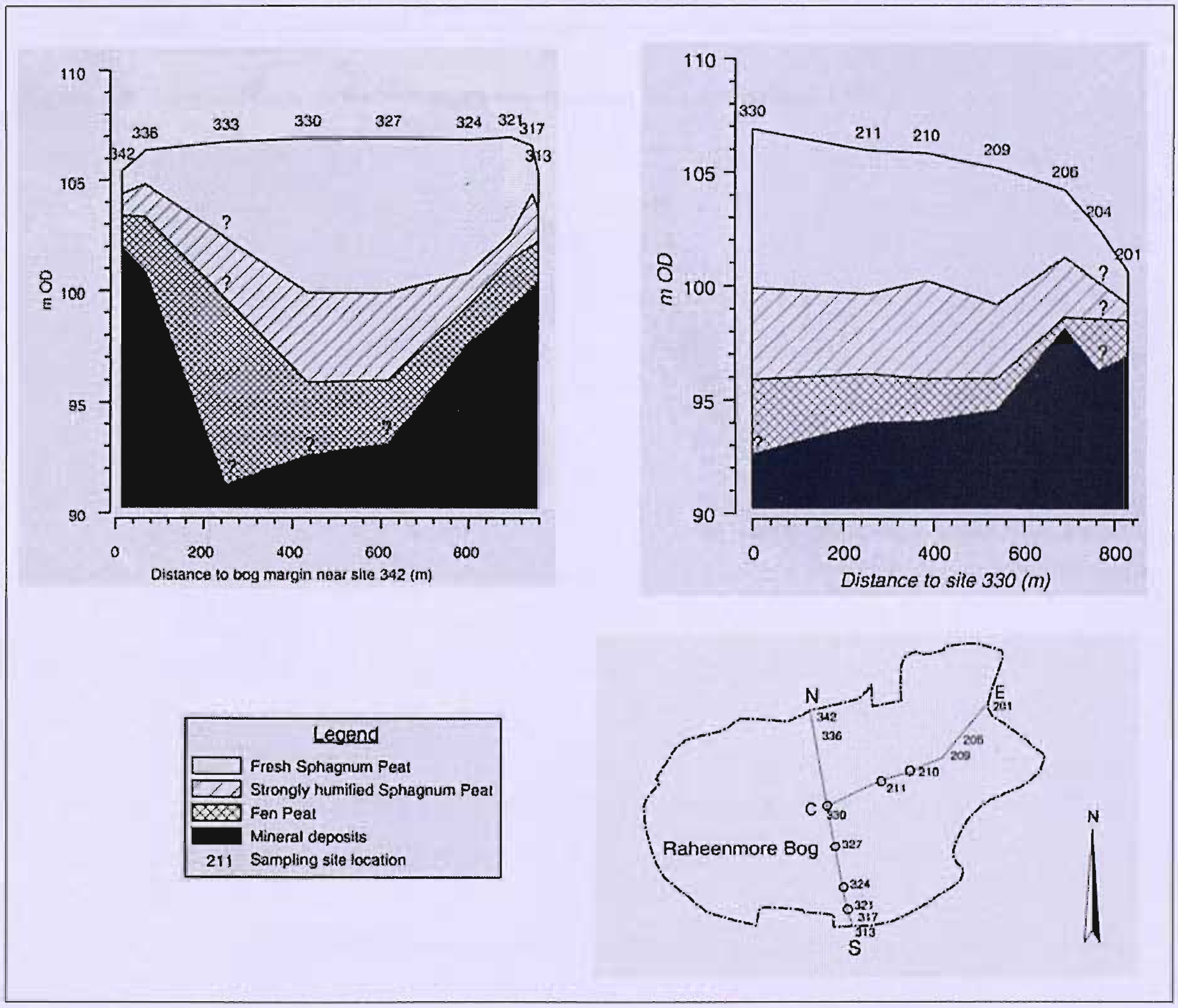

Figure 3.8: Stratigraphycal cross sections through Raheenmore Bog from North to South (top left) and along transect C to E (topright). Source: Van der Schaaf 1999.

In 1989 management work started as part of an Irish-Dutch project into the ecology and hydrology of the site. Based on the fieldwork on Raheenmore Bog and Clara Bog, a thesis was completed by Van der Schaaf (1999), dealing in detail with the hydrology of both sites. Management objectives focus on halting further degradation of the remnant bog vegetation.

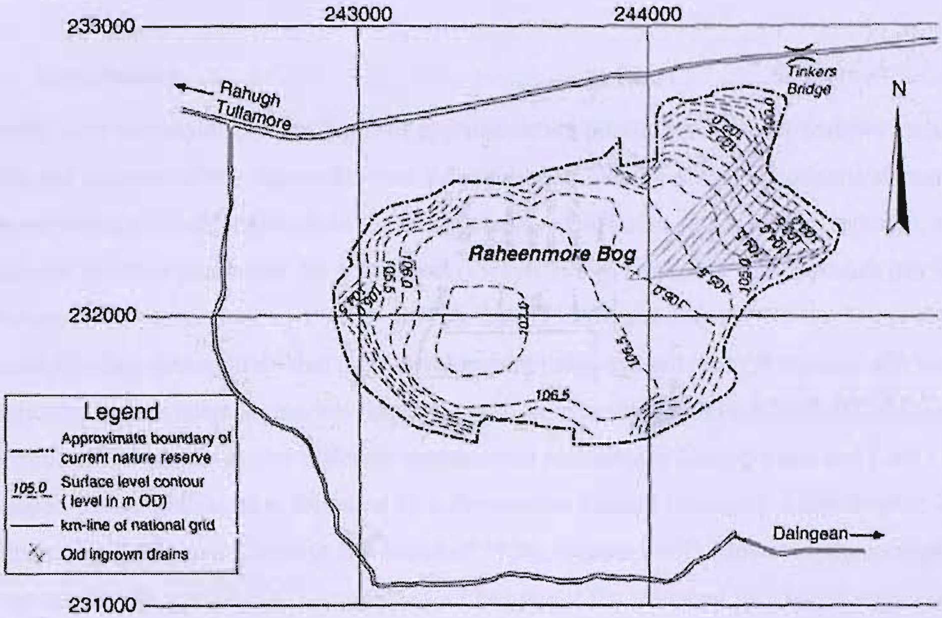

Figure 3.9: Contour lines of Raheenmore bog (source: Van der Schaaf 1999).

4 Methods

4.1 Introduction

To study mire succession several kinds of approaches are possible and recent reviews include that of Zobel (1988) and Joosten (1995). Space-for-time substitution or side-by-side comparisons attempt to deduce temporal changes in vegetation from the study of sites at different stages of development, assuming that spatial and temporal variations are equivalent (Pickett 1989). However, this approach has some shortcomings as pointed out by Walker (1970), Zobel (1988) and Joosten (1995). These authors argue that stratigraphic data demonstrate that mire development pathways are multidirectional and much more complicated than conceptual models might suggest, despite some common successional trends. This is also discernible, for example, in the different successional pathways at Cors Fochno and Cors Caron. The latter developed from a glacial lake, followed by a *Phragmites* fen and ultimately ombrotrophic bog development dominated by *Sphagnum* (Godwin and Mitchell 1938, Hughes 1997). However, the stratigraphy of Cors Fochno starts with marine clay continues as a *Phragmites* fen followed by a forest stage consisting of *Alnus*, *Betula*, *Pinus* and *Quercus*. After the woodland stage, an ombrotrophic raised bog developed (Godwin and Newton 1938, Slater 1972, Hughes and Barber 2003).

Tracing vegetation change in bog successions by direct observation is almost impossible because of the long duration of bog development (Zobel 1988). Direct monitoring is limited to a short time scale and has only been approached since the beginning of the 20th century. Pearsall (1917, 1918), for example, surveyed aquatic and marsh vegetation annually over three years. Mets (1982) observed certain patches within a raised bog by photographing them periodically over 17 years from 1959 to 1976. A slightly longer view enables re-mapping of past vegetation surveys as Backéus (1972) did. He re-mapped two areas on a Swedish bog comparing the results with maps of the same areas from 1910 made by L. von Post (von Post and Sernander 1910). Godwin *et al.* (1974) observed vegetation changes at Wicken Fen over a period of 49 years by re-surveying and taking photographs. Vegetation changes in two kettle-hole bogs after 33 years were studied by Schulz (1999) using photographs, aerial photographs and re-survey of vegetation collected by Slobodda (1966). A problem with re-surveys is that they rely on monitoring carried out in the past, but regular observation aiming for monitoring long-term ecosystem development only started very recently in most countries. The work of Godwin and Conway (1939) provides the possibility to compare contemporary vegetation from 1936/37 with the present day (2000–2002, this study). By combining this approach with palaeoecological records one can build a detailed history of vegetation change covering the last 2000 years.

To study vegetation changes in peatlands over several centuries or millennia requires a palaeoecological approach. Raised bogs preserve their own history and the history of their surroundings by forming peat (Godwin 1946, Barber 1982, Grosse-Brauckmann 1986, Barber 1993). Macrofossils, the remains of partly decayed plants, and testate amoebae are deposited *in situ* and small particles like pollen and ash, which may be derived from greater distances, are also preserved in the peat. Therefore palaeoecological research allows us to understand long-term changes in peatland vegetation communities and what might be expected in terms of community stability (Charman 1997).

4.2 Coring Strategy

4.2.1 Field stratigraphy

For all three study sites (see Figure 4.1), information about field stratigraphy was available from the literature. At Cors Caron field stratigraphy has been carried out by Godwin and Mitchell (1938). The authors cored cross-sections through the central parts of the Southeast Bog and the West Bog and described the peat in reasonable detail. From Cors Fochno, figures from Moore (1963) as well as Williams and Parker (1939) cited in Slater (1972) give an overview of the peat deposits along two cross-sections. Raheenmore Bog (and also Clara Bog) has been the subject of a joint Dutch-Irish raised bog study and has been hydrologically investigated. Field stratigraphical data along two transects are presented in van der Schaaf (1999).

4.2.2 Core sampling

4.2.2.1 General procedure

Before starting with core sampling, coring points were chosen where, as aerial photographs (Figures 4.2, 4.3) indicated, the bog surface seemed uncut and undisturbed. More specific aspects of core point selection are explained within the following section (4.3.2.2 Coring strategy of the different sites). Core details are shown in Table 4.2 including the contemporary vegetation cover and core location (for core locations see also Figures 4.2-4.4). At the beginning of the research, the core locations were marked on a map of the study sites obtained by the CCW. Later in the project, a handheld GPS was available which was used to determine the position of the core locations at Cors Fochno and of three of the shorter Cores from Cors Caron. The top of each core was sampled in a monolith tin (either 40×10×10 or 50×10 ×10 cm). The remaining parts of all long cores were taken in two alternating bore holes with a 30×9 cm Russian peat sampler modified after Barber (1984) with a 5 cm overlap between the different core samples following standard practices Barker *et al.* (1994). To minimise damage to the plant cover at the core location, patches of living turf around the monolith where carefully removed using a bread knife. After digging out the monolith and finishing coring, remaining peat was filled back into the borehole and the turf patches were placed back at their original location. All core samples were carefully transferred into labelled plastic drain pipe sections of 30 cm length. Then they were wrapped in carbon-stable plastic bags, sealed with tape and labelled. In the laboratory the core samples were stored at a temperature of 4° C following standard procedures (Barber *et al.* 1994). During sub-sampling much nematode activity was noticed in some of the monoliths. These monoliths were frozen to avoid possible contamination due to bioturbation.

4.2.2.2 Coring strategy of the different sites

Core sampling commenced at Cors Caron, which consists of three hydrologically independent peat domes. It was decided to concentrate research on this area firstly because the West Bog of Cors Caron is the most intact of the three peat domes, and secondly because the work of Godwin and Conway (1939) concentrated on this area. The field stratigraphical information available from Godwin and Mitchell (1938) and chronological results from Morriss (2001) suggests similar general trends in the late Holocene development of all three bogs. For investigation of the general long-term successional trends in all three bogs, cores from the central parts of each peat dome, covering the last 2000 years were required. To cover this time period it was estimated that a core length of 100-150 cm length would be sufficient. From the West Bog TRWA 2000, TWC 2000, TWD 2000 and from the Northeast Bog TNA E 2000 where taken, whereas from the Southeast Bog TRE 98, which was worked on by Morriss (2001), was used for macrofossil analysis.

Although similarities seem to occur in long-term successional trends between the three bogs, the present vegetation of each varies significantly and these changes might be of rather recent origin. Godwin and Conway (1939) reported the presence of moderately fresh *S. imbricatum* peat immediately below the recent vegetation cover of all three bogs of Cors Caron and also at Cors Fochno. To track this most recent vegetation change of plant communities across different parts of the West bog, including hummock and hollow microtopography, multiple coring of representative areas was needed. For this purpose short cores of 50 cm length were considered to be adequate. Four short cores (TWE 2002, TWF 2002, TWG 2002 and TWH 2002) were taken from the plant communities described by Godwin and Conway (1939), which had not yet been covered by the previous long cores. Table 4.1 provides information on the present vegetation cover at the core locations and Table 4.2 gives the vegetation communities at the core locations in 1936/37 when Godwin and Conway conducted their vegetation survey.

Table 4.1: Overview of the cores, their length and location.

Core	Length [cm]	Vegetation cover of core location	Core location + Grid reference
TRWA 2000	165	*Sphagnum papillosum* lawn	Cors Caron West Bog, Ceredigion, Wales; SN 67800 BNG 63600
TWC 2000	165	*Molinia*-cover	Cors Caron West Bog, Ceredigion, Wales; SN 68550 BNG 63390
TWD 2000	165	*Sphagnum cuspidatum* lawn in *Calluna* dominated area	Cors Caron West Bog, Ceredigion, Wales; SN 68700 BNG 65550
TNE A 2000	90	*Sphagnum* sect. *Cuspidata* lawn	Cors Caron Northeast Bog, Ceredigion, Wales, SN 69600 BNG 63600
TRE 98	112	*Sphagnum papillosum* lawn	Cors Caron Southeast Bog, Ceredigion, Wales; SN 68300 BNG 62200
TWE 2002	50	*Sphagnum magellanicum* hummock	Cors Caron West Bog, Ceredigion, Wales; SN 68351 BNG 63235
TWF 2002	50	*Scirpus cespitosus* dominated area	Cors Caron West Bog, Ceredigion, Wales; SN68390 BNG 63560
TWG 2002	50	*Molinia caerulea* lawn	Cors Caron West Bog, Ceredigion, Wales; SN68124 BNG 63325
TWH 2002	50	Former pool, now covered with *Narthecium ossifragum* and *Sphagnum pulchrum*	Cors Caron West Bog, Ceredigion, Wales; SN 67920 BNG 63400
CFA 2000	165	*Sphagnum* sect. *Cuspidata* lawn	Cors Fochno, Ceredigion, Wales; SN 63484 BNG 91346
CFB 2000	120	*Sphagnum austinii* hummock	Cors Fochno, Ceredigion, Wales; SN 63610 BNG 91747
CFC 2001	115	*Sphagnum* sect. *Cuspidata* hollow	Cors Fochno, Ceredigion, Wales; SN 63647 BNG 91736
CFD 2001	90	*Myrica gale* hummock	Cors Fochno, Ceredigion, Wales; SN 63320 BNG 91311
RM 2001	165	*Sphagnum austinii* lawn	Raheenmore Bog, Offaly, Ireland; Irish Grid reference: N 435 320

Figure 4.1: Raised bogs under investigation.

Figure 4.2: Core locations at Cors Caron.

1 TRWA 2000
2 TWC 2000
3 TWD 2000
4 TNEA 2000
5 TRE 98

6 TWE 2002
7 TWF 2002
8 TWG 2002
9 TWH 2002

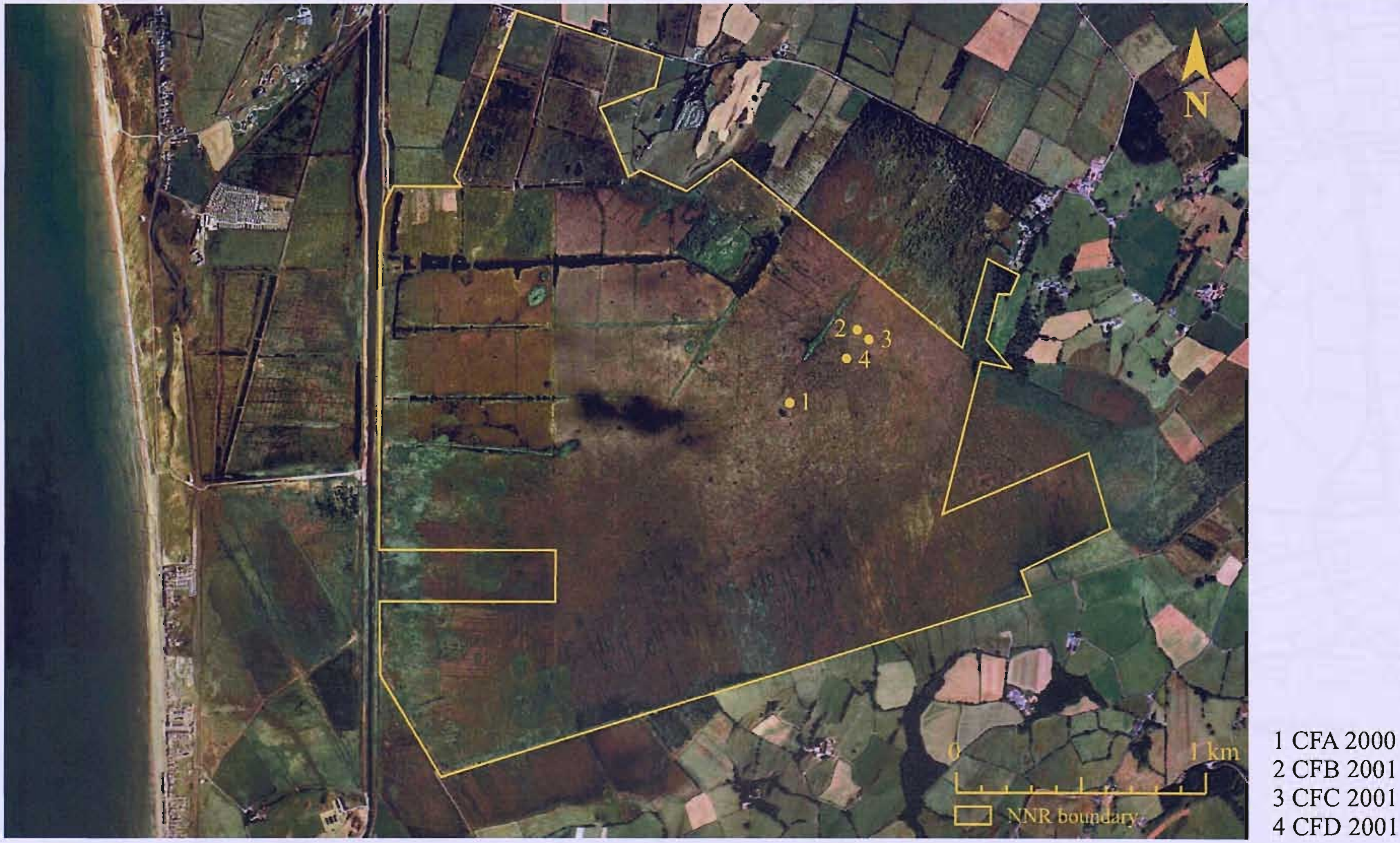

Figure 4.3: Core locations at Cors Fochno.

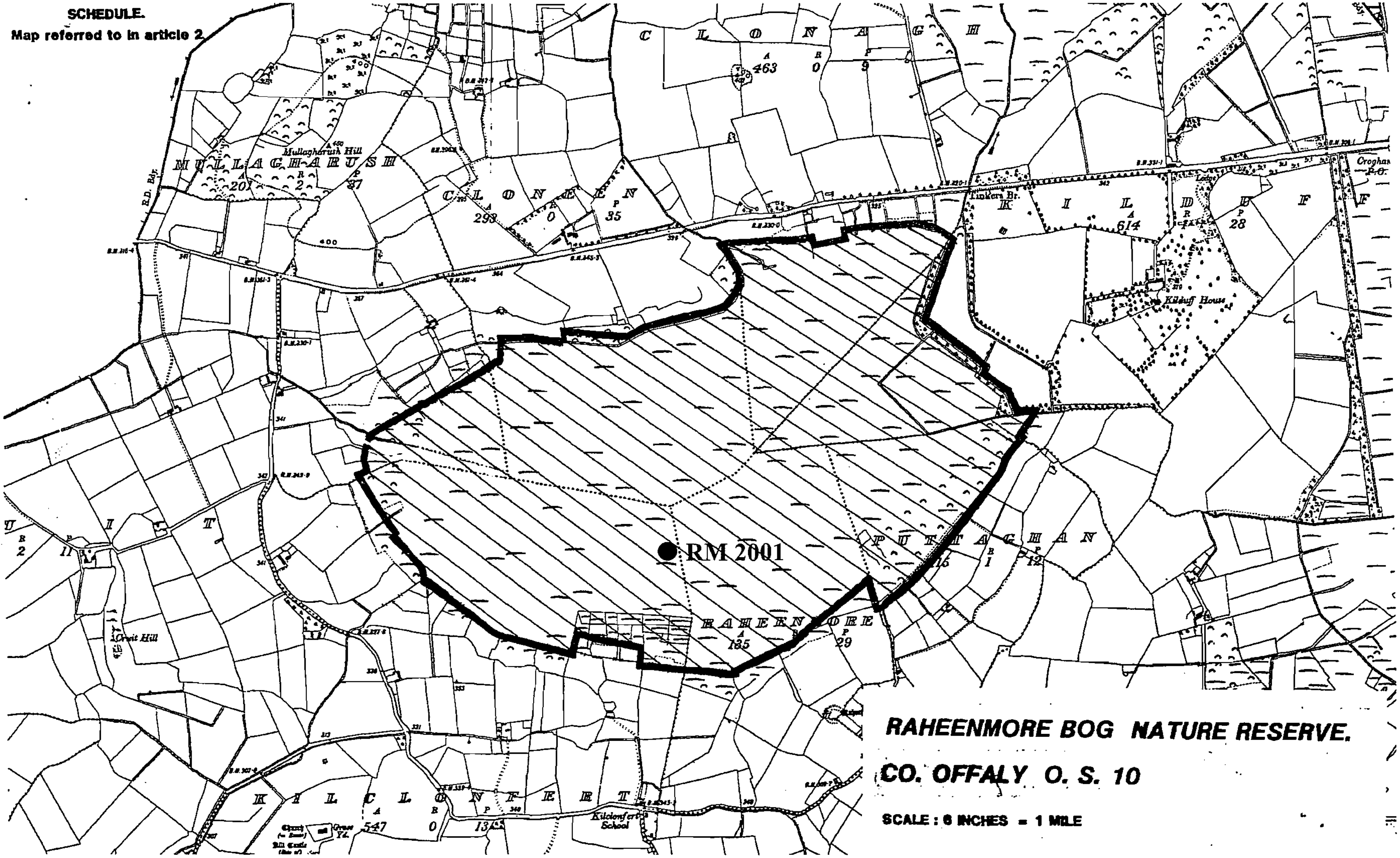

Figure 4.4: Core location at Raheenmore Bog.

Table 4.2: Vegetation communities at the core locations on the Cors Caron West Bog in 1936/37.

Core	Vegetation community in 1936/37
TRWA 2000	Regeneration Complex
TWC 2000	Sphagnetum
TWD 2000	Rand
TWE 2002	Scirpetum
TWF 2002	Sphagnetum-Scirpetum transition
TWG 2002	Molinietum
TWH 2002	Regeneration Complex

At Cors Fochno a multiple coring approach was also taken, covering different forms of micro-topography and vegetation cover. Micro-topographical features are much more pronounced on this site and the overall vegetation communities seem to be in a more natural state and less disturbed than at Cors Caron. However, core sampling at this site was somewhat more delicate. For example, taking the monolith from one of the *Sphagnum austinii* hummocks had to be done with great care. To prevent damage to the living *S. austinii* plants, the monolith was sampled slightly to the side of the hummock's top, where some plants had died off.

Field stratigraphical data of Raheenmore Bog (van der Schaaf, 1999) indicate several metres of fresh, slightly humified, *Sphagnum* peat over the upper strata of the raised peat dome. From this site a 150 cm core was taken from a *Sphagnum imbricatum* lawn, at the highest point of the mire expanse, following the advice of Irish site managers and van der Schaaf.

4.3 Laboratory Methods

4.3.1 Spheroidal carbonaceous particle (SCP) analysis

4.3.1.1 Introduction

As some changes in bog vegetation occurred only relatively recently, the ability to date younger peat layers was of importance. In recent decades analysis of spheroidal carbonaceous particles (SCP) has been developed as a tool to date peat and lake sediments of the last two centuries (Rose *et al.* 1995), which are too young for the establishment of a chronology based on radiocarbon dating. In this project SCP analysis has also been used to check the stratigraphic integrity of each core before starting macrofossil analysis. Spheroidal carbonaceous particles are formed and emitted due to combustion of fossil fuel (oil and coal) at high temperatures (Wik and Natkanski 1990, Rose *et al.* 1995). These particles are spherical and consist of elemental carbon (Goldberg 1985). From the fossil fuels used in the UK, only the combustion of coal and oil produces SCPs (Rose 1990). As the consumption of fossil fuels increased significantly with the onset of the Industrial Revolution in the nineteenth century, an analysis of the SCP record in lake sediments or peat allows us to date very recently formed sediments and peat. Advantages of this method are the low cost and it is relatively easy to carry out. To establish a chronology, diagrams of lake sediments, which have been reliably dated using radionuclids such as ^{210}Pb or varve counting, were established (Rose *et al.* 1995). They were used to relate undated diagrams to certain particle trends. However, the historical development of fossil fuel burning is variable in different regions. Thus for comparison with Cors Caron and Cors Fochno it is appropriate to choose pre-dated diagrams from Wales. For this purpose the diagrams published in Rose *et al.* (1995) were used. More recently SCP analyses have been carried out on peat profiles (Mauquoy 1997, Langdon 1999, Yang *et al.* 2001). As there is no significant movement of the SCPs in peat deposition, peat profiles can be used as an archive for reconstructing historical records of SCP deposition (Punning and Alliksaar 1997, Yang *et al.* 2001).

4.3.1.2 Laboratory preparation for SCP analysis

The preparation methods followed Rose (1990) and Rose *et al.* (1995) with modifications. Peat samples of 1 cm thickness were taken at 2 cm intervals within the top 40 to 42 cm of each core. The peat was dried overnight under an infrared lamp and 0.2 g of dried peat was transferred into a polyethylene tube. Then, 6 ml of concentrated HNO_3 were added to the sample and left overnight in a fume cupboard. After this, a further 6 ml of HNO_3 were added and heated for two hours in a water bath just below 100°C in the fume cupboard. Then the tubes were allowed to cool, centrifuged at 1500 rpm for 5 minutes and decanted. The residue was washed with distilled water three times and finally transferred into a small labelled glass vial of known weight. The vial was centrifuged and most of the remaining water carefully removed using a thin glass pipette. Next the vial, including the residue and some water, was weighed and the mass of residue and water calculated. The residue was than well mixed with the remaining water using the glass pipette and a drop from it weighed on a cover slip. Since the weight of the drop with the residue represents a 'x.' percentage of the entire content of the vial, also the SCP's present in the drop should roughly represent a 'x.' percentage of the entire SCP amount within the vial (and therefore within a gram of dry peat). With the known weight of both, the dr op (water + SCP's) and the vial content (water + SCP's), the amount of SCP's within the vial can be roughly estimatedfrom the amount of particles present in the drop on the cover slip. The water in the drop was then evaporated off and the cover slip mounted onto a microscope slide with Naphrax diatom mountant. The Particles on the entire slide were counted at ×400 magnification using a light microscope. and with their number and the known weight of the drop and the vial content the amount of total SCP's within the sample calculated. The concentration of the particles is shown in the the SCP diagrams in grams (g)/dry mass (chapter 5 section 5.1).

4.3.2 Radiocarbon dating

4.3.2.1 Introduction

Radiocarbon dating is used in this project to establish a chronology for deeper parts of the analysed peat profiles. This is of importance for studying mire development and changes in accumulation rates, which often need to be compared with other sites. This dating method is based on the fact, that the radioactive ^{14}C isotope, present in all living things, starts to decay after death. After 5570 $\pm$ 30 years (Mook 1986) half of the isotope has decayed. By measuring the remaining activity of a sample the proportion of its ^{14}C content can be calculated and its age estimated. The ^{14}C activity of the sample can be measured using different methods such as gas proportional counting or liquid scintillation counting which separate the ^{14}C atoms by their difference in radioactivity. A third method, Accelerator Mass Spectrometry (AMS) separates the atoms by their difference in mass. Its big advantage is that it can measure very small samples of only 1 mg of carbon Pilcher (1991), (Hedges 1995) within a very short time. Additionally it provides a greater reliability in radiocarbon dates (Hedges 1995) and was therefore chosen for this project. However, using such small amount of material for AMS dating, even minute amounts of contamination by modern carbon could severely effect the results (Shore *et al.* 1995, Wohlfahrt *et al.* 1998). AMS dating thus requires a careful choice of sampling material, a clean sampling procedure and the avoidance of all possible errors, which may potentially lead to contamination and therefore wrong ^{14}C dates.

The choice of the sampling material is of great importance. Particularly, if short-term variations are studied in peat-accumulation rates over 1000 years or less and ages need to be determined at various points through the peat profile in great accuracy (Nilsson *et al.* 2001). All sources of contamination should be excluded. One important issue, addressed by Wohlfarth *et al.* (1998) and Nilsson *et al.* (2001), is how small samples are handled before treatment in the radiocarbon laboratories. Nilsson *et al.* (2001) report that alkali-treated peat samples always resulted in greater ages than corresponding untreated peat samples. Wohlfarth *et al.* (1998) suggest that long storage time and/or low carbon content seem to result in radiocarbon ages that are too young. Their results show that the long-term storage (> 6 months) of wet macrofossil samples appears to have a significant effect on the radiocarbon age obtained, even if the samples are kept under cool and dark conditions. Since the sampling for the dating material is usually not carried out under sterile conditions, samples can be easily contaminated with microorganisms which may include the assimilation of recent CO_2, which can alter the result of the ^{14}C dating. Another factor which seems to have an influence on the obtained dates is the carbon content of the ^{14}C sample. Wohlfarth *et al.* (1998) found, that samples with low carbon content generally show larger age deviations, whereas samples with more than 1.4 mg carbon gave expected ages. Thus, the authors recommend that samples with an organic carbon content above 1.4 mg should be measured.

Another serious source of contamination arises from roots, present in sampling material (Olsson 1986, Kilian *et al.* 1995, Nilsson *et al.* 2001). Roots may grow down to half a metre as in case of *Eriophorum* or *Scirpus* (Boggie *et al.* 1958) or even deeper down to two metres (Saarinen 1996). The roots that penetrate the peat are considerably younger than the peat itself and reduce its apparent age, if present in the sample. The roots also transfer current atmospheric carbon to deeper peat layers. Ninety percent of the photosynthetically fixed CO_2 is allocated to roots (Wallen 1986). By contrast, Oldfield *et al.* (1997) point out that the dominant proportion of the root biomass is found at a shallow depth, giving a systematically younger age, which deviates only slightly from the ^{14}C moss age. However, Kilian *et al.* (1995) found that *Sphagnum* samples, containing ericaceous rootlets, dated 100-150 years too old, due to a reservoir effect. Regarding the problems arising from root contamination, several authors propose the use of well defined plant remains instead of bulk samples such as pure *Sphagnum* remains and other terrestrial mosses as well as above-ground plant remains for ^{14}C dating (Ohlson 1986, Kilian *et al.* 1995, Nilsson *et al.* 2001).

4.3.2.2 Sampling procedure

Before starting the sampling the whole working area was thoroughly cleaned to avoid any possible contamination. All tools were washed with distilled water and the working space around the binocular microscope was covered with aluminium foil. For sampling, *Sphagnum*-rich peat layers were chosen following the recommendation of Ohlson (1986), Kilian *et al.* (1995) and Nilsson *et al.* (2001). Before sampling from the core the surface of the peat was removed to avoid contamination. Peat samples were transferred into a 500 µm mesh plastic sieve. To disaggregate the peat samples they were washed through using distilled water, until all the unidentifiable organic matter (UOM) was removed. Ericaceous and other rootlets could also be removed by washing the *Sphagnum* pieces in the sieve with a water jet. The remaining clean material was then transferred into a glass petri dish, and suitable plant remains transferred into a little glass bowl. Those included, single *Sphagnum* leaves, *Sphagnum* stems and branches as well as Ericaceae wood and *Andromeda polifolia* leaves (the exact content of each sample is presented in Table 4.3). The *Sphagnum* pieces were then again cleaned of remaining rootlets. The gathered sample material was transferred into pre-labelled vials of known weight and surplus water removed with a thin glass pipette. Reweighing ensured that the sample contained at least 200 -500 mg of material. The vials were then topped up with distilled water, sealed, carefully wrapped and sent to the radiocarbon laboratory in Kilbride, Scotland, where the target preparations East were carried out. The AMS dating procedure was carried out in a radiocarbon laboratory in Arizona, USA. The obtained results (laboratory codes start with "AA") are shown below in Table 4.5, together with the radiocarbon results from the project of Morriss (2001), which start with the laboratory code "CAM".

Table 4.3: Overview of site code, depth, laboratory code, sample material and the results of ^{14}C dating.

Site Code	Depth (cm)	Laboratory code	Sample material	^{14}C age
TRWA 2000	23.5 – 24.5	AA-54195	*Sphagnum* section *Sphagnum* , *Eriophorum vaginatum* spindle, 1 *Andromeda polifolia* leaf, *Sphagnum* section *Cuspidata* stems, *Erica tetralix* leaves, *Calluna vulgaris* shoots	369±35
TRWA 2000	30	CAM-66652	*Sphagnum*	900±40
TRWA 2000	54	CAM-66651	*Sphagnum*	1060±40
TRWA 2000	77.5 – 78. 5	AA-54196	*Sphagnum* section *Sphagnum* & *Sphagnum* section *Cuspidata* stems and leaves	1506±36
TRWA 2000	97	CAM-66650	*Sphagnum*	1540±40
TRWA 2000	115	CAM-66649	*Sphagnum, Calluna vulgaris*	1700±40
TRWA 2000	133.5 – 134.5	AA-54197	*Sphagnum* section *Sphagnum* & *Sphagnum* section *Cuspidata* stems and leaves	1630±39
TRWA 2000	146	CAM-66648	*Sphagnum*	1910±40
TWC 2000	89.5 – 90.5	AA-54198	*Sphagnum* section *Sphagnum* stems and leaves, 1 *Eriophorum vaginatum* spindle	2205±41
TWC 2000	111.5 – 112.5	AA-54199	*Sphagnum* section *Sphagnum* stems and leaves	2321±36
TWD 2000	45.5 – 46.5	AA-54200	*Sphagnum* section *Sphagnum* stems and leaves	2187±37
TWD 2000	71.5 – 72.5	AA-54201	*Sphagnum* section *Sphagnum* leaves and stems	2044±37
TNEA 2000	25.5 – 26.5	AA-54202	*Sphagnum* section *Sphagnum* stems and leaves, *Erica tetralix* leaves, 1 *Rhynchospora alba* seed	950±34
TNEA 2000	51.5 – 52.5	AA-54203	*Sphagnum* section *Sphagnum* leaves, *Erica tetralix* leaf	1220±34
TNEA 2000	61.5 – 62.5	AA-54204	*Sphagnum* section *Sphagnum* leaves	1396±35
TRE'98	20	CAMS-64375	*Sphagnum, Ericaceae, Eriophorum vaginatum* spindles	820±40

TRE'98	37	CAMS-60857	*Eriophorum vaginatum* spindles	1610±40
TRE'98	54	CAMS-60859	*Sphagnum,* Ericaceae	1820±40
TRE'98	61.5 – 62.5	AA-54205	*Sphagnum* section *Sphagnum*	2044±36
TRE'98	71	CAMS-60858	*Sphagnum, Polytrichum,* Ericaceae,	2090±40
TRE'98	111.5 – 112.5	AA-54206	*Sphagnum* section *Sphagnum*	2258±37
CFA 2000	37.5 – 38.5	AA-54207	*Sphagnum* section *Sphagnum* leaves and stems, 3 *Rhynchospora alba* seeds	508±33
CFA 2000	55.5 – 56.5	AA-54208	*Sphagnum* section *Sphagnum* leaves and stems	930±34
CFA 2000	73.5 – 74.5	AA-54209	*Sphagnum* section *Sphagnum*	1194±36
CFA 2000	93.5 – 94.5	AA-54210	*Sphagnum* section *Sphagnum*	1382±37
CFA 2000	147.5 – 148.5	AA-54211	*Sphagnum* section *Sphagnum*	1725±37
CFB 2001	31.5 – 32.5	AA-54212	*Myrica gale* leaves, *Erica tetralix* petal, wood and leaves, *Calluna vulgaris* petal and leaves	modern
CFB 2001	49.5 – 50.5	AA-54213	*Sphagnum* section *Sphagnum* leaves and stems, 1 *Andromeda* polifolia seed, 1 *Myrica gale* leaf	149±34
CFB 2001	71.5 – 72.5	AA-54214	*Sphagnum* section *Sphagnum* leaves and stems	96±35
CFC 2001	31.5 – 32.5	AA-54884	*Sphagnum* section *Sphagnum* leaves and stems, *Erica tetralix* leaves	90±49
CFC 2001	57.5 – 58.5	AA-54885	*Sphagnum* section *Sphagnum* leaves and stems	949±46
CFC 2001	95.5 – 96.5	AA-54886	*Sphagnum* section *Sphagnum* leaves and stems	1510±49
CFC 2001	111.5 – 112.5	AA-54887	*Sphagnum* section *Sphagnum* leaves and stems; *Eriophorum angustifolium* leaf tips; *Calluna vulgaris* shoot tips; *Rhynchospora alba* seeds; *Scirpus cespitosus* seed	1507±36
CFD 2001	23.5 – 24.5	AA-54888	*Sphagnum* section *Sphagnum* leaves, stems and spore capsule lid	159±38
CFD 2001	29.5 – 30.5	AA-54889	*Sphagnum* section *Sphagnum* leaves, stems and spore capsule lid	253±34
CFD 2001	65.5 – 66.5	AA-54890	*Sphagnum* section *Sphagnum* leaves and stems; *Myrica gale* leaves; *Hypnum cupressiforme* leaves	650±36
CFD 2001	87.5 – 88.5	AA-54891	*Sphagnum* section *Sphagnum* leaves and stems; *Rhynchospora alba* seeds; *Erica tetralix* and *Calluna vulgaris* leaves and shoot tips	1035±36
RM 2001	35.5 – 36.5	AA-54879	*Sphagnum* section *Sphagnum* and section *Acutifolia* leaves and stems; *Rhynchospora alba* leaves; *Erica tetralix* leaves and wood	modern
RM 2001	55.5 – 56.5	AA-54880	*Sphagnum* section *Sphagnum* and section *Acutifolia* leaves and stems	597±66
RM 2001	79.5 – 80.5	AA-54881	*Sphagnum* section *Cuspidata* leaves and stems; *Erica tetralix* leaves, *Rhynchospora alba* leaves; *Eriophorum angustifolium* leaves	134±56
RM 2001	111.5 –112.5	AA-54882	*Sphagnum* section *Acutifolia* leaves and stems	1360±49
RM 2001	155.5 – 156.5	AA-54883	*Sphagnum* section *Acutifolia* leaves and stems	1566±49

4.3.2.3 Calibration

After the measuring of the sample ^{14}C activity, the radiocarbon laboratory reports the estimated ^{14}C age in years BP. Since there are variations in ^{14}C production through time, considerable differences arise between calendar ages and radiocarbon ages (Bartlein *et al.* 1995), which are illustrated in Figure 4.6.5. As Bartlein *et al.* (1995) point out, these differences between calendar ages and radiocarbon ages may have significant effects on the calculation of rates of change and the detection of time-transgressive features as well as synchronous events such as extinction. Therefore, the radiocarbon age needs to be converted to a distribution of calendric dates by calibration with samples of known age (Stuiver and Reimer 1993, Taylor *et al.* 1996). This distribution of calendric dates can be interpreted as a discrete probability distribution function describing the probability that the sample was derived from a given calendric date (Stuiver and Reimer 1989). Figure 4.6 shows as an example the calendric calibration of ^{14}C sample AA-54196 (TRWA 2000/78 cm depth).

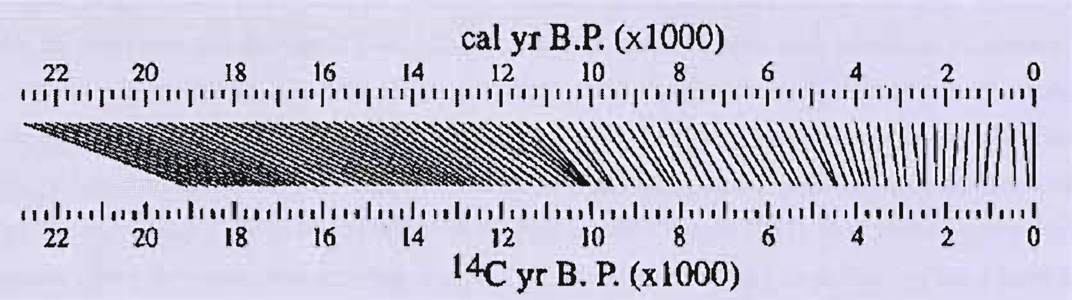

Figure 4.5: Illustration of the differences between calendar ages and radiocarbon ages (Bartlein *et al.* 1995).

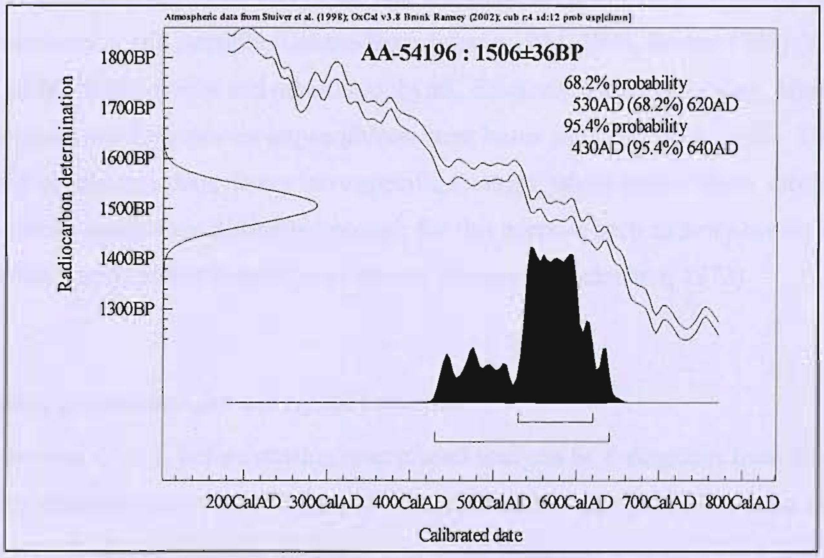

Figure 4.6: Example of calendric calibration of the radiocarbon sample AA-54196 (TRWA 2000/78 cm depth).

The simplest method of calibration is the Intercept Method (Bowman and Leese 1995). However, Bowman and Leese criticised "*that calibrated dates can be faithfully represented only by probability distributions that fully take account of both the error term on the radiocarbon result and the effect of the wiggles in the* *calibration curve*" Bowman and Leese (1995, p. 104). The authors conclude that the Intercept Method fails to do that and suggest instead the use of computer programs, which use the Bayesian Methodology, which was also recommended by Biasi and Weldon (1994). Despite of its shortcomings, the Intercept Method is still widely used as shown by Telford *et al.* (2004), who demonstrate that Intercept based methods are sensitive to small changes in the mean of the radiocarbon date. As suggested by other authors before, Telford *et al.* (2004) emphasise that computer programs such as OxCal (Bronk Ramsey 1995) employing the Bayesian Method should be used for calibration. Following this recommendations the calibration of all radiocarbon results of this project, including those available from the project of Morriss (2001), was performed using the calibration programme OxCal (Bronk Ramsey 1995) and the 2σ range.

4.3.3 Plant macrofossil analysis

4.3.3.1 Introduction

Macrofossil analysis has a key role in the palaeoecological approach of this project. The term 'macrofossil' includes all vegetative and propagule parts of plants but also animal remains such as insects, Cladocera, Acari and other invertebrates. The bulk of raised bog peat consists of subfossil *Sphagnum* remains. Sphagna grow from the tip, whereas the lower parts of their shoots die off and become preserved in the acidic, anoxic, waterlogged environment of the catotelm. In this way the peat layers superimpose one after another while carrying the water table close to the surface with the peat growth (Barber 1982). Bog plants become buried at the place where they were once growing (Barber 1993) and therefore the composition of the macrofossil remains still reflects the composition of the former vegetation communities. The processes leading to peat formation, the limitations of the method as well as and interpretation of macrofossil assemblages are discussed in detail in chapter 2 (section 2.3). Despite some limitations, macrofossil analysis allows a relatively detailed reconstruction of the past environment and its conditions (Grosse-Brauckmann 1986). The tissue structures of many sub-fossils remain preserved, and despite mass loss, their identification down to species or subgenus level is still possible (Grosse-Brauckmann 1974, 1990, Barber 1993). The identifiable remains include leaves of *Sphagnum* and other bryophytes, Ericaceae leaves and twigs, *Myrica gale* leaves, *Eriophorum vaginatum* and *Eriophorum angustifolium* stem bases and all kinds of seeds. The rootlets of Ericaceae and most monocotyledons do not have specific features, which would allow species identification. Only a few Cyperaceae rootlets are distinctive enough for this purpose such as *Eriophorum vaginatum*, *E. angustifolium*, *Scheuchzeria palustris* and *Carex limosa* (Grosse-Brauckmann, 1972).

4.3.3.2 Laboratory preparation for macrofossil analysis

As mentioned in section 4.4.1.1, before starting macrofossil analysis SCP diagrams from all cores were made to ensure that the uppermost peat stratigraphy was undisturbed. The peat cores were sampled for macrofossils at intervals of 4 cm (sample thickness 1 cm). An exception is core TRWA 2000, where sampling has been carried out at an interval of 2 cm. From the cores peat samples of approximately 4 cm^3 were taken using surgical scalpels and 0.5 cm wide spatulas. To avoid contamination the surface of each core was carefully scraped off before sampling, and all tools were thoroughly cleaned with tap water after each sampling. Fresh *Sphagnum* peat and roots were first snipped through before removal from the core. The peat was then transferred into a set of sieves consisting of a 500 µm mesh sieve and below this a 125 µm mesh sieve and gently washed through using five litres of water.

The fraction smaller than 500 µm remaining in the second sieve was transferred into a transparent plastic trough of 17.5 × 11.5 cm size and some water added. On the microscope the plastic trough was underlain with graph paper and all small items such as seeds, fungal fruit bodies, mites and other zoological remains were counted using a Nikon SMZ-U binocular microscope and a handheld counting machine. Then both fractions of the sample were re-united, mixed in a plastic vessel and the percentage of all macrofossils estimated using the Quadrat and Leaf count method (Barber *et al.* 1994b). The technique was evolved in order to provide a semi-quantitative picture of macrofossil samples within a reasonable time. A square grid graticule of 10×10 (covering 1 cm^2 at ×10) was used to determine the abundance of vegetative plant remains. This was carried out fifteen times for each sample. After this, 100 *Sphagnum* leaves were picked randomly and mounted onto a microscopic slide with Aquamount and examined in order to identify the *Sphagnum* leaves down to species level, where possible. On finishing the analysis these slides were kept in an archive and the peat samples were stored in plastic tubes in a 25% ethanol solution. After the analysis macrofossil diagrams were created using the programmes TILIA version 1.12 and TILIA Graph, version 1.18 (Grimm 1991). In the macrofossil diagrams the bulk of macrofossils are expressed as volume percentage. Small items such as seeds, spore capsules or fungal fruit bodies occur in varying abundance but never form high volume percentages. To track this potentially important variation they are presented in numbers. Table 4.4 gives an overview of the kind of presentation of macrofossils in the diagrams.

Table 4.4: Representation of macrofossil types in the macrofossil diagrams.

Remains	**Shown in diagrams as**
UOM	Percentage
All rootlets	Percentage
Erica and *Calluna* leaves and shoots	Percentage
All seeds	Numbers
Monocot rootlets	Percentage
Vegetative plant tissues	Percentage
Eriophorum vaginatum spindles	Numbers
Bryophytes (except *Kurzia pauciflora*)	Percentage
Bryophytes spore capsules and lids	Numbers
Sphagnum stem leaves	Numbers
Zoological remains	Numbers
Fungal fruit bodies	Numbers
Myrica leaf fragments, *Andromeda* and *Vaccinium oxycoccus* leaves	Numbers
Kurzia pauciflora fragments, charred material and quartz	Presence
Cladocera shells	Presence

4.3.3.3 Identification of vegetative plant remains

Vegetative plant remains originating from raised bogs consist mainly of *Sphagnum* mosses, Ericaceae and Monocotyledon roots along with leaves and shoot tips from dwarf shrubs. The number of determinable plant species found in peat, according to Grosse-Brauckmann and Streitz (1992), is more than twenty Pteridophyta and Spermatophyta and about sixty Bryophyta. The belowground parts of many vascular plants are often difficult to identify down to species level. However, some species such as *Eriophorum vaginatum* or *Scirpus caespitosus* possess very distinctive epidermal cell patterns within the basal leaves, which allow their reliable determination. For Bryophytes the situation is quite different. *Sphagnum* remains are often extremely well preserved and frequently one encounters the whole plant, still with the branches and leaves attached. This circumstance enables the analyst to determine *Sphagnum* down to section or species level. With increased awareness of *S. austinii* and *S. austinii* as separate species (Thingsgaard 2002), remains of the *S. imbricatum* complex, were determined down to species level. This includes the core from Raheenmore bog (RM 2001), TRE'98, TWF 2002, TWH 2002 from Cors Caron and CFB 2001, CFC 2001 along with CFD 2001 from Cors Fochno. For determination the publication of Hill (1988) was used. Within core RM 2001 the preservation of the *Sphagnum* was extremely good, enabling the counting of spreading and pending branches. Together with the *Sphagnum* leaf count several parts of the stem were mounted onto the slide in order to check the stem cortex for comb fibrils. It is assumed that if comb fibrils are present, they are preserved in the subfossil stage since those of *S. papillosum* were clearly recognisable within the subfossil material.

The remains of other mosses are also often very distinctive, for example the leaves of *Racomitrium lanuginosum* or the leaf bases of *Polytrichum alpestre* (Grosse-Brauckmann 1974). In contrast to the latter, only very few Hepaticae are found in peats, such as *Kurzia pauciflora* or charred remnants of *Odontoshisma sphagni*. For identification of vegetative plant remnants and Bryophytes, Grosse-Brauckmann (1972, 1974) and Katz and Katz (1977) were used in combination with the reference collection of the Palaeoecology Laboratory and also a personal reference collection. Further literature used for the identification of Bryophytes were the drawings in Landwehr and Barkman (1978), along with Daniels and Eddy (1990) and Fram and Frey (1992).

4.3.3.4 Identification of fruits and seeds

Unlike many vegetative plant remains, seeds and fruits are much more often identifiable down to species level, but it needs to be considered that subfossil fruits and seeds might have undergone change in form and size, compared with contemporary material, due to fossilising effects. Reference collections should therefore also include 'artificially' aged and fossil material, which have been reliably determined (Lang 1994). For identification Grosse-Brauckmann and Streitz (1992), Bertsch (1941) and Beijerinck (1976) were used, together with reference samples.

Some seeds, especially if they are rare and very small, do prove difficult to identify. Examples are, for instance, the subfossil seeds of *Drosera intermedia* and *D. rotundifolia*. *Drosera* seeds are an appropriate example to demonstrate how seeds change during fossilisation. Another difficulty is that subfossil *D.*

rotundifolia seeds mostly lose their seed-coat (testa). They then closely resemble seeds of *Juncus* (see Figure 4.7).

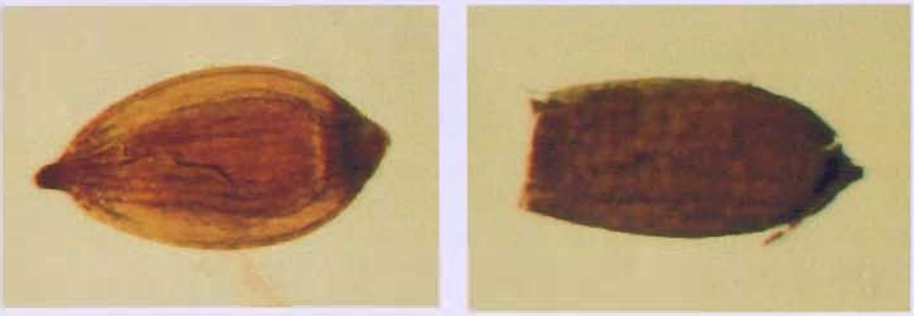

Figure 4.7: Seeds of Juncus (left) and *Drosera rotundifolia* (right).

4.3.3.5 Identification of zoological remains

Amid the plant macrofossils occur many zoological remains. They never reach high volume percentages and might be less important in the reconstruction of bog development. However, some could be useful as indicator species, such as remains of Cladocera or Chironomidae. Another group which is most plentiful, occurring in almost every sample, are Acari (Oribatida). Although the composition of species seems to vary between different bog habitats there is very little published material dealing with the ecology of Oribatida in bog habitats. However, the publication from Markkula (1986), who found that the Oribatida communities of hummocks and hollows in a virgin bog were markedly different, underpins that Oribatida are potentially useful as indicator species in palaeoecological studies. The fauna of disturbed raised bog habitats have a much greater diversity. For example, in peat cuttings Hydracari occur in high numbers whereas they are very rare in undisturbed bog pools. As soon as *S. cuspidatum* spreads in the cuttings the zoological diversity shrinks in favour of the raised bog specific fauna (Burmeister 1990). The website http://www.s2you.com/edis/edis_left.php?projectID=obif&dbid=vim, and van Geel (1978) and Solhøy (2001) were used for identification. The Oribatida found in the peat are shown in Figure 4.8.

Parachipteria punctata, subfossil

Ceratoppia sexpilosa,subfossil

Hypochtonius rufulus, subfossil

Predatory mite, recent

Nanhermania, recent

Platynothrus peltifer, subfossil

Limnozetes, subfossil

Figure 4.8: Oribatida found in the peat cores from the investigated sites.

4.3.3.6 Identification of fungal remains

The diversity of macrofossil fungal remains, such as fruit bodies, found in raised bogs is rather small. Probably the most distinctive are the fruit bodies of *Cenococcum* sp. which provide information about aeration of the uppermost peat stratum and therefore also about past water levels. Another fungi, which may be encountered, are the fruit bodies of the so-called Type 8 F (van Geel 1978), which includes the genus *Stomiopeltis*. These are mainly associated with dead litter of Ericaceae and *Sphagnum*.

4.4 Vegetation survey on the West Bog of Cors Caron

4.4.1 Introduction

Re-mapping of vegetation provides a method of tracking short-term vegetation changes over several decades, but there are very few early 20th century surveys of peatland vegetation. The work of Godwin and Conway (1939) is among the first detailed surveys on peatlands and offers a unique chance to follow the recent vegetation development of Cors Caron (West Bog) over the last sixty-five years. In the seasons of 1936/37 the authors, accompanied with a team of assistants, completed a comprehensive vegetation survey of the West Bog of Cors Caron. The results are published in Godwin and Conway (1939). Based on information from this publication the same area was partly re-mapped in the seasons of 2001/02 to investigate potential changes in the vegetation. It was intended that the vegetation survey should also complement the palaeoecological data for the following reasons. At first, the re-survey covers a much bigger area than that represented by single cores taken for macrofossil analysis. Second, in contrast to macrofossil assemblages, which are subject to selective preservation, the vegetation records potentially contain[1] the full species assemblage which is present at the time of sampling.

4.4.2 Summary of the 1936/37 raised bog vegetation survey by Godwin and Conway

The West Bog vegetation survey was carried out during the summers of 1936 and 1937. The authors, accompanied by a team of undergraduate and postgraduate assistants, established a baseline measuring 1900 m, parallel to the long axis of the West Bog along its eastern margin. Every 100 m along the baseline transects were laid at right angles to the baseline and subdivided into 100 m segments. The transects were labelled with a capital letter, so creating a grid of 100×100 m (Figure 4.9). Along the transects observers collected vegetation data and noted changes in vegetation confined to a 20 m wide belt central on each transect. The observers were instructed to walk along the transect until the character of the vegetation changed from the spot where they started. Next they had to walk back to the point of the transition between the two vegetation types. The observers had to walk over the previous section and record a range of vegetation attributes (Table 4.5) using standardised cards. This approach was used to record the vegetation for each homogenous section of the vegetation along the transect. The results of these quantitative pseudo-estimations were reproduced as diagrams and distribution maps in Godwin and Conway (1939) (see Figures 4.10 and 4.11) and analyses of these data resulted in a map showing the different vegetation communities of the West Bog (Figure 4.10). The characteristics of each of these communities were described in detail in separate sections (Godwin and Conway 1939, pp. 321) and are summarised in chapter 6, section 6.1.2. Tables 4.5 and 4.6 give an outline of the information content of Godwin and Conway's diagrams and highlights the information of use to the re-survey completed for this survey in 2001/02.

In addition to the transects thirteen quadrats were recorded, to help document the different communities of the West Bog (Figure 4.10). These quadrats are printed as figures in Godwin and Conway (1939), with symbols indicating the coverage of each species occurring in quadrats 1, 2, 4, 8 and 9. For quadrats 3, 5, 6

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[1] In the 1936/37survey of Godwin and Conway not all present species were included in the survey of the transect and in the 2001/02 re-survey very small liverworts were not recorded.

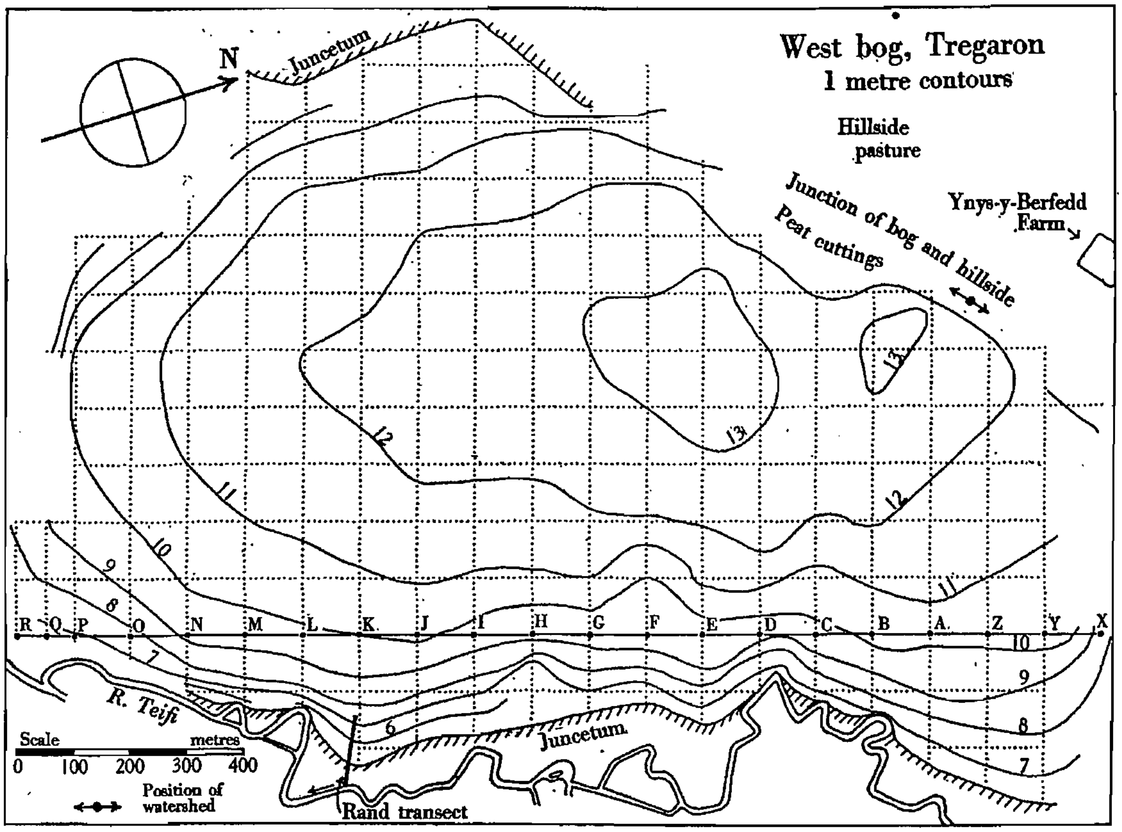


Figure 4.9: Map of the West Bog of Cors Caron showing the grid established by Godwin and Conway (1939).

Table 4.5: List of features that were recorded along the West Bog transects, established by Godwin and Conway (1939).

a) Estimation of the percentage of homogenous vegetation units covered by following components (these had to add up to 100%):
- Pools > 30 cm wide - Pools < 30 cm wide - living *Sphagnum* carpet (excluding *S. cuspidatum* and *S. tenellum*) - *Scirpus* and *Eriophorum vaginatum* - *Cladonia arbuscula* (ex. *sylvatica*)
b) Division of the area covered by pools into percentages of the major pool types
- Pools filled with *Sphagnum* spp. - Pools partly filled with *Sphagnum* spp. - Pools carrying sparse growth of *Rhynchospora alba* - Pools carrying dense growth of *Rhynchospora alba* - Pools bare or with *Zygogonium ericetorum* only
c) Estimation of frequencies of phanerogams on a scale 0-5 and of cryptogams on a scale of 0-3 and various other changes such as slope, roughness of ground, presence of drainage channels

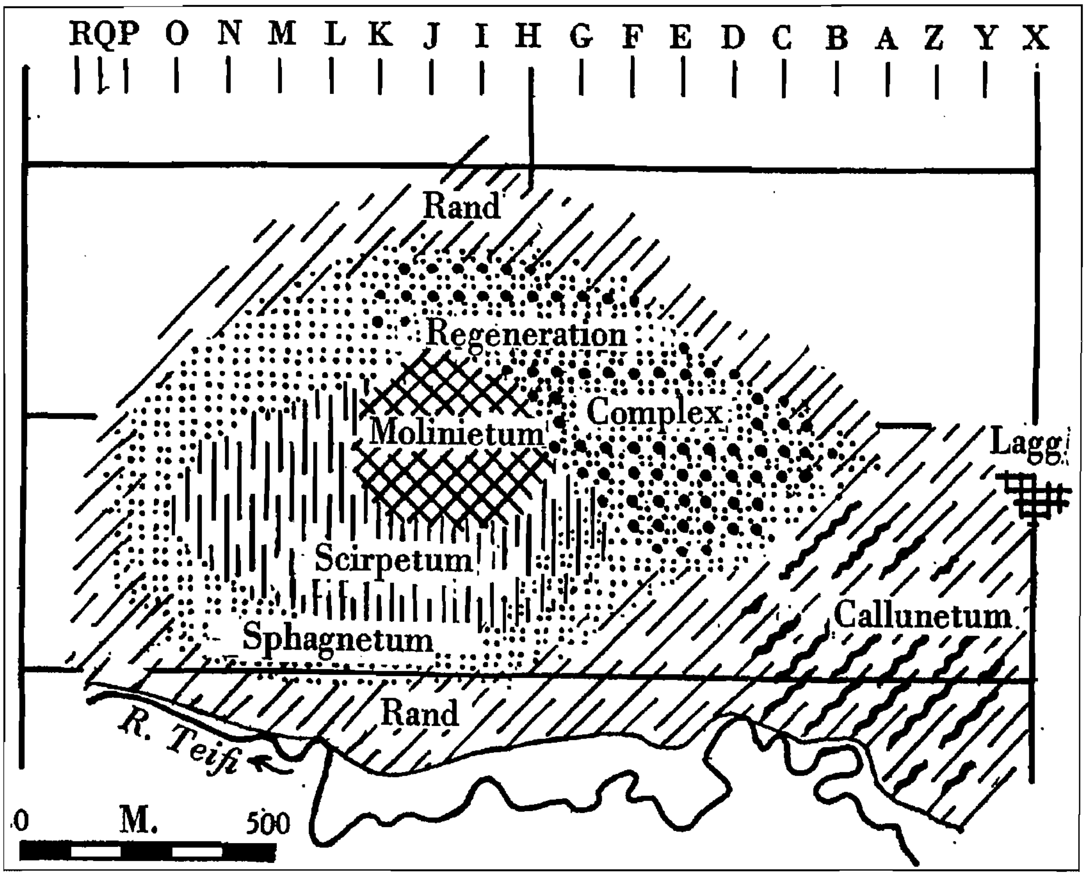


Figure 4.10: Vegetation map of the West Bog published by Godwin and Conway (1939).

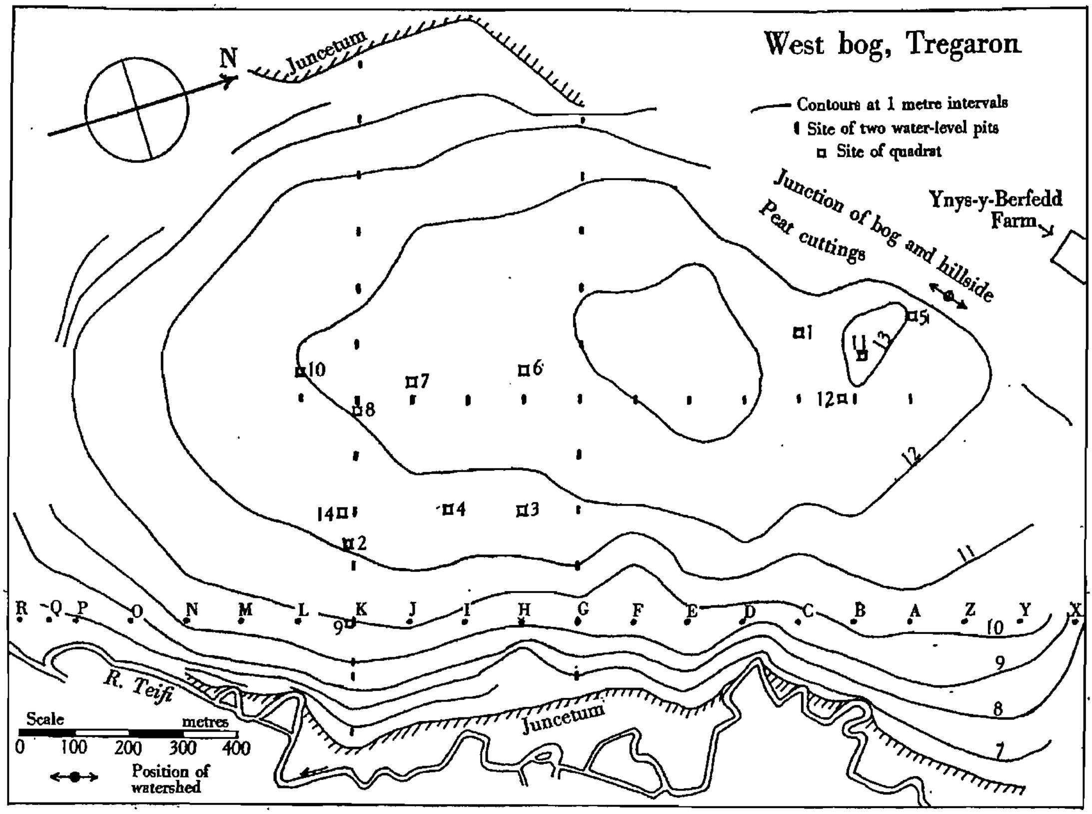


Figure 4.11: Map of the West Bog of Cors Caron showing the location of the quadrats, sampled by Godwin and Conway in 1936/37. (Source: Godwin and Conway 1939, p. 353)

4.4.3 Field work preparation

When work on the literature survey for this project started, it became clear that the publication by Godwin and Conway (1939) represented only a partial a collection and summary of the original field data 1936/37. Accordingly, Cambridge University was visited to search Godwin's archive for missing vegetation data which remained unpublished. This includes the vegetation data, for quadrats 10, 11, 12 and 14 and some of the recorded features along the transects such as, for example, cover data for *Scirpus cespitosus* and *Eriophorum vaginatum* (Table 4.4 a) as well as cover values for other vascular plants and bryophytes (Table 4.4 c). Unfortunately, the search for the missing data was unsuccessful, only stratigraphical notes for the Cors Caron Southeast Bog were found. Therefore the comparison had to be made with the information presented in the paper published by Godwin and Conway (1939). Of the thirteen original quadrats, no information was published for quadrats 10, 11, 12 and 14, thus excluding them from the re-survey. For some reason quadrat 13 was not mentioned in the publication (Godwin and Conway 1939).

4.4.4 Re-establishment of the transects and quadrats

To re-establish the base line and the 100×100 m grid, Godwin and Conway's (1939) original grid map, (Figure 4.9) was used. The figure was scanned into a graphic program and overlain with the British National Grid using the meander loops of the River Teifi to achieve correct alignment. The thirteen quadrats were also drawn onto the new map using a map from Godwin and Conway (1939), p. 353, which is reproduced here in Figure 4.10. From the reprinted version of the base map (Figure 4.10) the national grid reference of the points on the baseline could be calculated and relocated. The fieldwork for the re-survey was carried out in the summers of 2001 and 2002. For the relocation a Differential Global Positioning System (DGPS) OmniSTAR was used, which achieves sub-metre accuracy. Before starting relocation with this backpack DGPS a correction procedure had to be followed in order to avoid introducing errors into the position solution. Then the accuracy of the Ordnance Survey (reference of the map) map was checked using the DGPS at several benchmarks around Cors Caron.

All relocated points of the baseline were marked with bamboo canes which where labelled with a flag for better visibility. The canes were then more precisely positioned on a straight line and 100 m apart from each other using the Geodimeter 422, which was set up at point I (see Figure 4.9). After the re-establishment of the baseline the transects were set up, also using the Geodimeter 422 from point M to F at 90° the baseline. They were marked every 50 m with a bamboo cane attached with labelled flag material.

The positions of the central points of the thirteen 5×5 m quadrats were also calculated from the re-print of the 100×100 m grid (Figure 4.8) and re-located using the Differential GPS. The centre points of the quadrats were marked with a bamboo cane and to distinguish the quadrat canes from those of the offsets they were marked with green plastic flag material.

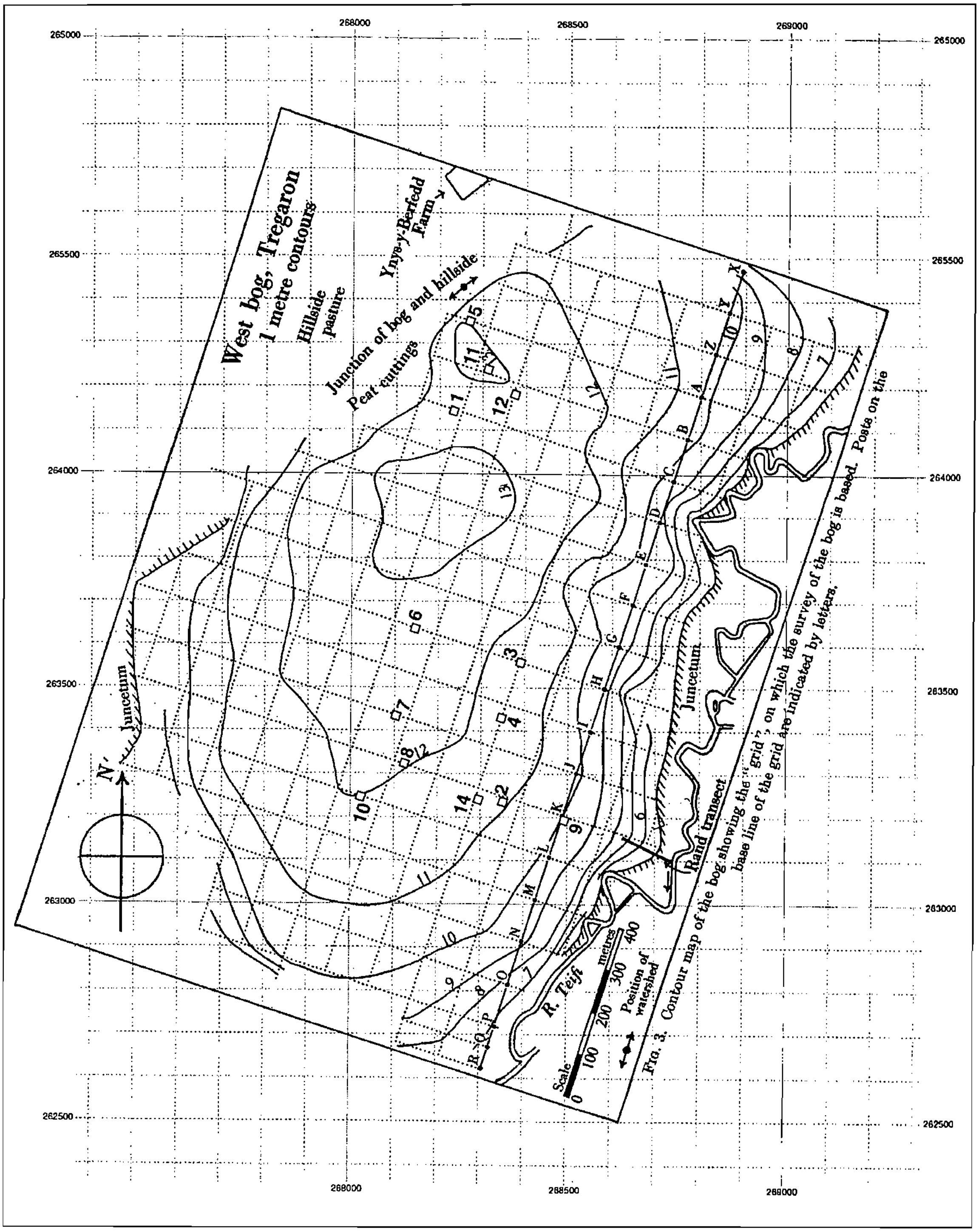


Figure 4.12: Godwin and Conway's original grid from 1936/37 overlain with the British National Grid.

4.4.5 Vegetation survey of the transects and quadrats.

4.4.5.1 Re-surveying of the quadrats

After the re-establishment of the grid and the quadrats the re-survey started at the relocated 5×5 m quadrats in August 2001. When relocating the central points of the original quadrats it was considered unlikely that the relocated points would exactly match those of the original survey. Accordingly it was decided to sample a series of quadrats within a larger plot centred upon the calculated position of the original quadrat. As the error in relocating the original quadrats was calculated to be no more than +/- 12 m a plot of 25 m surrounding the re-calculated positions was selected for subsequent sampling. Each of the 25 m plots was marked at each corner with labelled oak posts and subdivided using a tape measure into twenty-five 5×5 quadrats. Initially, five 5×5 m quadrats per 25×25 m plot were considered for sampling, but this was found to be too time-consuming and the survey effort was downscaled to three quadrats selected from tables of random numbers. While none of the three quadrats would be likely to conform to the precise original position of Godwin and Conway's quadrats, this number does at least provide a minimum standard of replication for comparison against the original data. Each selected 5×5 m sub-quadrat was again divided into twenty-five 1×1 m plots using short bamboo canes and string. The vegetation of every square metre was then mapped by recording the percentage cover of all taxa onto a standard vegetation table. Figure 4. 13. shows the approach for quadrat No. 6. The results of the resurvey of the quadrats are presented as vegetation charts in the appendix.

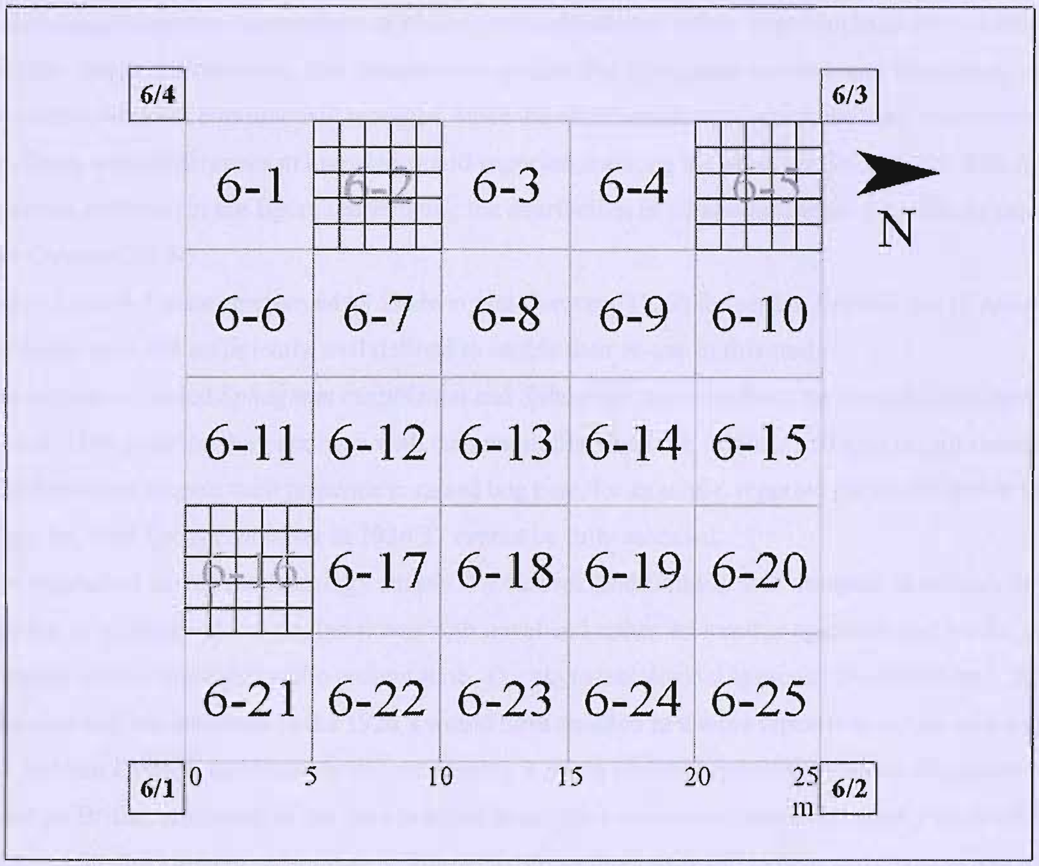


Figure 4.13: Approach of the quadrat survey on quadrat 6. The code numbers 6/1-6/4 are the labels on the marker posts; the numbers in light grey represent the randomly selected 5×5 quadrats for sampling with superimposed 1×1 m grid.

4.4.5.2 Survey of the transects.

The survey of the West Bog needed to be approached in such a way that the results would be comparable with the data in Godwin and Conway (1939). For fieldwork Godwin and Conway had the support of more than 20 assistants in the 1930s but during the fieldwork in 2001/02 only 5 people gave assistance establishing the grid. The vegetation re-survey was carried out by one person, which although time consuming, eliminated between-observer errors. Thus the re-survey of the transects was restricted to the central offsets D-M due to limited time and assistance during the fieldwork seasons. Several problems emerged with regard to the feasibility of repeating the 1936/ 37 mapping methodology:

(1) The pools, as one of the most conspicuous features of the surface in the 1936/37 survey, had disappeared entirely. Therefore many of the categories recorded in 1936/37 (see Table 4.5) could not be repeated at all. An experimental trial testing the 1936/37 approach for the remaining vegetation types showed that an accurate estimation of percentage cover of the different categories is very hard to assess within a large area of 20 m width and more than 20 m length.

(2) At the present time there appear to be no clear transitions between different vegetation communities along the re-mapped transects, with the exception of the *Molinia* dominated areas. Additionally the former distinctive hummock and hollow system of the Regeneration Complex, reported by Godwin and Conway (1939) is less pronounced now than in 1936/37.

(3) The 1936/37 survey was undertaken by a large number of people of varying expertise. Between-observer variation was significant, as pointed out by Godwin and Conway (1939), particularly when undertaking subjective assessments of plant species abundance within large blocks of 20 m width and variable length. Furthermore, less conspicuous species like *Sphagnum tenellum* and *Vaccinium oxycoccus* were not continuously recorded, since the observers did not recognise them when standing up. There were differences in knowledge and experience among the observers in 1936/37. This is, for example, reflected in the figure representing the distribution of *Cladonia* (Figure 4.15 /28) in Godwin and Conway (1939).

(4) The 0-3 and 0-5 scales employed by Godwin and Conway (1939) for certain floristic and physical attributes were not sufficiently well defined to enable their re-use in this study.

(5) The authors excluded *Sphagnum cuspidatum* and *Sphagnum tenellum* from the overall *Sphagnum* record. They justified their decision with the assumption that both of these *Sphagna* do not contribute to peat formation despite their presence in raised bog peat, for example, reported earlier by Weber (1902). Thus, the total *Sphagnum* cover in 1936/37 cannot be fully assessed.

(6) The vegetation survey methodology adopted by Godwin and Conway was designed to utilise a large number of different observers, but it was both novel and rather informal in approach and would almost certainly not be employed at the present time. The phytosociological approach developed by J. Braun-Blanquet and his followers in the 1920's would have resulted in a more repeatable survey of the site – the fact that Godwin and Conway did not employ it might possibly reflect the general reluctance amongst British ecologists of the time to adopt descriptive continental methodologies. Points 1-5 above demonstrate the inherent difficulties in following the methodology of Godwin and Conway and a different approach was employed fro re-mapping the transects in 2001.

The transect data from Godwin and Conway (1939) represent the average percentage cover or abundance score of each recorded category (see Table 4.4) confined to a 20 m wide belt. It can therefore be assumed that these averaged data should be approximately representative of any point within the 20 m belt within each block of vegetation. As sharp transitions between vegetation communities were not apparent, vegetation quadrats were recorded at regular intervals of about 50 m along the transects. The quadrats were 3×3 m wide and representative of the surrounding vegetation within the 20 m belt along the transect. Obviously modified vegetation (for example the tacks of a carrier vehicle, the argocat) was avoided and quadrats were relocated adjacent to the disturbed areas. In some cases the location of a 3×3 m quadrat and the location of one of the 5×5 m quadrats recorded earlier, were identical enabling use of the average data for the 5×5 m quadrat to be used instead of recording an additional 3×3 m quadrat.

The 3×3 m size of the quadrats was a compromise. The size used by the NVC for raised bog habitat is 2×2 m. However, it has to be regarded that the raised bog vegetation at Cors Caron is disturbed. A 2×2 m quadrat would possibly cover the present Ericaceae and Monocotelydons but since *Sphagnum* is scarce this quadrat size would not cover all of the *Sphagnum* species present in the surroundings of the quadrat. This assumption is supported by the vegetation records themselves which often contain only one or two percent of a *Sphagnum* species (the total of all vegetation records is represented in the appendix). Since these one or two percentage points are mostly represented by a single patch or cushion, they could be easily missed by a smaller quadrat size. Therefore it was considered that a smaller quadrat than 3×3 would be unrepresentative of the surrounding vegetation. However, a larger size would lose accuracy if not divided into smaller compartments, which is very time-consuming. Each 3×3 m quadrat was recorded within 10 m around the 50 m marker bamboo canes designating the transects. The GPS position of the quadrats was recorded with a handheld GPS (accuracy 5-7 m). The data gained by this approach have the advantage that the cover of the individual species is estimated and given in percentage terms. They are presented as vegetation charts in the appendix. The data can be compared with those from 1936/37 and can also be used as a baseline for future vegetation monitoring.

4.4.6 Comparison of the 1936/37 and 2001/02 vegetation data

4.4.6.1 Retrieving the transect data

The results from the 1936/37 transects were presented as graphs and diagrams in Godwin and Conway (1939), and are reproduced in Figures 4.14 and 4.15. The graphs in Figure 4.14 represent the primary data collected by the observers and the diagrams in Figure 4.15 were derived from the primary data. Not all of these figures were useful for retrieving data. An example is the second graph row in Figure 4.14, which represents "*that percentage of the area covered by pools, which consists of pools filled with Sphagnum*". As this category also includes *S. pulchrum* and *S. papillosum*, no assumptions could be drawn concerning the percentage cover of aquatic Sphagna. Tables 4.6 and 4.7 provide an overview of the usable information content of Godwin and Conway's transect data. To retrieve the cover data from the original figures in Godwin and Conway (1939) the graphs and diagrams were imported into COREL DRAW version 8, fitted with a grid-scale and printed (Figures 4.16 and 4.17).

To assess possible errors occurring during the processing due to the simplicity and small size of the original diagrams, the cover of *Sphagnum* (excluding *S. cuspidatum* and *S. tenellum*) was used to check the accuracy of the retrieved data. *Sphagnum* cover data are presented in two different figures in Godwin and Conway's paper; first, as the sixth graph row in Figure 4.14, and second as the diagram labelled "Much *Sphagnum*" in Figure 4.15. The diagram in Figure 4.15 shows the areas of the West Bog supplying a 10-15 % (black) and ≥15 % (single-hatched) cover of *Sphagnum*. These two sources of data are compared in Figure 4.18 which provides a cellular representation of the West Bog. Cell numbers represent the percentage cover of

Ecology (Godwin & Conway)

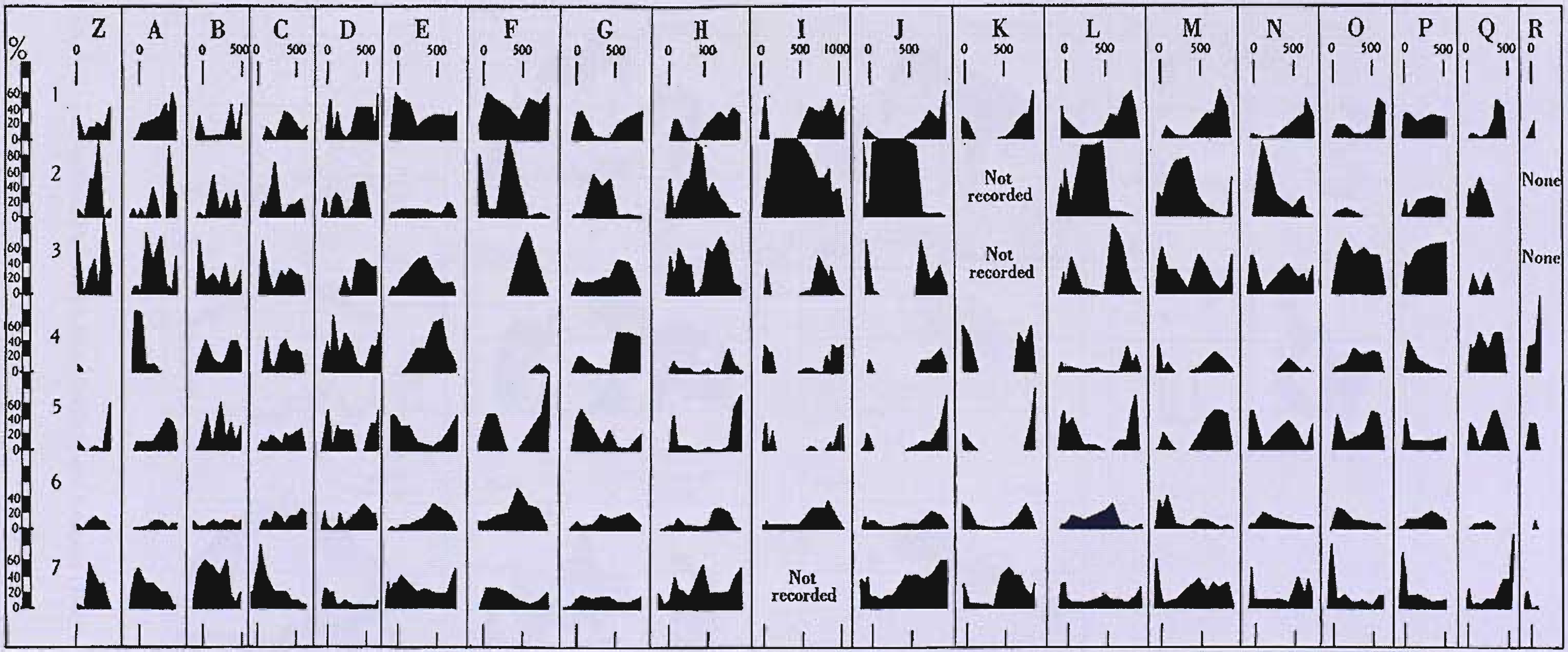


FIG. 17. Results of quantitative estimations made along the offsets of the grid. Each small graph shows the variation of one characteristic along a transect. Each vertical row gives the results for one transect. Horizontal rows show the following characteristics. (1) Percentage of surface covered by pools more than 30 cm. in width. (2) That percentage of the area covered by pools, which consists of pools filled with *Sphagnum*. (3) That percentage of the area covered by pools, which consists of pools partly filled with *Sphagnum*. (4) That percentage of the area covered by pools, with bare mud or *Zygogonium* only. (5) That percentage of the area covered by pools, with sparsely scattered *Rhynchospora*. (6) Percentage of surface covered by living *Sphagnum* carpet (excluding *S. cuspidatum* and *S. tenellum*). (7) Percentage of surface covered by *Calluna*.

Face p. 342

Figure 4.14: Diagrams in Godwin and Conway representing the results of the transect data.

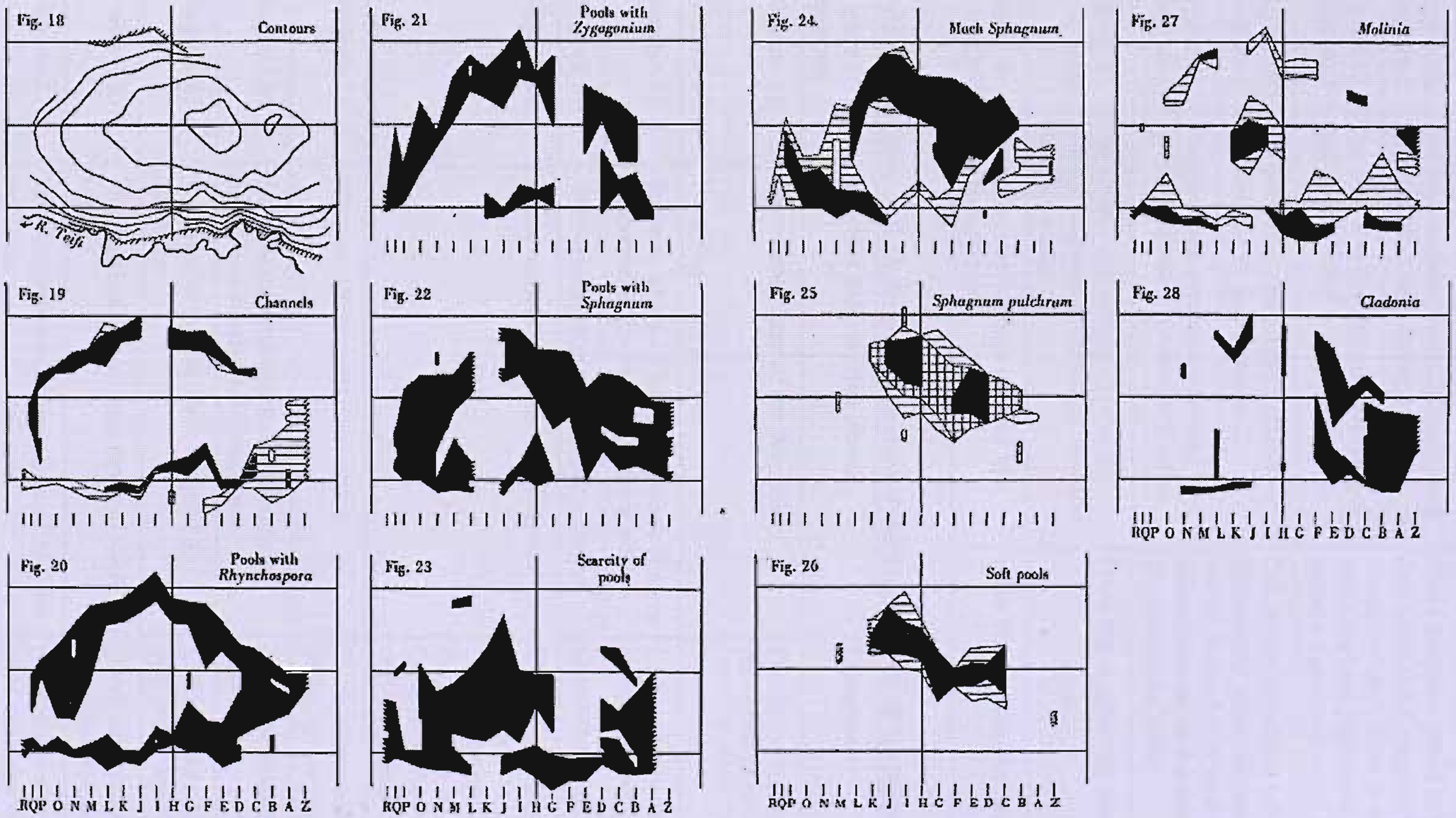


Fig. 18. Contour map of the bog.

Figs. 19–28. Results of estimations made along the transects of the grid, expressed in the form of distribution maps. Saw-edging indicates that estimations were not made on the adjacent transect.

Fig. 19. Black indicates presence of eroding channels, shading the presence of overgrown channels.

Fig. 20. Area in which 15% or more of the area covered by pools consists of pools with sparse *Rhynchospora*.

Fig. 21. Area in which 15% or more of the area covered by pools consists of pools with *Zygogonium* only.

Fig. 22. Area in which 20% or more of the area covered by pools consists of pools partly filled with *Sphagnum*.

Fig. 23. Areas in which less than 15% of the surface is covered by pools more than 30 cm. wide.

Fig. 24. Black, areas with 15% or more of the surface covered by living *Sphagnum*; shaded, the corresponding areas 10–15%.

Fig. 25. Black, *S. pulchrum*, has frequency 3; cross-hatch, frequency 2; single hatch, frequency 1.

Fig. 26. Black, all the pools "soft"; shading, some of the pools soft.

Fig. 27. Black, *Molinia* has frequency 4 or 5; shaded, frequency 1, 2 or 3.

Fig. 28. *Cladonia* covers 15% or more of the surface.

Figure 4.15: Facsimile of Figures 18-28 of Godwin and Conway (1939).

Table 4.6: Outline of the information content of figure 17 p. 342 in Godwin and Conway (1939) regarding the transects.

Figure / Diagram	**Provides information about:**	**Comments:**
Figure 17, diagram 1	The surface percentage covered by pools wider than 30 cm	There is no information about the total pool cover, thus this category can not be retrieved
Figure 17, diagram 2	The pool surface percentage consisting of pools filled with *Sphagnum*	These diagrams could in theory be used to gain data about the *S. cuspidatum* and *S. tenellum* cover, but since there is no information given about the total pool cover, it is impossible to retrieve these data
Figure 17, diagram 3	The pool area percentage consisting of pools partly filled with *Sphagnum*	
Figure 17, diagram 4	The pool area percentage covered only by bare mud or *Zygogonium.*	Can not be calculated because of lack of information about the total pool cover; even if this information were be available there is still no information about the coverage of *Zygogonium* or *Rhynchospora alba*
Figure 17, diagram 5	The pool area percentage covered by sparse scattered *Rhynchospora alba.*	
Figure 17, diagram 6	The surface percentage covered by living *Sphagnum* excluding *S. tenellum* and *S. cuspidatum*	From this diagram the data could be retrieved
Figure 17, diagram 7	The surface percentage covered by *Calluna vulgaris*	From this diagram the data could be retrieved

Table 4.7: Outline of the information content of the diagrams 18-28 in Godwin and Conway (1939).

Figure / Diagram	**provides information about:**	**Comments:**
Diagram 18	The contour lines of the West Bog	Possibly comparable with the data from the Geodimeter
Diagram 19	The presence of channels	
Diagram 20	The area where 15 % of the surface or more is covered by pools with sparse *R. alba*	Unfortunately there is no information about the coverage of *R. alba* itself.
Diagram 21	The coverage of pools with *Zygogonium*	Shows the main range of *Zygogonium*
Diagram 22	The coverage of pools with *Sphagnum*	These diagrams could be used theoretically to gain data about the *S. cuspidatum* and *S. tenellum* cover, but since there is no information given about the total pool cover, it is impossible to retrieve these data
Diagram 23	The area where pools were scarce	Gives information about the distribution of the former pool system
Diagram 24	Provides information about the surface percentage covered by *Sphagnum*	From this diagram the data could be retrieved.
Diagram 25	The distribution and main range of *S. pulchrum*	Limited information about the coverage of *S. pulchrum* itself.
Diagram 26	The distribution and main range of 'Soft' pools.	Gives information about the distribution of the former pool system
Diagram 27	The distribution and main range of *Molinia caerulea.*	Limited information about the coverage of *M. caerulea* itself.
Diagram 28	The area where *Cladonia arbuscula* (ex. *sylvatica)* covers 15 % or more	Shows the main range of *Cladonia.*

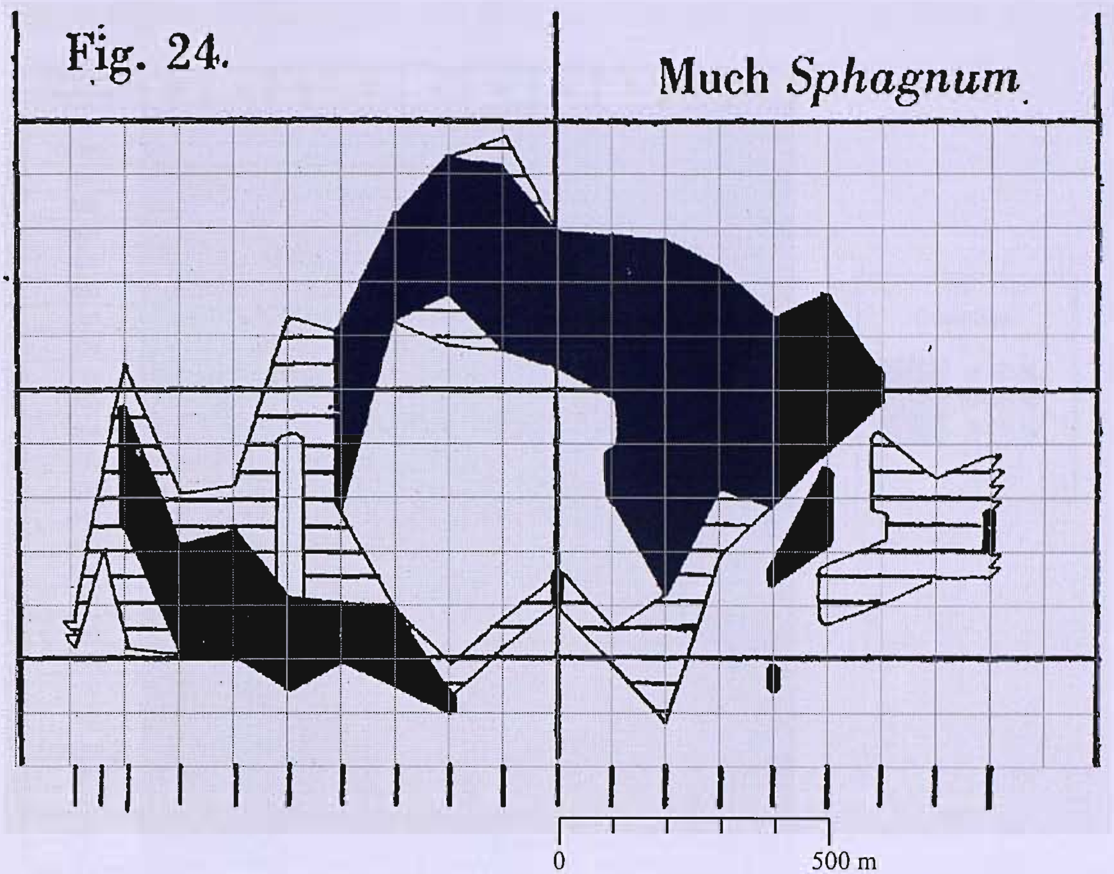


Figure 4.16: Original Figure from Godwin and Conway (1939) fitted with a grid scale.

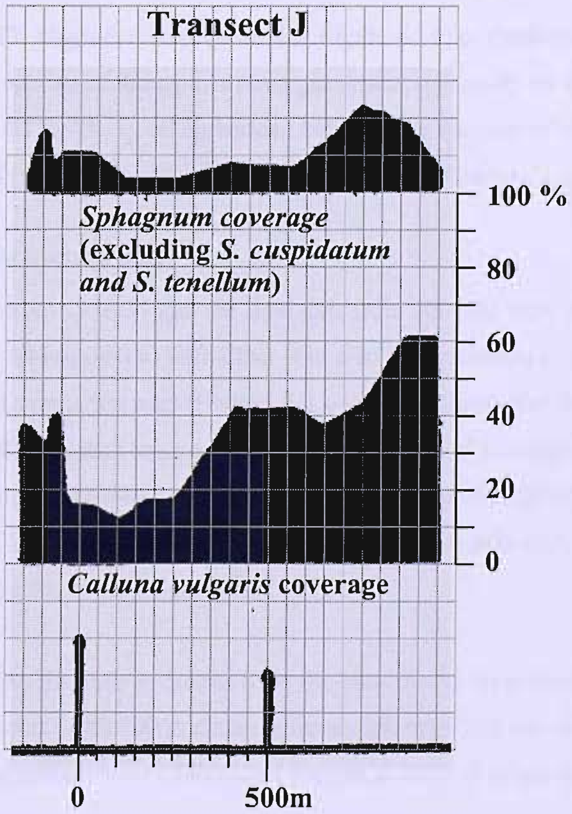
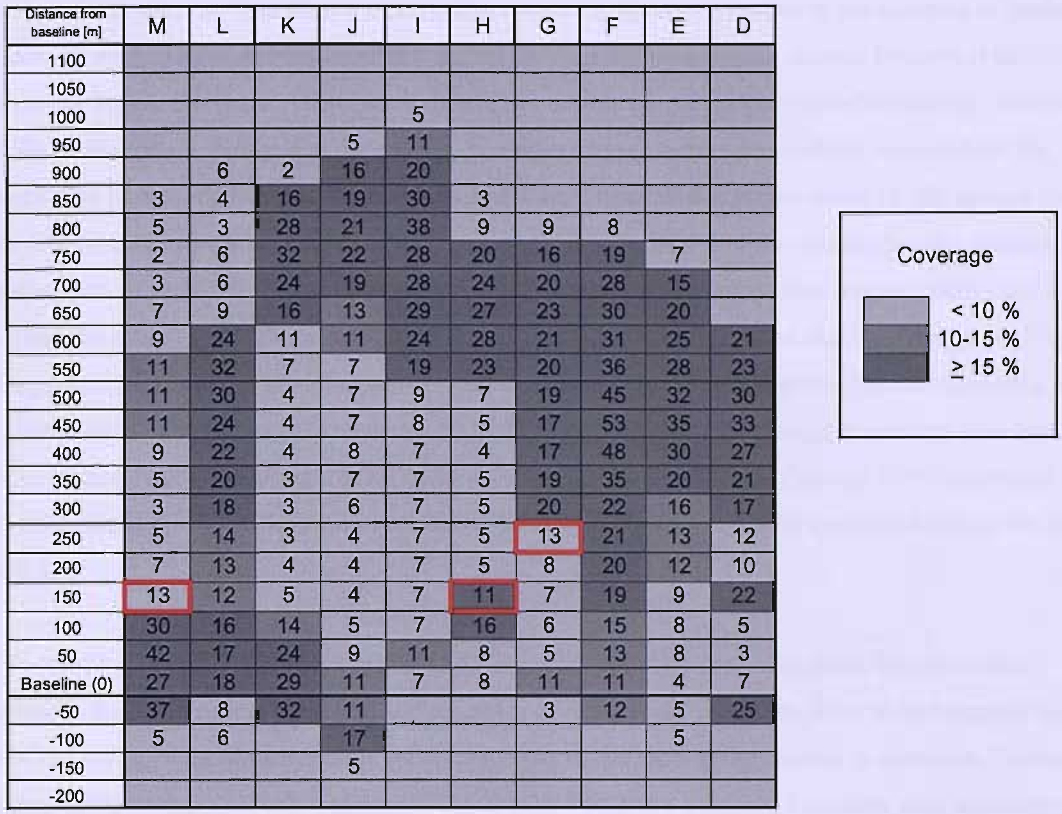


Figure 4.17: Fraction of Figure 4.14 belonging to transect J fitted with a grid scale.



Distance from baseline [m]	M	L	K	J	I	H	G	F	E	D
1100										
1050										
1000					5					
950				5	11					
900		6	2	16	20					
850	3	4	16	19	30	3				
800	5	3	28	21	38	9	9	8		
750	2	6	32	22	28	20	16	19	7	
700	3	6	24	19	28	24	20	28	15	
650	7	9	16	13	29	27	23	30	20	
600	9	24	11	11	24	28	21	31	25	21
550	11	32	7	7	19	23	20	36	28	23
500	11	30	4	7	9	7	19	45	32	30
450	11	24	4	7	8	5	17	53	35	33
400	9	22	4	8	7	4	17	48	30	27
350	5	20	3	7	7	5	19	35	20	21
300	3	18	3	6	7	5	20	22	16	17
250	5	14	3	4	7	5	13	21	13	12
200	7	13	4	4	7	5	8	20	12	10
150	13	12	5	4	7	11	7	19	9	22
100	30	16	14	5	7	16	6	15	8	5
50	42	17	24	9	11	8	5	13	8	3
Baseline (0)	27	18	29	11	7	8	11	11	4	7
-50	37	8	32	11			3	12	5	25
-100	5	6		17					5	
-150				5						
-200										

Coverage

- ▨ < 10 %
- ▨ 10-15 %
- ▨ ≥ 15 %

Figure 4.18: Comparison between the retrieved data sets of Figure 4.14/6 and 4.15. The data retrieved from Figure 4. 14/6 are given as numbers, the data retrieved from Figure 4.15. as shading.

Sphagnum read off Figure 17, diagram 6 (represented in Figure 4.14) of Godwin and Conway (1939), while cell shading denotes the categories of *Sphagnum* cover presented separately by the authors in Figure 24 (represented here in Figure 4.15). The good agreement between the two sets of data suggest that reasonable accuracy has been achieved in extracting the data from Godwin and Conway's original published figures.

4.4.6.2 Comparison of the transect data

All retrieved coverage data from 1936/37 and the field data from 2001/02 were entered into EXCEL files and plotted as tables. These tables, next to each other, can also be considered as vegetation maps (Figures 6.1.a+b to 6.6. a+b). A third vegetation map (Figures 6.1.c to 6.6.c) shows the changes in a particular species over the last 65 years. If sufficient data were available, as in the case of *Calluna vulgaris* or *Sphagnum* (excluding *S. cuspidatum* and *S. tenellum*), the change is shown as percentage of the total coverage. Otherwise, as in the case of *Sphagnum pulchrum* or *Molinia caerulea*, only shifts in distribution and /or presence of the particular species could be compared.

The vegetation maps show the distance in metres from the baseline (in 50 m steps) at the left side and the letters which name the transects (with 100 m distance from each other) on top of each table. Each cell within the tables represents the percentage cover of the plant species at the 3×3 m quadrats, which were sampled along the transects.

4.4.6.3 Retrieving and comparison of the quadrat data

To retrieve the vegetation data from the original quadrats the figures representing the quadrats in Godwin and Conway were used. It was assumed that the distribution and cover of the species symbols relatively represent the vegetation cover. Therefore it should be possible to re-gain the vegetation data by 'surveying' the cover of the species symbols in the figures. To retrieve the data the same method was used for the transects. The figures representing the quadrats 1 to 9 were fitted with a grid-scale of 10×10 squares (see Figure 4.19) and the percentage cover of the plant symbols estimated. For the comparison the modern field vegetation data of each 1×1 m plot belonging to a 5×5 m quadrat were typed into separate tables in EXCEL files. Then the average vegetation cover of each 5×5 m quadrat was calculated and the average of all three 5×5 m quadrats, within each 25×25 m square, was determined. For the comparison the averaged data were then plotted into a table against the retrieved 1936/37 vegetation data of the original quadrats (see Tables 6.2 and 6.3). Unfortunately not all figures for quadrats presented in Godwin and Conway (1939) provided full information about the vegetation. An overview of the information available for each quadrat is given in Table 4.8.

The 're-survey' of the figures from Godwin and Conway is based on the assumption, that the codes employed in the paper reflect the actual surface cover of the species. However, it has to be regarded that some of the codes might not adequately reflect the cover of the species they intend to represent. Therefore, in order to obtain a more objective picture of the change within the quadrats, frequency data were extracted from both Godwin and Conway's quadrats and the quadrats recorded in 2001. The frequency data are based on the presence of a species in each of the twenty-five 1×1 m cells for each quadrat. On this data set Detrended Correspondence Analysis (DCA) was carried out. The results of the comparison including the DCA are presented in chapter 6, section 6.1.2.1.

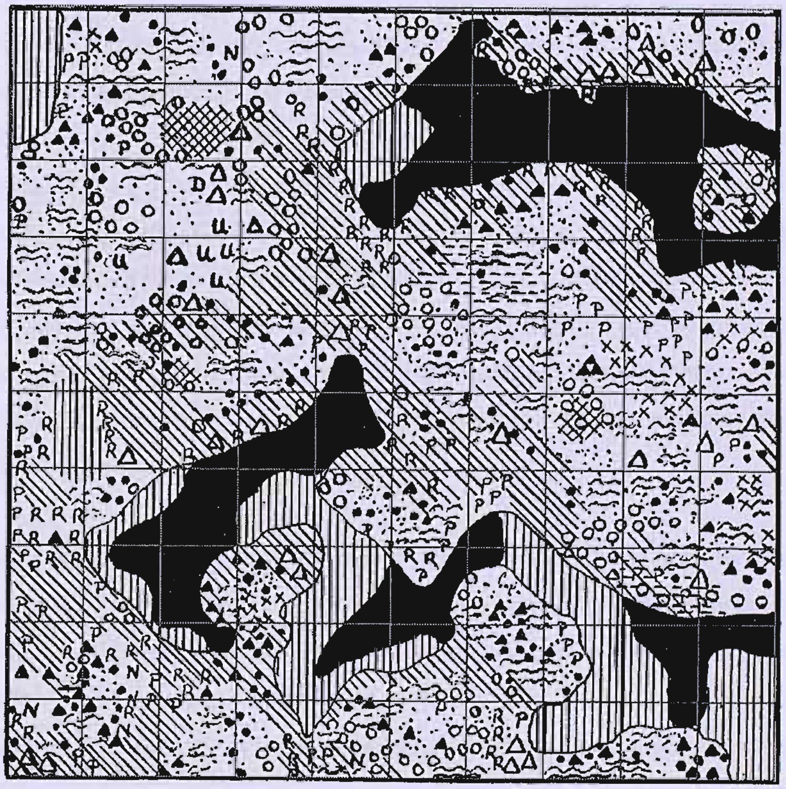


Figure 4.19: Original figure of quadrat 1 from Godwin and Conway (1939) fitted with a grid scale.

Table 4.8: Overview about the information available from each quadrat.

Quadrat	Available information about the vegetation
1, 2, 4, 8, 9	Vascular plants, *Sphagnum* and Bryidae; no information about Hepaticae
3	Information about selected features (*Calluna vulgaris*, *Erica tetralix* , *Cladonia* arbuscula, *S. tenellum*, *S. papillosum* and open water)
5, 6, 7	Information about selected features (*Empetrum nigrum*, *E. angustifolium*, *Molinia caerulea*, *S. pulchrum*, *S. cuspidatum*, *S. papillosum* and open water)
10, 11, 12, 14	No information was published.

4.4.7 Processing of the 2001/02 vegetation data for an analysis of modern vegetation patterns

In addition to the comparison of past and recent vegetation data sets, the modern vegetation data provide an opportunity to analyse the patterns in the contemporary vegetation distribution. As the 25×25 m quadrats are established permanently they can be used as a basis for future monitoring of the vegetation development on the Cors Caron West Bog. For this purpose the coverage and distribution of each species surveyed is presented in the Figures 6.7 to 6.12. in vegetation maps in the same way as for the comparison of the 1936/37 and 2001/02 data sets.

4.5 Statistical Methods

4.5.1 Detrended Correspondence Analysis (DCA)

In order to extract ecological patterns from the results of macrofossil analysis and vegetation re-survey statistical methods have been applied. One of them is Detrended Correspondence Analysis (DCA), which is useful for extracting patterns from relatively complex data sets. A detailed introduction to how this technique works is given by ter Braak (1995). DCA is one of several multivariate techniques, which are collectively termed ordination. These techniques arrange sites, or in this project, samples along axes on the basis of data on species frequency. Their results are presented in two dimensions (two axes) in a diagram in which samples are represented by points in two-dimensional space. The aim of ordination is to arrange the points along a latent gradient, in a way that samples that are close together correspond to sites that are similar in species composition, and points that are far apart correspond to sites that are dissimilar in species composition. Ordination techniques can also help to show whether important environmental variables have been overlooked in ecological analyses.

DCA is based on correspondence analysis (CA), one of the most popular ordination technique amongst ecologists. It provides simultaneously an ordination for the sites and an ordination for the species. The technique uses the fact that species commonly show bell-shaped response curves with respect to environmental gradients. Environmental data are not needed for CA. CA 'extracts' the ordination axes from the species data alone and can be applied to presence-absence data and also to abundance data. If the indicator values of species are known, the environmental variable of a sample can be estimated from the species composition that it contains, by averaging the indicator values of these species. The ordination axes of CA are termed eigenvectors with each eigenvector associated with a corresponding eigenvalue. The eigenvalue is equal to the maximum dispersion of the species scores on the ordination axis, and therefore a relative measure of the importance of the axis, with the first axis having the largest eigenvalue, the second the second largest eigenvalue and so on. The eigenvalues lie between 0 and 1. Eigenvalues over 0.5 usually indicate a good separation of the species along the axis.

However, CA is susceptible to two major faults. The first one the so-called “arch-effect” or “horseshoe-effect”, which is a mathematical artefact, corresponding to no real structure in the data. When analysing samples from diverse habitats along a single environmental gradient, the ordination on the principal axes does not always produce a linear sequence of species but an arch-like shape. The second fault is a result of the first, the compression of data points at the ends of the axes, therefore not preserving ecological distances (Kovach 1995).

DCA was developed by Hill and Gauch (1980) as a heuristic modification of CA and designed to correct its two major faults. This is achieved by detrending the data, where the axis is divided into a number of segments, within which the site scores of axis 2 are adjusted by subtracting their mean.

In interpreting ordination diagrams of CA and DCA one should be aware of the following aspects:

- Species points at the edge of the diagram are often rare species, lying there either because they prefer extreme (environmental) conditions or because their few occurrences by chance happen to be at sites with extreme conditions.
- Species at the centre of the diagram may either be unimodal with optima at the centre, or bimodal, or unrelated to the ordination axes.
- Species that lie between the centre and the outer edge are most likely to show a clear relation to the axes.

The DCA diagrams presented in chapter 5 (section 5.3.1) were established by transferring the macrofossil data from TILIA into a computer program termed TRAN. This program transforms the data into Condensed Cornell format, which can be processed by the computer programme CANOCO (ter Braak 1988). The latter programme executes the calculation for the DCA. Within this program the options where chosen to detrend the data by segments and to down weigh rare species. The results where imported into EXCEL to produce the final DCA diagrams.

4.5.2 Two Way INdicator SPecies ANalysis (TWINSPAN)

TWINSPAN is a method suitable for ecological data. It was used for the analysis of the 3×3 m quadrats, which were recorded along the transects in 2002 (see section 4.1.10.2). An overwiew of the method is given in Kent and Coker (1994). TWINSPAN classifies simultaneously species and samples and is based on dividing a reciprocal averaging ordination space. The procedure was described by Gauch (1982). In phytosociology the presence or absence of so-called differential species is used to separate plant communities or groups of vegetation quadrats from each other (as a qualitative rather than a quantitative concept). One set of differential species characterises form one group and another set the other group of plant communities. Hill *et al.* 1975 introduced the concept of pseudospecies in order to adapt abundance data to be a qualitative equivalent. For this purpose the species abundance scale is divided into a series of pseudospecies, which can then be used in the process of making a division. If percentage cover data are analysed, the species are divided into five pseudospecies, for example *Sphagnum papillosum*:

Sphagnum papillosum 1 percentage cover <2%
Sphagnum papillosum 2 percentage cover 3-5 %
Sphagnum papillosum 3 percentage cover 6-10 %
Sphagnum papillosum 4 percentage cover 11-20 %
Sphagnum papillosum 5 percentage cover > 20 %

If up to 2 % of the species occur in a quadrat, it is coded as *Sphagnum papillosum* 1, but if, for example, more than 20 % occur in a quadrat, all five pseudospecies are coded as present. The detail of the method is complex; however the output of the technique and one of the most useful features of TWINSPAN is the final ordered two-way table, which is produced at the end of the TWINSPAN analysis (see Table 6.10 in chapter 6, section 6.2.1.1). The species names and numbers are arrayed along the left side of the table and quadrat numbers vertically on the top of each column. The sorted data of the vegetation are presented in the main block of the table, where quadrats and species are sorted in a way that they form groups of quadrats and species. In the past, this work had to be carried out by hand by the phytosociologist in a time-consuming process. The result of this is to concentrate the data down diagonally in the table from top left to bottom right. Species, which do not fit easy into the overall diagonal trend appear at the top or bottom of the table, for example *Pleutozium schreberi* or *Sphagnum fimbriatum* in Table 6. 10. The array of zeros and ones at the right and bottom sides of the table are the dichotomised key for the species (right) and quadrats (bottom) showing both, the group structure and the sequence of divisions. The division starts with the line of numbers closest to the main block of the table. Each of these groups is then split further, indicated by the second line of numbers towards the outer margin of the table.

5 Results of the palaeoecological research

Macrofossil analysis is the main approach in this research project. It provides the opportunity to investigate long-term vegetation and biodiversity changes in mire development. The potential and limitations of this method have been discussed in detail in chapter 2 (section 2.3). Often palaeoecological work on raised bog macrofossils has been carried out on single cores in order to track climate changes (Barber 1994, Hughes *et al.* 2000, Langdon 2000, Blundell 2002). This is based on the findings of Barber (1981) and Barber *et al.* (1998) in Cumbrian raised bogs, where variation between profiles has been slight and seemed to be less in the past than observation of present vegetation patterns might suggest. In the current project multiple cores of two different raised bogs in West Wales (Cors Caron and Cors Fochno) have been analysed in order to track the vegetation development of the last two millennia in detail. Research objectives, which will be examined in this chapter include:

1) To characterise the main pathways of raised bog vegetation succession on the investigated sites during the late Holocene, covering the last 1000-2000 years.
2) Examine the possible causal factors driving late Holocene vegetation succession at the investigated sites.
3) To understand the causes of the slow down in peat accumulation in the Cors Caron bogs.
4) To examine the history of *Sphagnum austinii* in both Welsh raised bogs and compare it with that of an Irish site (Raheenmore Bog) where the species is still abundant.
5) To examine the histories of species (*Betula* spp., *Myrica gale*, *Molinia caerulea*), which naturally occur little on raised bogs but have been become problematic more recently.

The first part of this chapter deals with the chronology of the analysed profiles. This includes the results of radiocarbon dating and spheroidal carbonaceous particles (SCP) analysis as well as the search for similarities and differences between the chronologies of the different profiles and sites. The second part of chapter 5 records and compares the results of the macrofossil analyses, presented in the macrofossil diagrams (Figures 5.29-5.42). Before the presentation of the results of each core, an explanation is given of the reasons for sampling each core. In the third part the results of the detrended correspondence analysis (DCA) are presented in Figures 5.43 to 5.68. At the end of this chapter in section 5.4, a summary is provided for each of the investigated sites.

5.1 Chronology

The following sections present the chronology of the analysed cores from Cors Caron, Cors Fochno and Raheenmore Bog. The chronologies, shown as age-depth models, are based on the results of the radiocarbon dating and the SCP analyses. Figure 5.1 provides a legend for the various types of dates used in the age-depth models. The ^{14}C data points in the age-depth models represent the mid-point of the highest probability of the one sigma range of the radiocarbon analysis. Every ^{14}C data point in the age-depth models is fitted with error bars covering the two sigma range. The dates used in the text are the calculated midpoints of the highest point in the probability distribution of the one sigma range. As they derived from a statistical calculation, they are only 'approximate' dates and must not be taken literally. Together with the age-depth models the SCP records of each profile are presented. The SCP record can be used as a dating tool for upper and top peat strata of modern age (Rose *et al.* 1995, Yang *et al.* 2001). Figure 5.2 originates from Rose *et al.* (1995) and shows the general course of the SCP record (Figure 5.2.a) and ^{210}Pb dated SCP profiles from Welsh and Irish lake sediments (Figure 5.2.b+c), which are used as an aid to assess the age of the SCP profiles of the investigated sites. The dates derived from the SCP analysis are fitted with error bars of twenty year range for the 1970's subsurface peak and with forty year range for the point at which the SCP amounts increase. As the point of increased SCP numbers was often not possible to determine in the SCP profiles of Cors Caron, it does not appear in the age-depth models.

△ Date marking the onset of *Pinus* presence deriving from Morris (2001)

◇ Dates deriving from the SCP record

◈ Radiocarbon dates deriving from Morriss (2001)

◆ Radiocarbon dates of the current project

□ Radiocarbon date of the current project, possibly out of range

Figure 5.1: Legend for the data points used in the age-depth models.

Another group of values, which have to be treated with caution are those of the average accumulation rates per year. The high pore volume of peat containing up to 97 % water is very prone to subsidence if a mire is drained. The highest rates of peat subsidence occur immediately after drainage affecting the top peat layers the most (Eggelsmann 1990b). It is very likely that peat extraction on the margins of all of the investigated raised bogs has caused slight to significant subsidence, as reported from Irish raised bogs by van der Schaaf (2000). Subsidence concerns, in particular, the smaller Southeast and Northeast Bogs of Cors Caron, where the scale of peat excavation is much larger compared to the size of the peat body than at the West Bog. Thus the calculated average accumulation rates are 'at least' values since the original bog surface might have been higher than the current one. However, even the calculation of an 'at least' accumulation rate gives an aid to assess the rate of peat growth within each profile. The accumulation rate of the peat layers formed in modern times has not been calculated because these strata have a much lower bulk density than those beneath and are therefore not comparable with each other.

To assess the average accumulation rates within the peat profiles there are two options, (1) to interpolate between adjacent ^{14}C dates or (2) to fit a trend line to a group of data points. The option chosen was dependent on the following circumstances:

- Single dates were directly connected if they originated from depths where the macrofossil assemblage changes significantly as for example in TWC 2000 and TWD 2000 (Figures 5.32 and 5.33) from very weakly humified *S. austinii* peat to strongly humified radicell peat. It is assumed that with the change in the dominating macrofossils then the accumulation rate also changes, which justifies this approach,

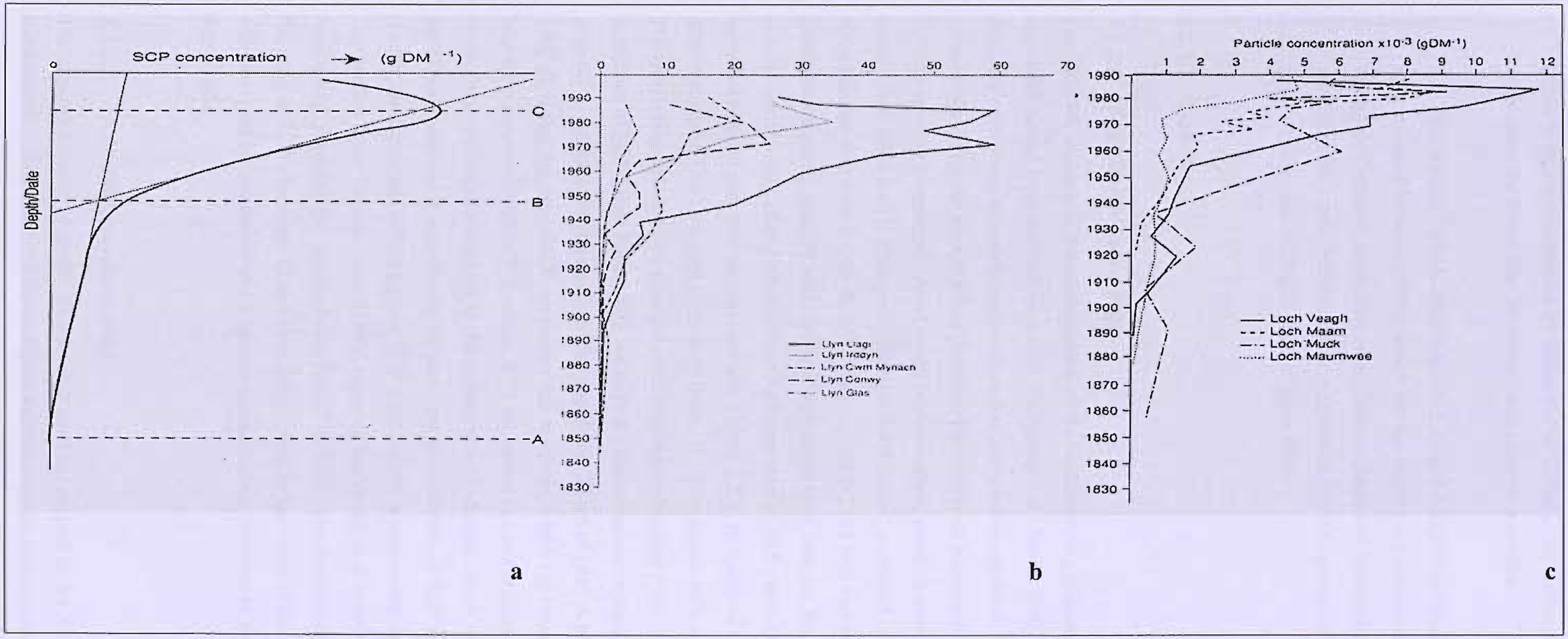


Figure 5.2: Schematic SCP profile and ^{210}Pb dated SCP profiles from Welsh and Irish late sediments.

a) The schematic SCP profile showing the start of the SCP record (A), the increase in SCP's (B) and the subsurface peak (C).

b) ^{210}Pb dated SCP profiles from Welsh lake sediments used as reference profiles for the SCP diagrams of Cors Caron and Cors Fochno.

c) ^{210}Pb dated SCP profiles from Irish lake sediments used as reference profiles for the SCP diagram of Raheenmore Bog.

The figures originate from Rose et al. (1995).

which is also recommended by Telford *et al.* (2004). The author suggests that this approach is best when there are fewer than 20 radiocarbon dates on a profile.

- For TRE'98 and TRWA 2000 (Figures 5.29 and 5.31) chronological data were already available from the project of Morriss (2001), which are not located at borderlines where the macrofossil assemblage changed. Therefore trend lines were fitted to groups of radiocarbon dates representing about the same accumulation rates. Trend lines have also been fitted to groups of data if they were approximately in a line as in the case of TNEA 2000 (Figure 5.30).

5.1.1 Cors Caron

5.1.1.1 TRE' 98 (Southeast Bog)

For TRE'98, originating from the summit of the Southeast Bog (Figure 4.2), four radiocarbon dates and an age-depth model were available from the PhD project of Morriss (2001). Since the current project focuses on different objectives, two additional radiocarbon dates were submitted. With a total number of six radiocarbon dates, the start of *Pinus* presence (derived from Morriss 2001) and the SCP features (see Figure 5.4), an enhanced age-depth model could be established, which is presented in Figure 5.3. The additional radiocarbon dates lead to changes in the age-depth model, presented in Morriss (2001). The average accumulation rate from *c.* 260 BC (112 cm) to *c.* 60 BC (62 cm) was very high (at least 3.88 years/cm). The accumulated peat is slightly humified and dominated by *S. austinii*. However, the peat accumulation rate slowed significantly after *c.* 60 BC from 3.88 years/cm to 57.8 years. Over this time period mostly highly humified radicell peat was formed (see also Figure 5.27). In medieval times (*c.* 1200's) the accumulation almost stopped. Until the start of modern times, at 16 cm depth, only six centimetres of peat accumulated. The overlaying peat is much younger since it contains frequent *Pinus* pollen (Morriss 2001) and also higher quantities of SCP's (see Figure 5.4). As there is also no typical regional pattern in the SCP record it is difficult to estimate the time scale of the uppermost 20 cm of peat. A peculiar feature in the SCP record of TRE'98 is that the rise in SCP numbers starts at 20 cm, which has been dated to the medieval period. The highest concentration of SCP's occurs at 16 cm, where the peat consists of *S. cuspidatum* remains. At this depth *Pinus* pollen also emerges in the pollen record (Morriss 2001). However, the top 10 cm of *S. papillosum* peat and *S. papillosum* contain very low numbers of SCP's and must therefore have formed very recently and after the 1970's highest SCP input, which is presumably located somewhere in the *S. cuspidatum* layer. Johnson *et al.* (1990) reported that decay in *S. cuspidatum* hollows is higher than in hummocks, therefore the accumulation rate of hollows must be slower than in hummocks. If this is the case, the peak in SCP's between 12 to 14 cm depth could be the result of the combination of higher SCP's influx and slow peat accumulation which makes a reliable determination of the time scale in this SCP profile impossible.

5.1.1.2 TNEA 2000 (Northeast Bog)

The age-depth model of profile TNEA 2000 from the summit of the Northeast Bog is shown in Figure 5.5. Between the *c.* 640's and *c.* 1100 AD there had been a peat accumulation of about 12.83 years/cm. It is

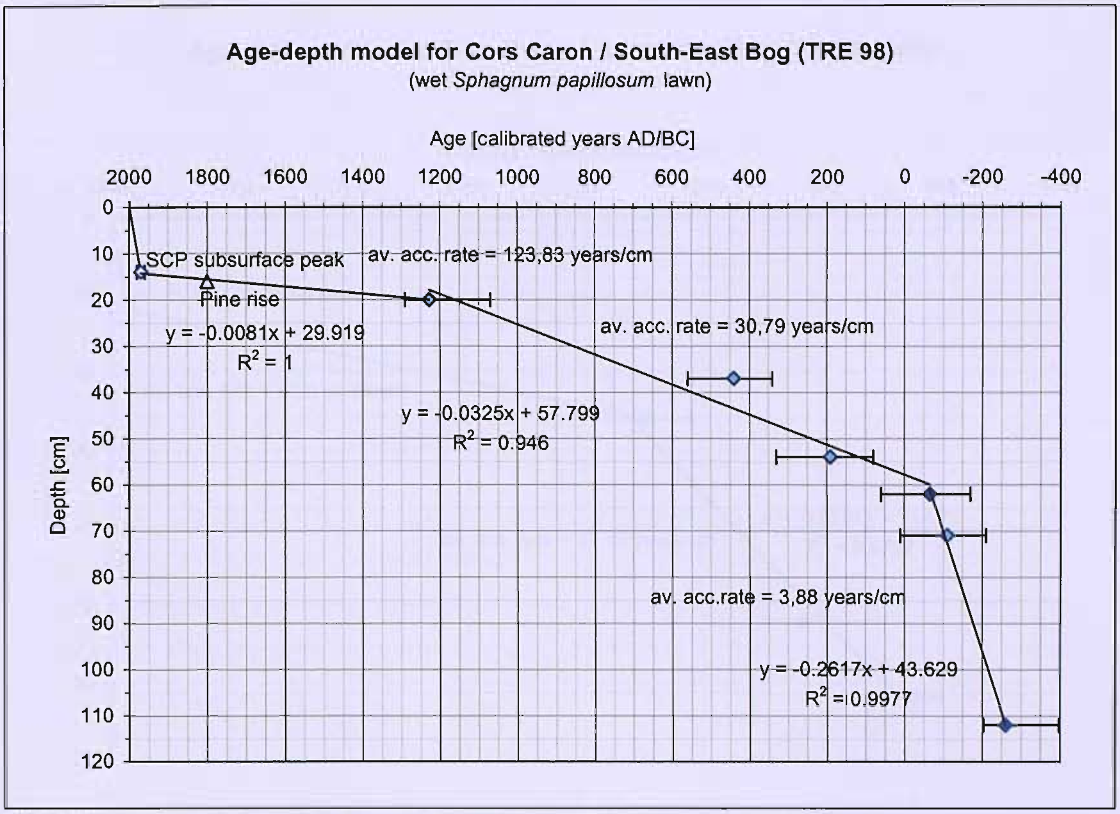


Figure 5.3: Age-depth model of TRE'98.

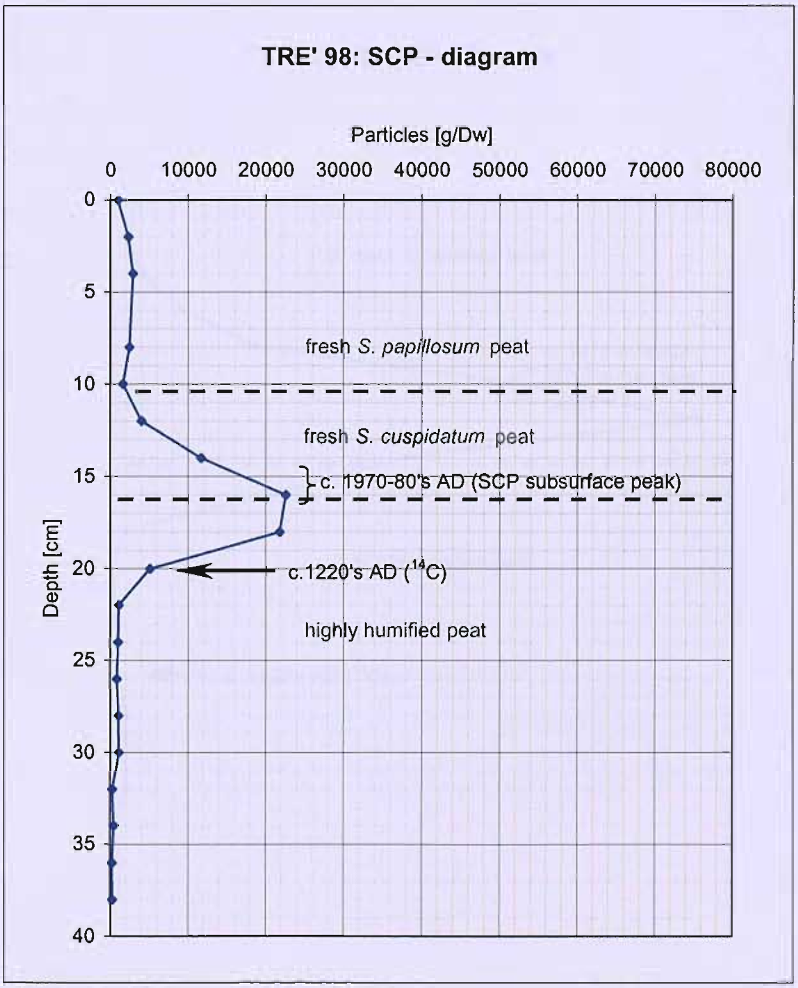


Figure 5.4: SCP diagram of TRE'98.

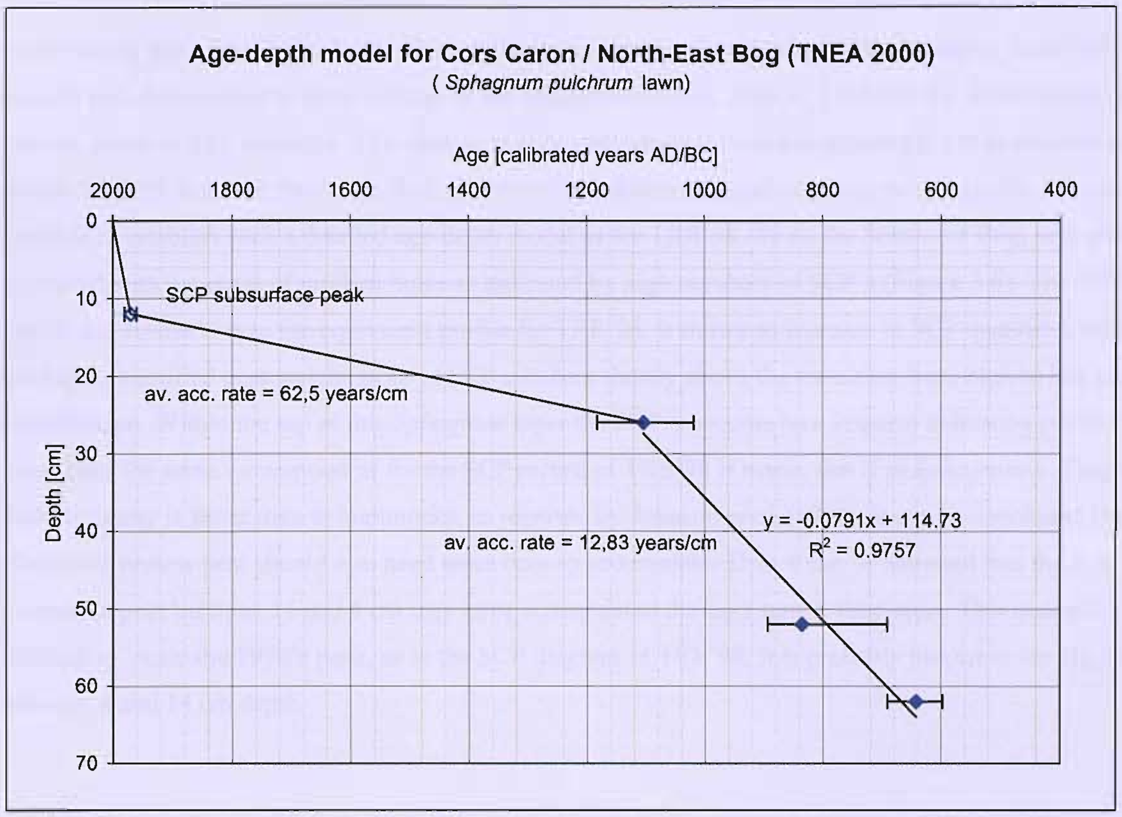


Figure 5.5: Age-depth model of TNEA 2000.

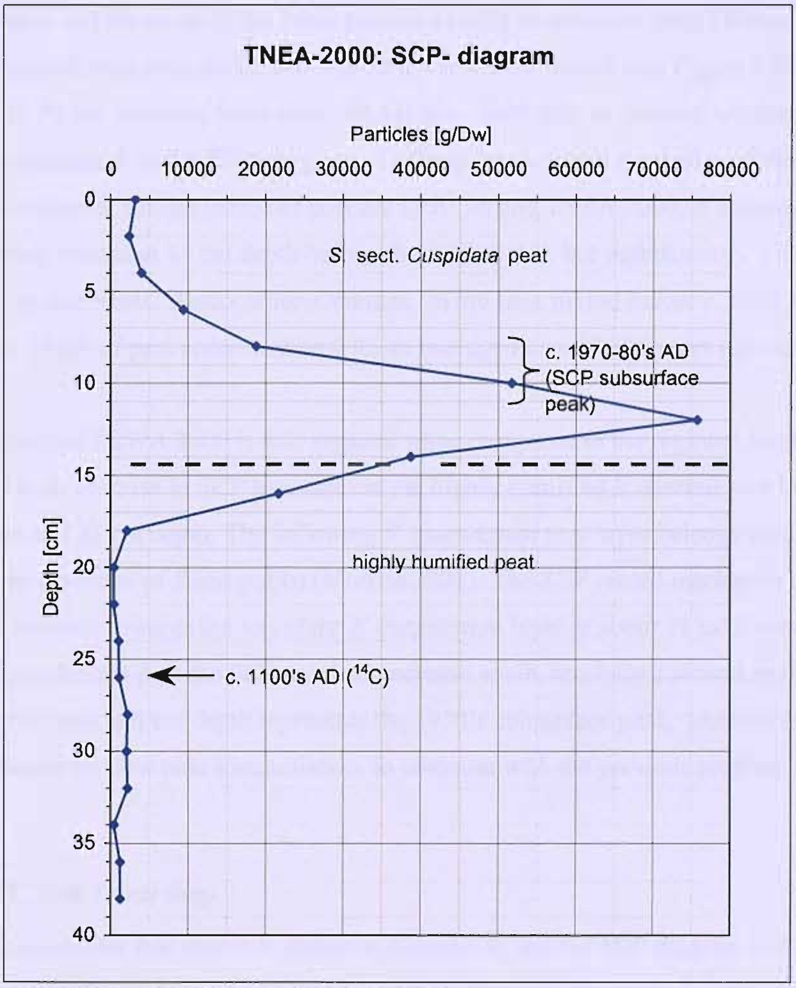


Figure 5.6: SCP diagram of TNEA 2000.

worth noting that after 52 cm depth, where *Sphagnum* dominated peat is underlain by highly humified radicell peat there seems to be no change in the accumulation rate. After *c.* 1100 AD the accumulation rate slowed. down to 62.5 years/cm. This change in accumulation is similar but apparently not as extreme as in profile TRE'98 from the Southeast Bog. However, with fewer radiocarbon dates on this profile it is not possible to establish such a detailed age-depth model as for TRE'98. As on the Southeast Bog, peat growth re-started with the onset of modern times as indicated by high numbers of SCP's (Figure 5.6). The SCP profile has similarities to the equivalent profile for TRE'98. It shows an increase in SCP quantities within the highly humified peat and the peak of SCP numbers shortly above the transition from high to low peat humification. Within the top of this *Sphagnum* layer the SCP's become less frequent indicating post-1970's time. Here the same assumption as for the SCP record of TRE'98 is made, that if in *Sphagnum* s. *Cuspidata* hollows decay is faster than in hummocks, as reported by Johnson *et al.* (1990), it can be concluded that *S.* s. *Cuspidata* hollow peat should also need more time to accumulate. Thus it can be assumed that the *S.* s. *Cuspidata* peat between 14 and 8 cm may have accumulated during a longer time-span. This makes it difficult to locate the 1970's peak, as in the SCP diagram of TRE'98. It is probably hidden in the big peak between 8 and 14 cm depth.

5.1.1.3 TRWA 2000 (West Bog)

The age-depth model for the profile TRWA 2000 is presented in Figure 5.7. As for core TRE' 98 several radiocarbon dates and the onset of the *Pinus* presence could be obtained from Morriss (2001). These dates were complemented with three additional ones and a new SCP record (see Figure 5.8). For the depth interval from 146 cm to 30 cm, reaching from about 90 AD to *c.* 1060 AD, an average accumulation rate of 8.41 years/cm was calculated. In the following period of bog development a substancial slow down in peat accumulation occurred, similar to that of profiles TRE' 98 and TNEA 2000. It is assumed that this slow down had already started at 34 cm depth before about 1060 AD, but unfortunately a date at this depth was not supported by the NERC Radiocarbon Comittee. In the time period before *c.* 1060 AD to *c.* 1800 AD there was only 14 cm of peat accumulation with an average rate of 73.25 years per cm.

The SCP diagram of TRWA 2000 is also atypical when compared to the regional record of Rose *et al.* (1995). There is an increase in SCP quantities in the highly humified *S. austinii* peat layer of medieval age, between 35 cm and 21 cm depth. The following *S. cuspidatum* peat layer belongs to modern times, as indicated by the presence of *Pinus* pollen (Morriss 2001). The SCP record reaches its maximum value at 18 cm depth and reverses towards the top of the *S. cuspidatum* layer at about 11 to12 cm depth. In the overlaying *S. papillosum* peat the SCP numbers increase again, reaching a second peak at 6 cm depth. It is assumed that the peak at 6 cm depth represents the 1970's subsurface peak, whereas the peak at 18 cm seems rather to be caused by slow peat accumulation, in common with the previous profiles.

5.1.1.4 TWC 2000 (West Bog)

The age-depth model for this profile is shown in Figure 5.9, and the SCP diagram in 5.10. It derives from the margin of the West Bog mire expanse (see Figure 3. 2). Between the two lower dates from 90 cm to 112 cm,

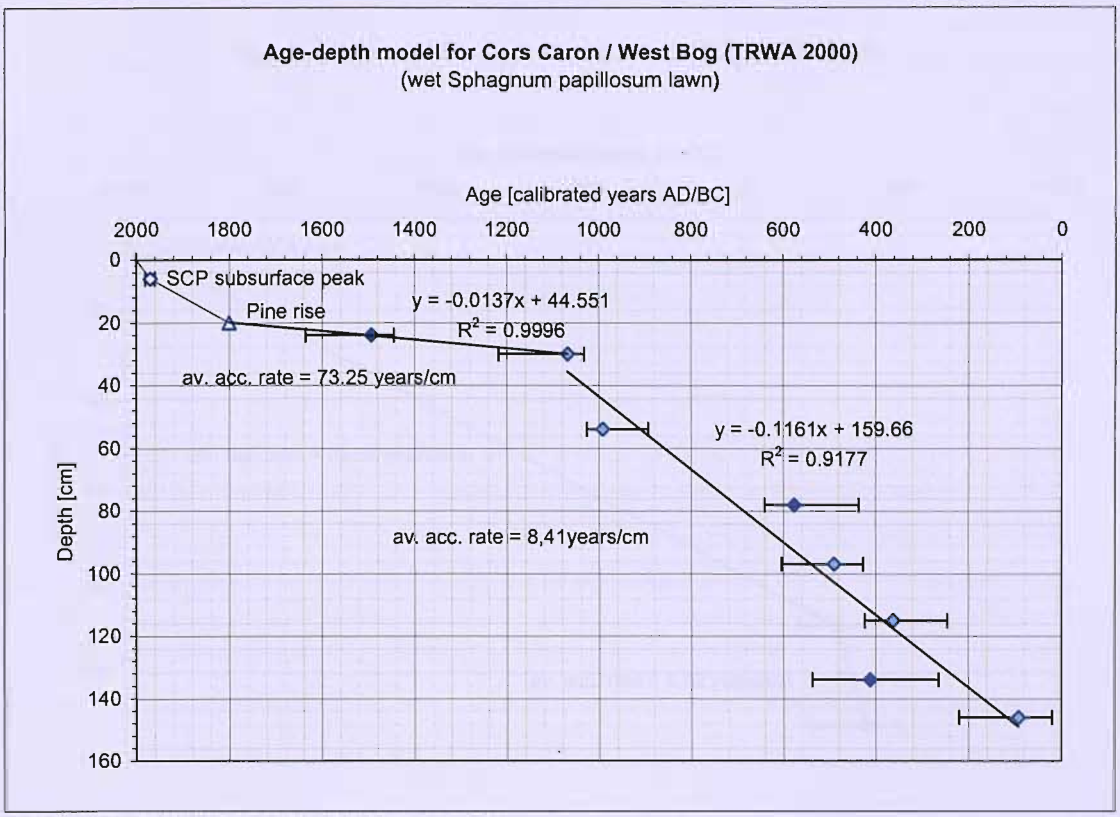


Figure 5.7: Age-depth model of TRWA 2000.

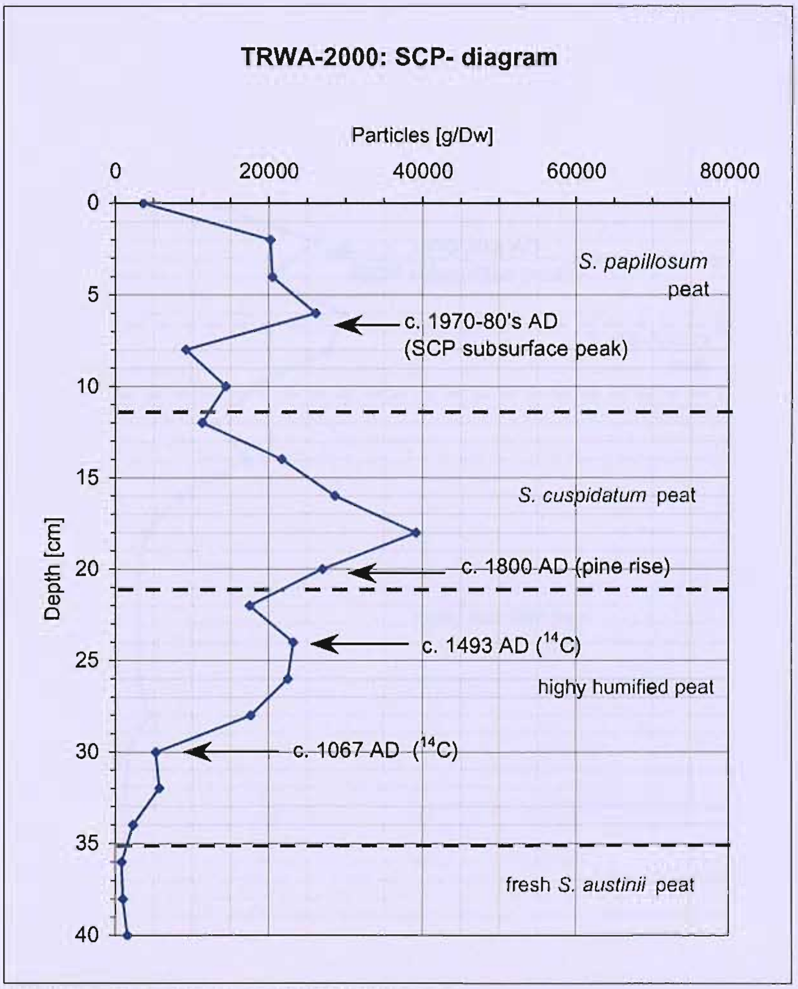


Figure 5.8: SCP diagram of TRWA 2000.

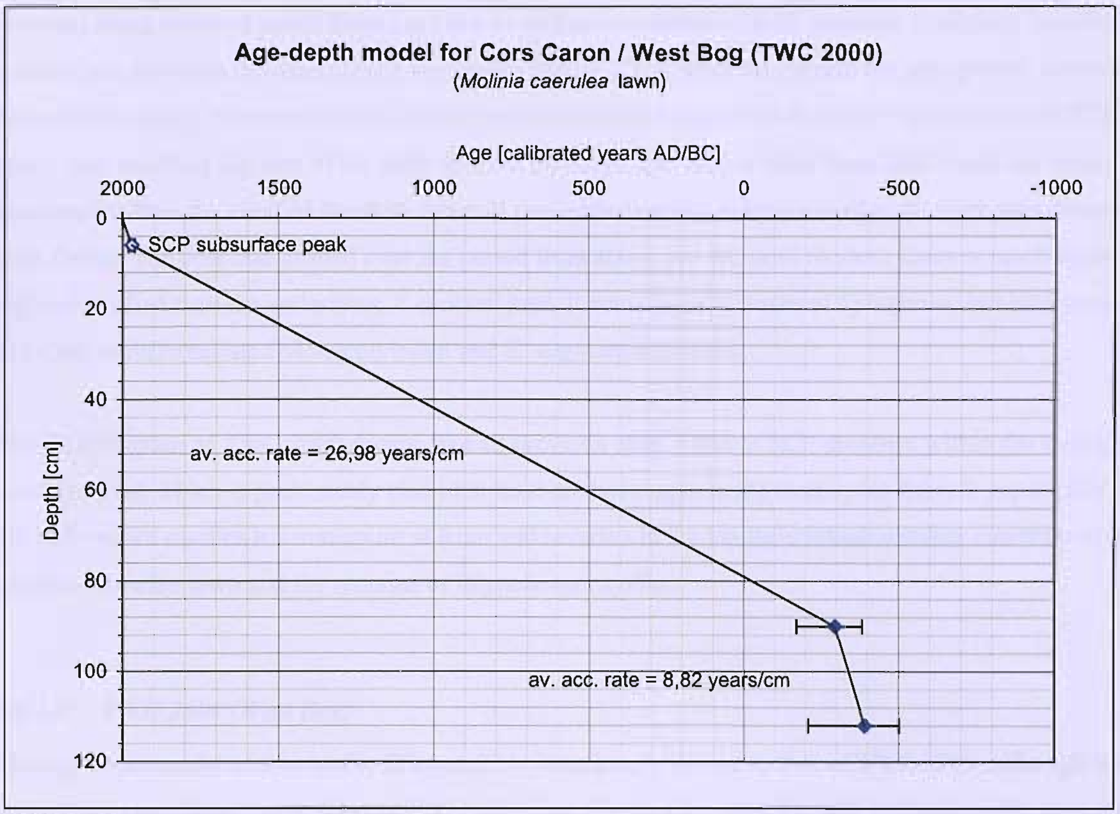


Figure 5.9: Age-depth model of TWC 2000.

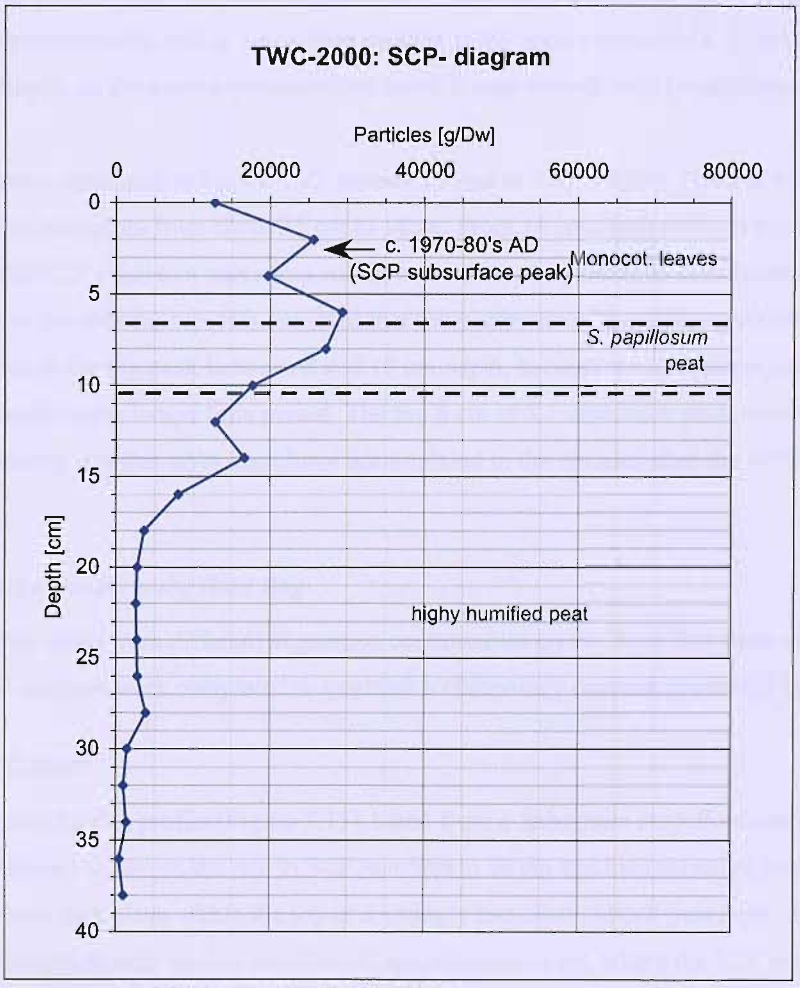


Figure 5.10: SCP diagram of TWC 2000.

covering about hundred years, there has been a rapid accumulation of 8.82 years/cm in slightly humified *S. austinii* peat (see also the macrofossil diagram in Figure 5.32). After this period the peat growth slowed down substantially, in common with all the previous profiles but at a much earlier time (about 390 BC). The upper date, marking the start of the slow down at 90 cm (*c.* 290 BC) is older than 2000 years and about 1300 years earlier than the onset of the slow down in peat accumulation at the summit of all three peat domes of Cors Caron. The peat that formed over the period from about 400 BC until modern times is much more highly humified than the underlying *S. austinii* peat. It contains only traces of *Sphagnum*, but high amounts of UOM, undifferentiated Monocotyledon and *E. vaginatum* rootlets.

The SCP diagram of TWC 2000 shows, like all previous ones, a rise of SCP numbers within the strongly humified peat, which is presumably also of at least medieval age. In the overlaying fresh *S. papillosum* peat the SCP record reaches it's maximum at 6 cm and reverses in the top layer which consists currently of living *Molinia caerulea* lawn and the remains of *Rhynchospora alba.*

5.1.1.5 TWD 2000 (West Bog)

The age-depth model of this profile (Figure 5.11) is strikingly similar to that of TWC 2000. although it is about 1 km apart from the location of TWC 2000 (see Figure 4.2). Here the peat is already older than 2000 years at 72 cm depth (cal. BC 761-404), where the stratigraphy changes from a highly humified peat to a layer of fresh *S. austinii* peat (cal. BC 380-120). Above this fresh *S. austinii* layer the peat is highly humified with UOM, Monocotyledon and *E. vaginatum* rootlets as the main components. In common with profile TWC 2000, there is an even more extreme slow down in peat growth until recent times.

The SCP diagram, presented in Figure 5.12, resembles that of TNEA 2000. There is a slight increase in the highly humified peat strata from about 35 cm to 14cm. From 14 cm depth towards the top of the profile, the quantities of the SCP's rise to a maximum within two centimetres and drop in concentration within the next four centimetres towards the top. It is assumed that the maximum of the SCP input in this profile is also probably hidden in the big peak between 8 and 10 cm depth, because the *Sphagnum* cuspidatum peat may have accumulated over a longer time period. The top 8 cm of *S. cuspidatum* peat contain very low numbers of SCP's indicating that this layer must have accumulated in the decades after the 1970's.

5.1.1.6 Short cores from the West Bog

Four short cores, taken from different vegetation communities on the West Bog have not been radiocarbon dated but SCP analyses were completed to establish a chronology on these profiles (Figures 5.13-5.16).

5.1.1.7 TWE 2002

The SCP diagram for this profile (Figure 5.15), taken from a *Sphagnum magellanicum* hummock (for location see Figure 3.2) shows the rise in SCP numbers at 30 cm and the maximum peak at 22 cm depth. This development took place within the top of a strongly humified radicell peat layer. Above this layer the stratigraphy changes to very weakly humified *S. magellanicum* peat, where the SCP record reverses to

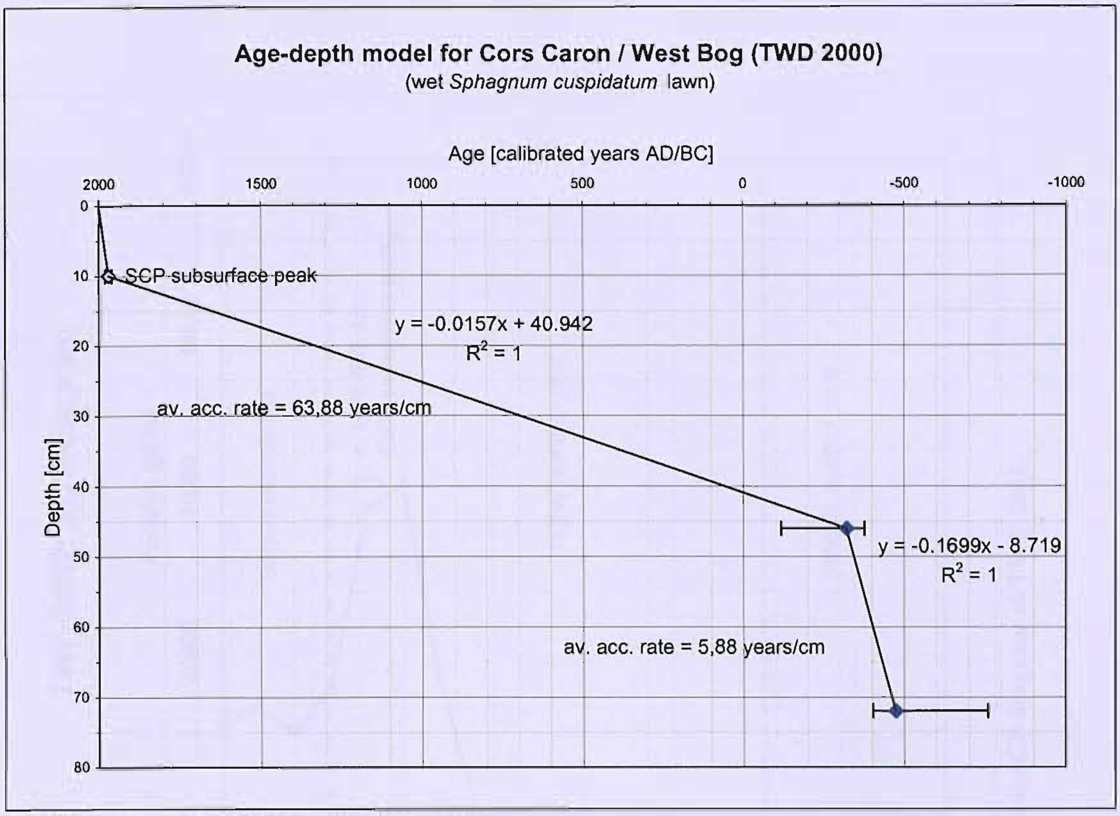


Figure 5.11: Age-depth model of TWD 2000.

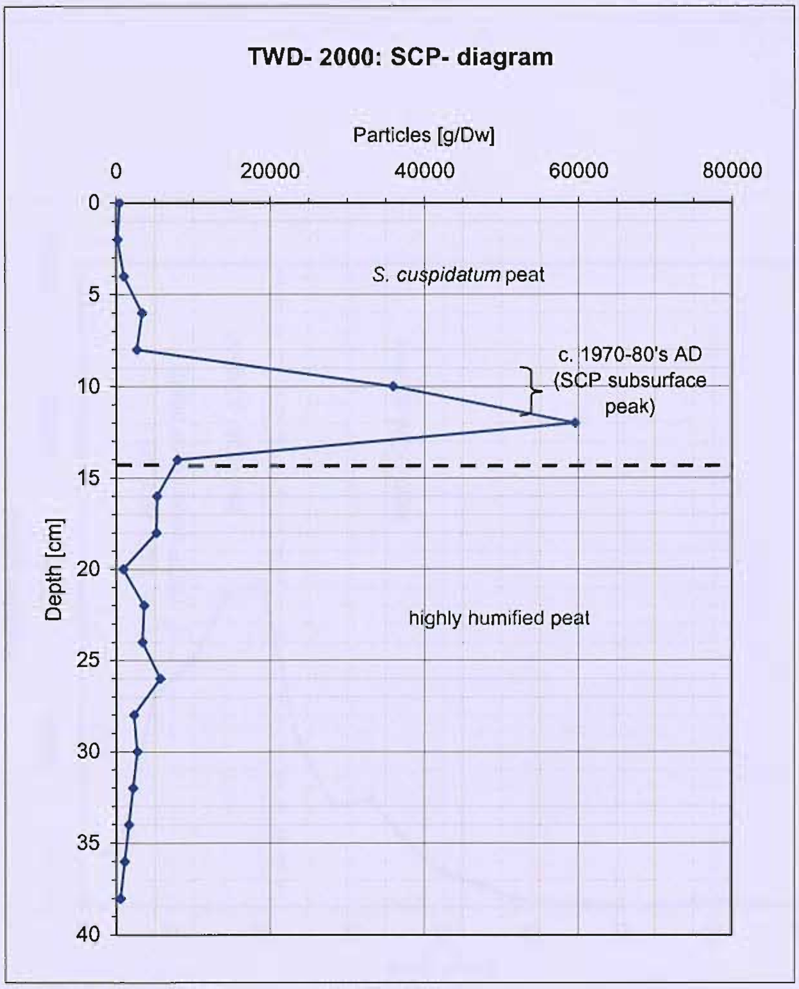


Figure 5.12: SCP diagram of TWD 2000.

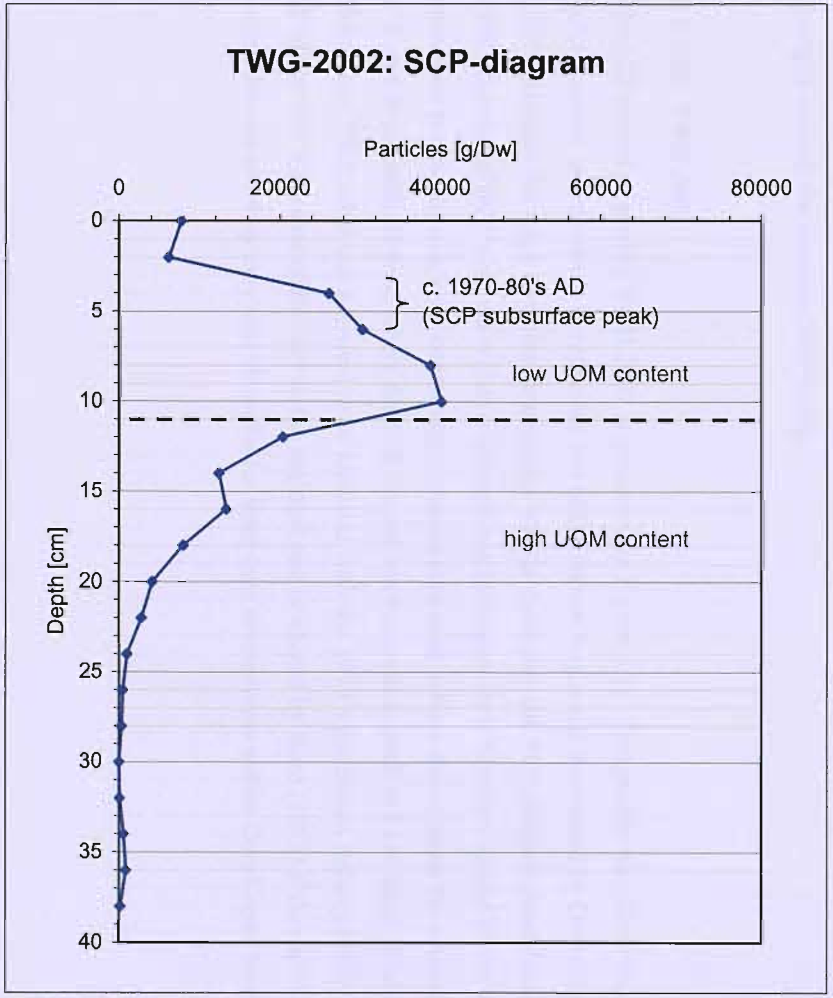


Figure 5.13: SCP diagram of TWG 2002.

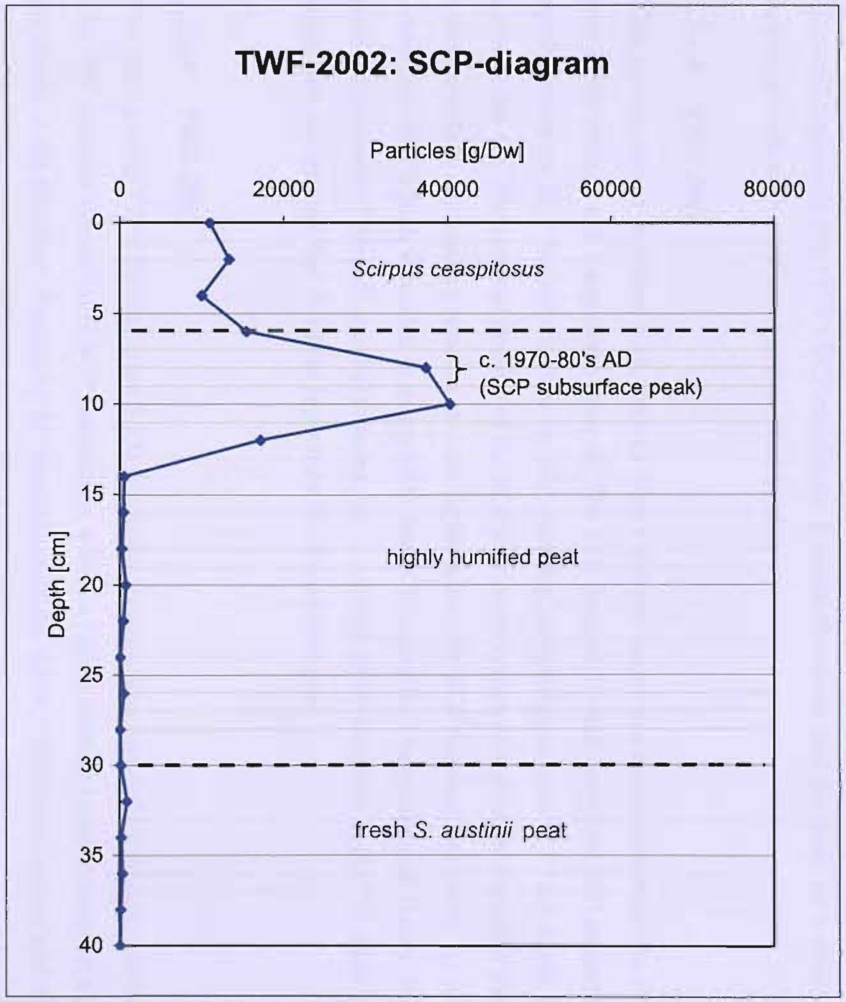


Figure 5.14: SCP diagram of TWF 2002.

relatively low numbers with a smaller, second peak at 12 cm depth. Since the slow accumulation rate of the highly humified peat could account for the maximum in SCP's, it is more likely, that the smaller peak at 12 cm depth represents the 1970's SCP maximum. It seems therefore, that the trend for a rather recent increase in peat growth is also reflected in this short profile.

5.1.1.8 TWF 2002

This profile, shown in Figure 5.14, derives from a *Scirpus cespitosus*-dominated area (see Figure 3.2) and was cored through a *S. caespitosus* tussock. The SCP diagram reveals very low SCP amounts until 14 cm depth, where the SCP frequencies rise rapidly, reaching the maximum peak at 10 cm depth, while reversing towards the top. The rise and decline of the SCP maximum occurs in a strongly humified peat layer, which is overlain with *S. caespitosus* remains at 6 cm depth, where the SCP numbers are lower. As it is not clear, where the 1970's peak is hidden in this profile, the SCP record is of restricted use. Below 30 cm depth the peat is composed of fresh *S. austinii* remains. As *S. austinii* never occurred in the ^{14}C dated cores in modern times one can assume that this peat layer may be of medieval age.

5.1.1.9 TWG 2002

The short profile TWG 2000 (Figure 5.13) originates from an area invaded by modern *Molinia caerulea.* The SCP diagram shows rising SCP frequencies within a highly humified peat stratum between 24 and 12 cm depth. In the top layer, formed by *M. caerulea* remains, the SCP maximum occurs and reverses within the top few centimetres, which are formed by living *M. caerulea.* It is therefore somewhat problematic to interpret this profile objectively. One interpretation could be that the lower parts of the peak are caused by a slow accumulation and the real increase in SCP's may be located between 4 and 8 cm depth, were it is hidden by accelerated accumulation of organic matter. However, for a better interpretation more detailed dating is needed, for example lead dating.

5.1.1.10 TWH 2002

The SCP record of profile TWH 2002 is presented in Figure 5.16. This profile was taken from a *S. pulchrum* hollow, which was assumed to represent one of the former bog pools mentioned by Godwin and Conway (1939). Despite the more complex stratigraphy of this short core the SCP diagram resembles that of TWE 2000. The rise of SCP's occurs within a *Sphagnum papillosum* layer between 30 and 26 cm depth and the maximum is reached in a layer containing *S. cuspidatum* peat. Above this stratum the stratigraphy changes to *S. pulchrum*-radicell peat, where the SCP record reaches another peak at 8 cm depth. The latter peak is, like that of TWE 2000 and assumed to be identical with the 1970's maximum influx of SCP's. Although not all of the SCP diagrams relate easy to the regional one produced by Rose (1995) if they all look similar, within the one site they may still be useful for inter-core connections within Cors Caron for example.

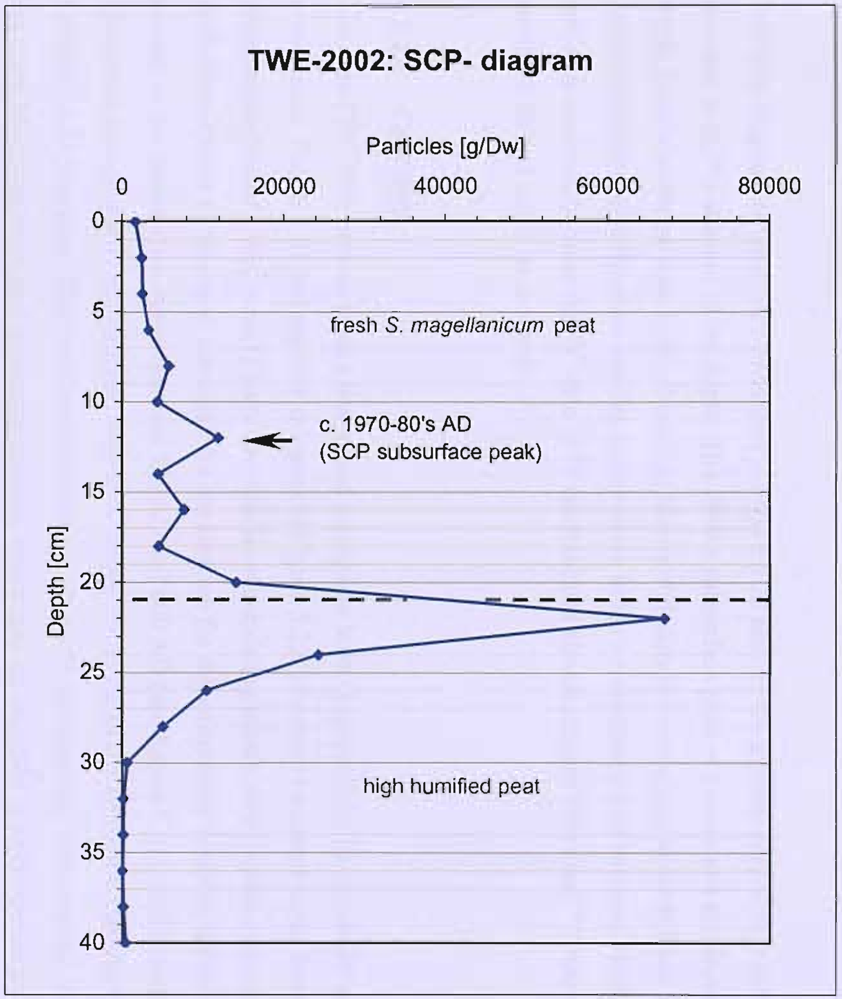


Figure 5.15: SCP diagram of TWE 2002.

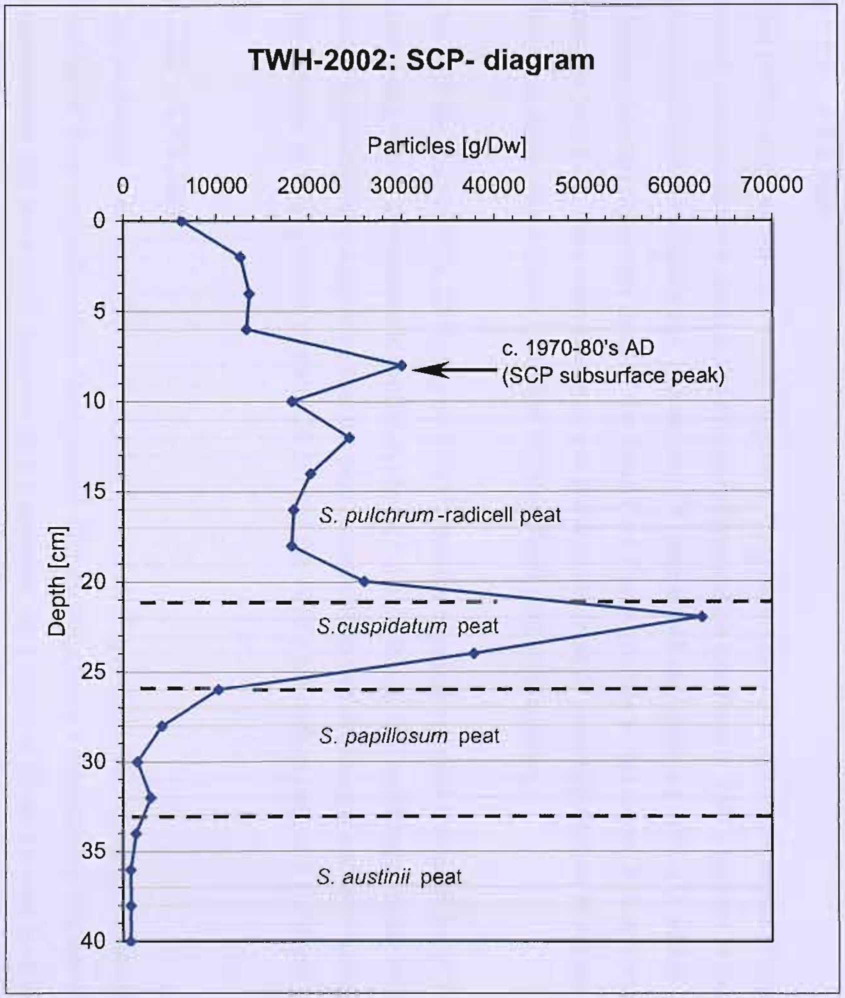


Figure 5.16: SCP diagram of TWH 2002.

5.1.2 Cors Fochno

5.1.2.1 CFA 2000

This profile originates from a wet *Sphagnum* s. *Cuspidata* lawn. The age-depth model (Figure 5.17) shows a smooth continuous slow down in the average accumulation rate from *c.* 7.06 years/cm at the bottom of the profile to 24 years/cm at the top. The earliest ^{14}C date at 148 cm depth is *c.* 280 AD, which is considerably younger than the peat strata in all of the dated Cors Caron profiles at this depth. It is noteworthy, that between 56-74 cm, the accumulation rate is lower in the fresh *S. austinii* peat than in the previous zone of 74-94 cm depth where higher humified UOM-radicell peat accumulated.

The SCP diagram of CFA 2000 (Figure 5.18) looks like a typical regional course of the SCP record resembling that of the schematic profile in Figure 5.2.b. In this profile no changes occur between highly and weakly humified peat, suggesting that the peat accumulation was continuous and more or less homogenic. The increase in SCP's occurs at about 20 cm and the 1970's subsurface peak at 8 cm depth.

5.1.2.2 CFB 2001

This profile has been taken from a *S. austinii* hummock (Figure 3.3). The age-depth model (see Figure 5.19), established from two radiocarbon dates and the SCP record, shows a considerable increase in the accumulation rate from 29.41 years/cm to 9.9 years/cm. At a depth of 72 cm the peat is of medieval age (*c.* 1100 AD), which is much younger than the peat at this depth within profile CFA 2000. Above 50 cm depth the accumulation rate increases although the peat contains much more UOM, Ericaceae and Monocotyledon remains, which is assumed to have a lower accumulation rate than the more *Sphagnum*-rich peat below 50 cm (see macrofossil diagram in Figure 5.39).

The SCP diagram of CFB 2001 presented in Figure 5.20 also shows a rather typical SCP record, with an increase in SCP's at about 32 cm depth. The 1970's subsurface peak is located at 4 cm depth. At 19 cm depth there is a change from highly humified Monocotyledon-Ericaceae peat towards fresh *S. austinii* peat. Despite this change in the plant species a slow down in the accumulation rate between 50 and 19 cm seems not have occurred because the ^{14}C date at 50 cm indicates almost modern times and ^{14}C dating of peat at 32 cm depth turned out to be modern.

5.1.2.3 CFC 2001

The core CFC 2001 derives from a wet mixed *Sphagnum* lawn (Figures 4.3). Its age-depth model is presented in Figure 5.21 and the SCP diagram in Figure 5.22. The two lowermost dates form the lower and upper borderline of a very weakly humified peat layer consisting mostly of *S. papillosum* and *S. pulchrum*. Both dates appear to be almost identical. An explanation for this occurrence could be the fact that there is a plateau in the radiocarbon curve between 550 AD and 600 AD (see Figure 5.23). Additionally, the *Sphagnum* peat probably accumulated very fast. Above 96 cm depth the average accumulation rate slows down to 14.34 years/cm. This may be plausible since above 96 cm depth the peat contains less *Sphagnum* but more Monocotyledon and Ericaceae remains, which may be expected to have formed peat less rapidly

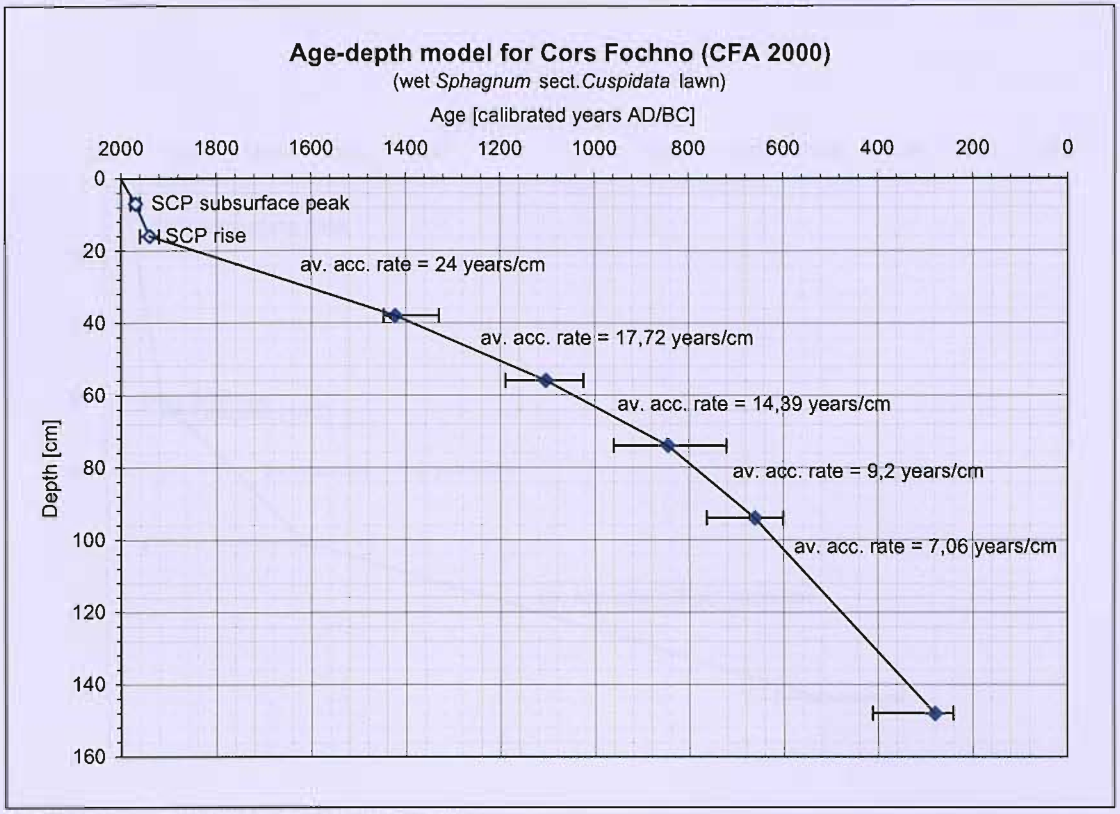


Figure 5.17: Age-depth model of CFA 2000.

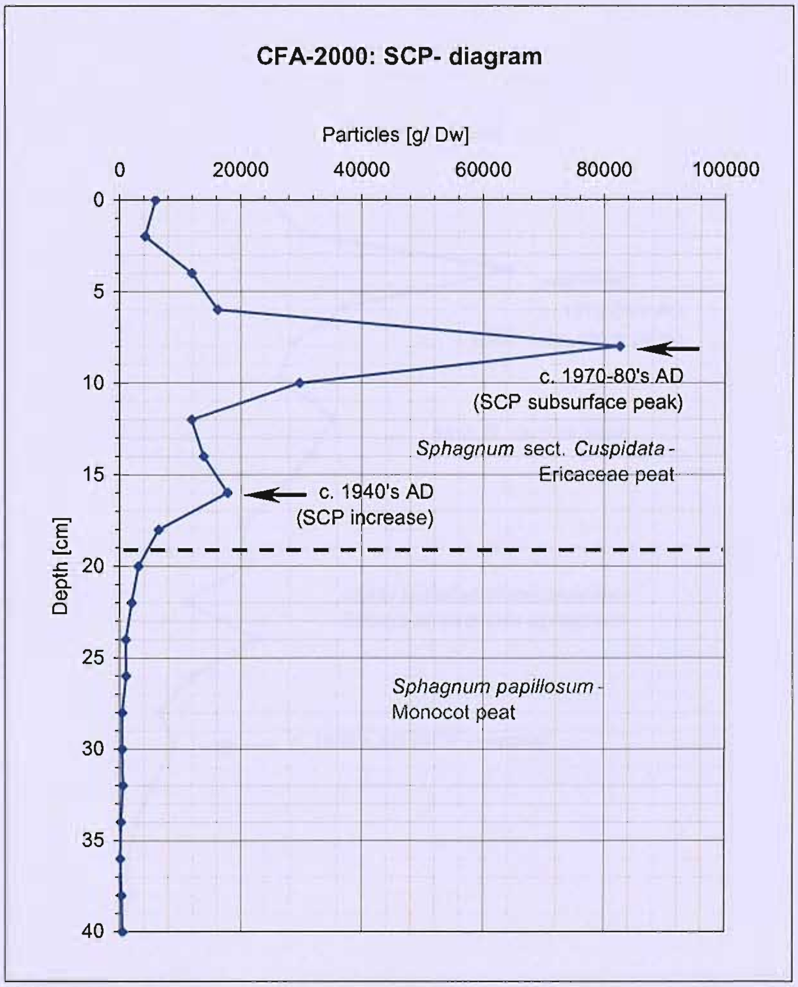


Figure 5.18: SCP diagram of CFA 2000.

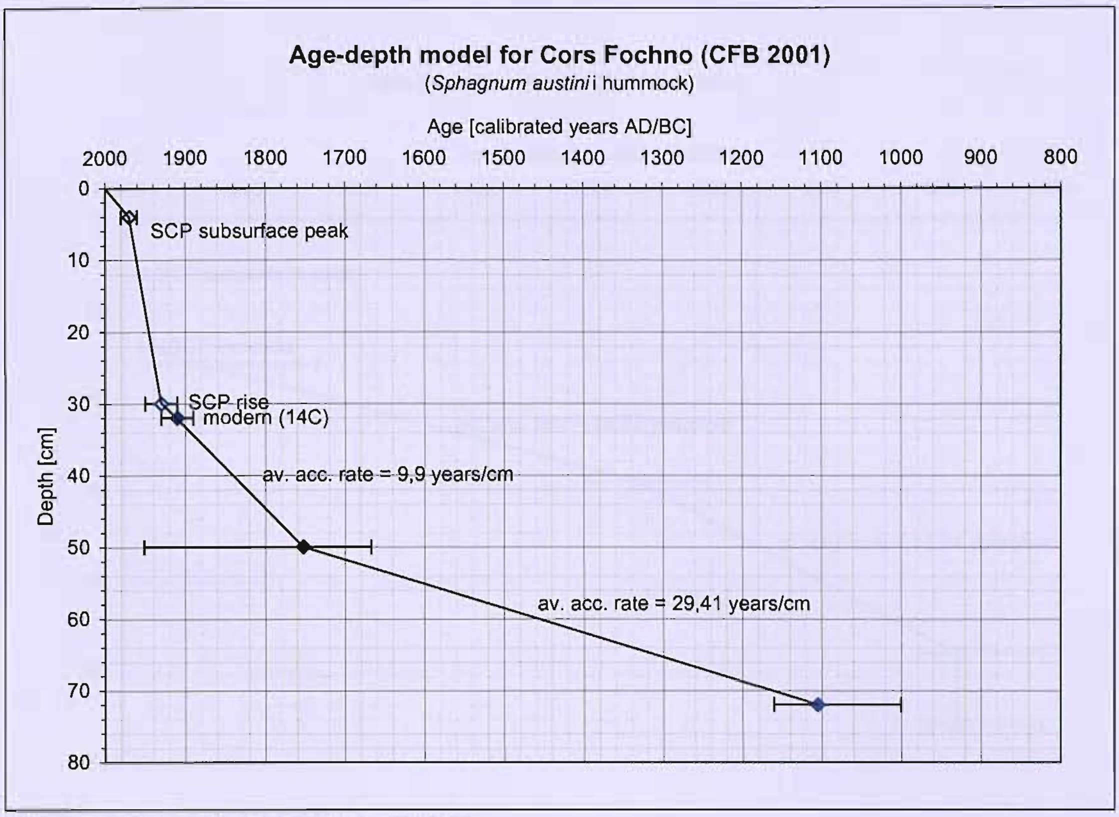


Figure 5.19: Age-depth model of CFB 2001.

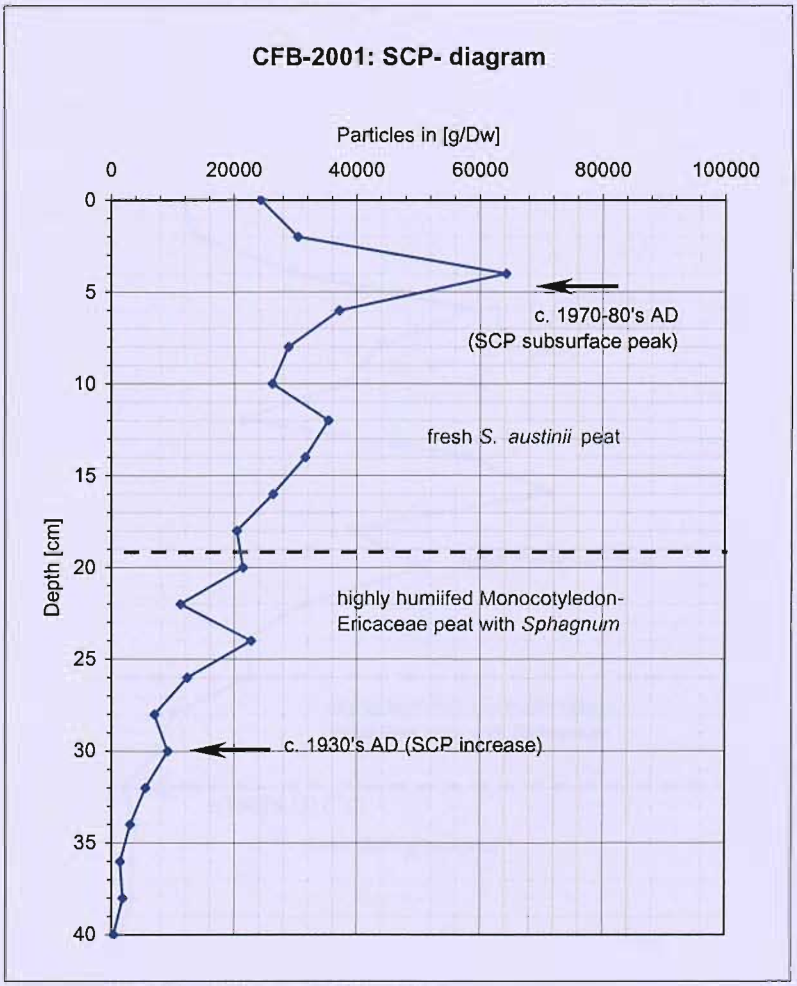


Figure 5.20: SCP diagram of CFB 2001.

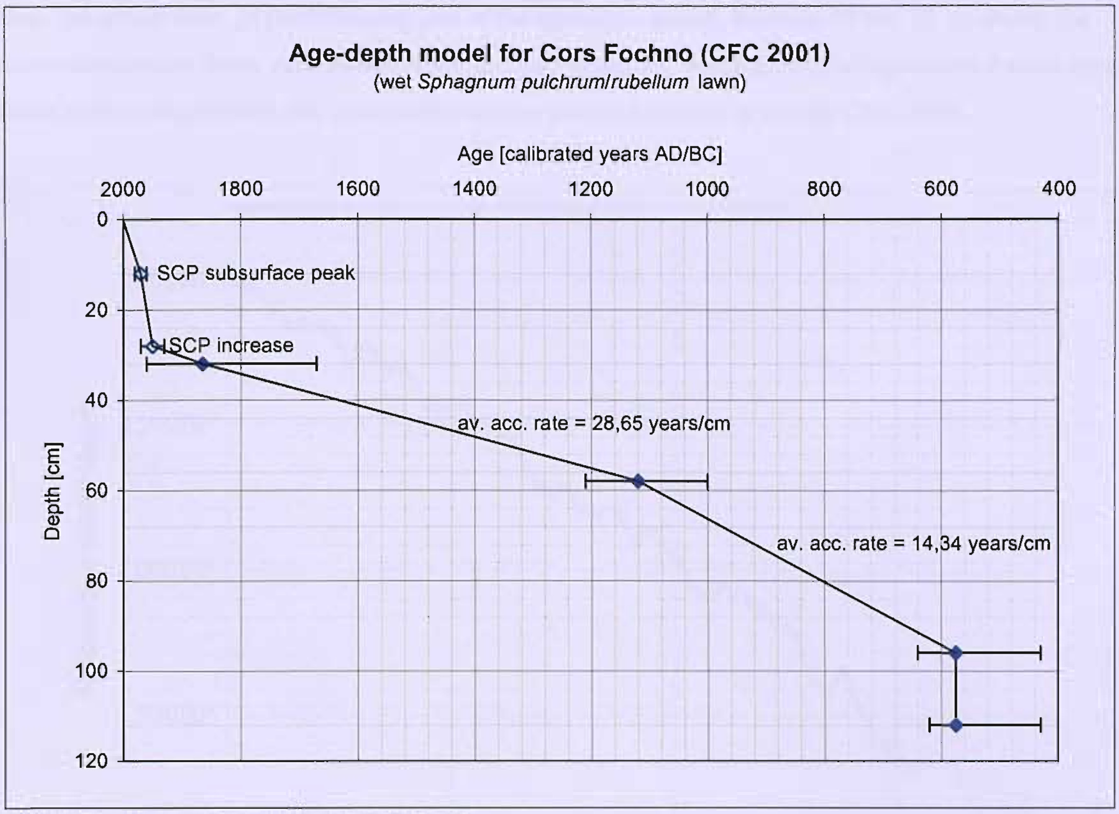


Figure 5.21: Age-depth model of CFC 2001.

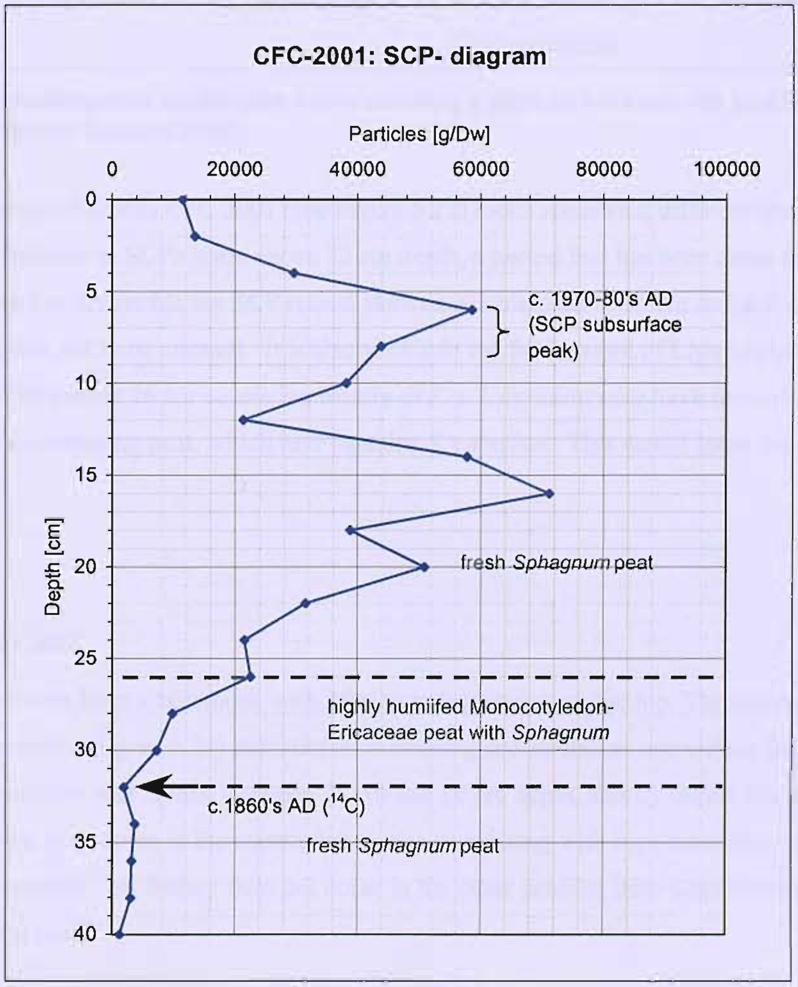


Figure 5.22: SCP diagram of CFC 2001.

than *Sphagnum* does. In the following part of the age-depth model, between 58 and 32 cm depth, the accumulation rate slows even further down to 28.65 years/cm, which gives the impression that the overall trend in the accumulation rate is towards a decline in accumulation as in core CFA 2000.

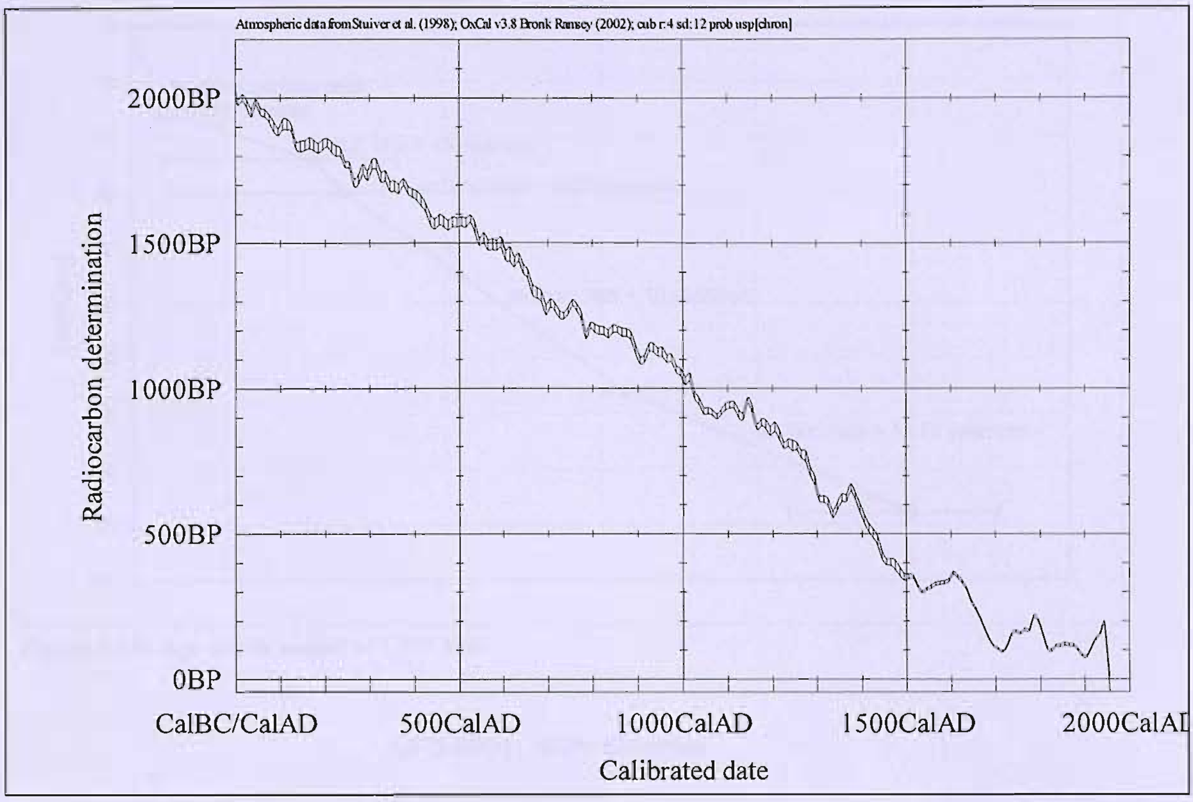


Figure 5.23: Radiocarbon calibration curve showing a plateau between 400 and 600 cal. AD (source: OxCal v 3.8 Bronk Ramsey 2002).

The SCP diagram of profile CFC 2001 (see Figure 5.22) looks somewhat different from the others, of Cors Fochno. The increase in SCPs starts above 32 cm depth, a period that has been dated to the mid-19th century. In the upper part of the profile the SCP record shows a double peak at 16 cm and at 6 cm depth. However, this feature seems not to be unusual. It is also visible in the SCP record of Llyn Lagi (Rose *et al.* 1995) in Figure 5.2.b. The peat at 16 cm consisting mostly of *S.* s. *Cuspidata* may have formed over a longer time period than the overlaying peat, which also contains *S. rubellum*. This would leave the 6 cm peak indicating the 1970's.

5.1.2.4 CFD 2001

This core was taken from a hummock with *Myrica gale* growing on the top. Throughout most of the profile the age-depth model (Figure 5.24) indicates an increasing accumulation rate within *Sphagnum*-dominated and weakly humified peat layers. Between 24 cm and 16 cm depth, shortly before the increase in the SCP record, there is a slow down in the accumulation rate correlating with high amounts of UOM and the final decline of *S. austinii*. This feature does not occur in the other profiles from Cors Fochno and seem not to reflect a general trend.

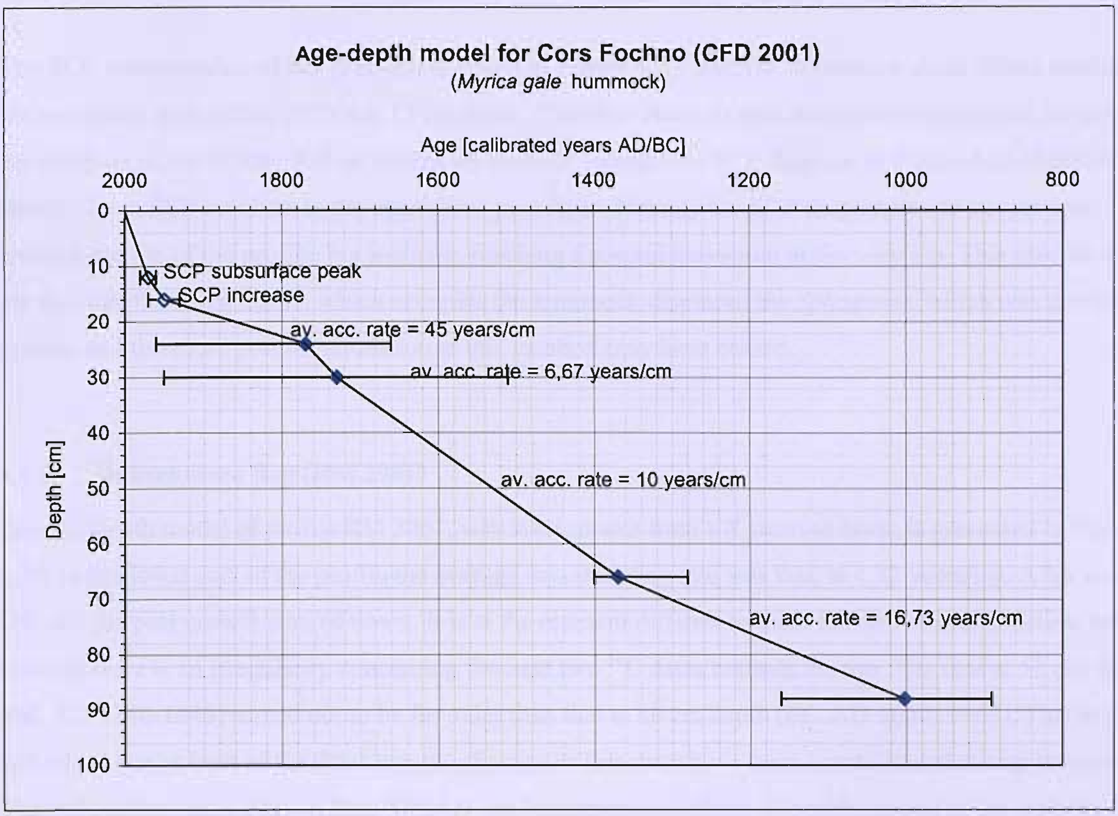


Figure 5.24: Age-depth model of CFD 2001.

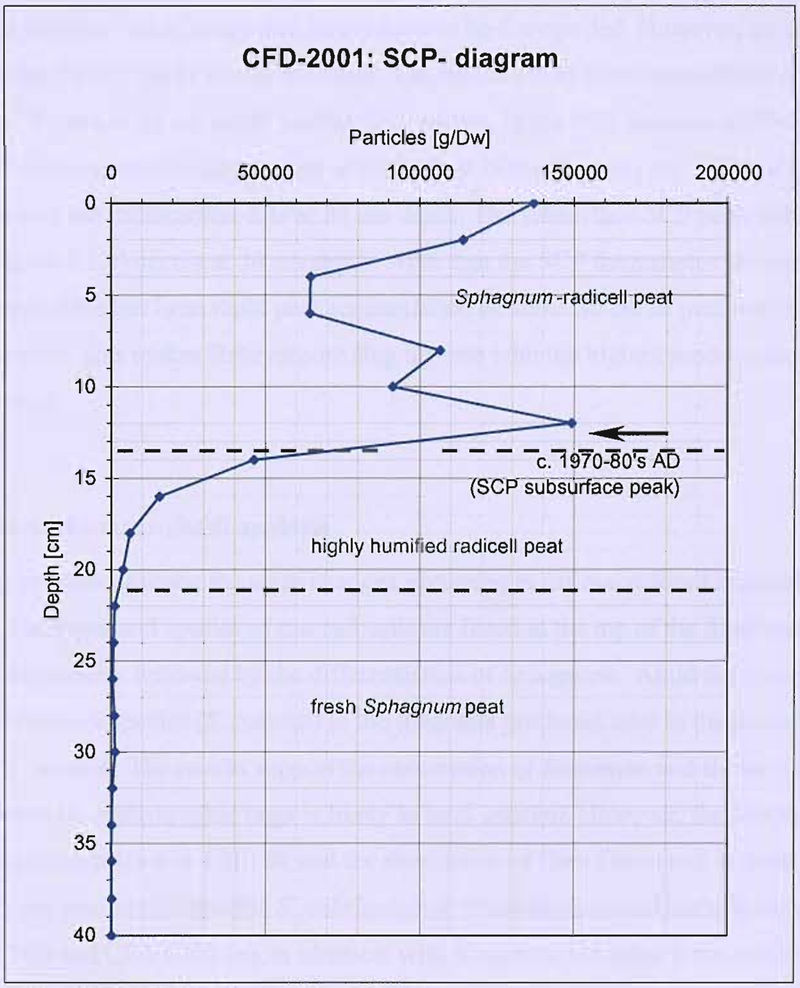


Figure 5.25: SCP diagram of CFD 2001.

The SCP concentration of this profile, presented in Figure 5.25, starts to increase at about 20 cm reaching the maximum peak of the 1970's at 12 cm depth. The slow down in peat accumulation between 24 and 16 cm depth seem not to have had an impact on the SCP record. The SCP diagram in Figure 5.24 shows a steady rise in SCP numbers in the considered peat layer. Notably the SCP frequencies do not reverse towards the top of the profile, but increase, reaching a second maximum at the very top. This may be due to the fact that the *Myrica gale*, which occupies the hummock displaced the *Sphagnum,* which was previously present and therefore peat accumulation at this location may have ceased.

5.1.3 Raheenmore Bog (RM 2001)

The age-depth model of profile RM 2001, which originates from a *S. austinii* lawn, is presented in Figure 5.26. In the lower part of the profile the average accumulation rate was fast, at 4.32 years/cm. After about 670 AD the peat growth slowed down. It is at the moment difficult to track the rate of accumulation further because there is an irregularity concerning the next two ^{14}C dates towards the top. The date at 56 cm depth (cal. AD 1280-1440) turned out to be far older than that at 80 cm depth (cal. AD 1660- 1960). This implies that either one or both of the dates are out of range or they may have been contaminated during processing. The radiocarbon laboratory in East Kilbride has been contacted about this problem and in the reply the laboratory considers that accidental switching of the two radiocarbon dates to be highly unlikely. The date at 80 cm depth is possibly out of range and would have to be disregarded. However, an additional peat sample will be sent to the NERC lab to clarify the issue. The top 38 cm of the peat profile is of modern age, as indicated by a ^{14}C date at 36 cm depth and the SCP record. In the SCP diagram of RM 2001 (Figure 5.27) increased SCP amounts are already present at the bottom of the diagram and indicate modern times, which is in accordance with the radiocarbon date at 36 cm depth. The subsurface SCP peak indicating in Ireland the 1980's (see Figure 5.2.c) occurs at 30 cm depth. After that the SCP frequencies reverse. This implies that in very recent times there has been rapid peat accumulation of about 30 cm of peat within the last three decades at the core location. This makes Raheenmore Bog the one with the highest modern accumulation rate of the three bogs studied.

5.2 Results of the macrofossil analysis

The following sections describe the main changes occurring in the macrofossil assemblages of the sampled peat profiles. The types and species of macrofossils are listed at the top of the diagrams starting with the general peat components followed by the differentiation of *Sphagnum*. Amid the *Sphagnum*, *S. imbricatum* was identified down to species (*S. austinii*) in the diagrams produced later in the project. In those it is referred to as *S. austinii*. The results support the assumption of Stoneman and Barber (1993) that any *S. imbricatum* found on ombrotrophic bogs is likely to be *S. austinii*. However, the fact that the species has been continuously identified in TRE, 98 and the short cores of Cors Caron and in three cores from Cors Fochno justify the assumption that the *S. imbricatum* in the cores analysed early in the project, TRWA 2000, TWC 2000, TWD and CFA 2000 too, is identical with *S. austinii* but since it has not been identified it is referred to as *S. cf. austinii*.

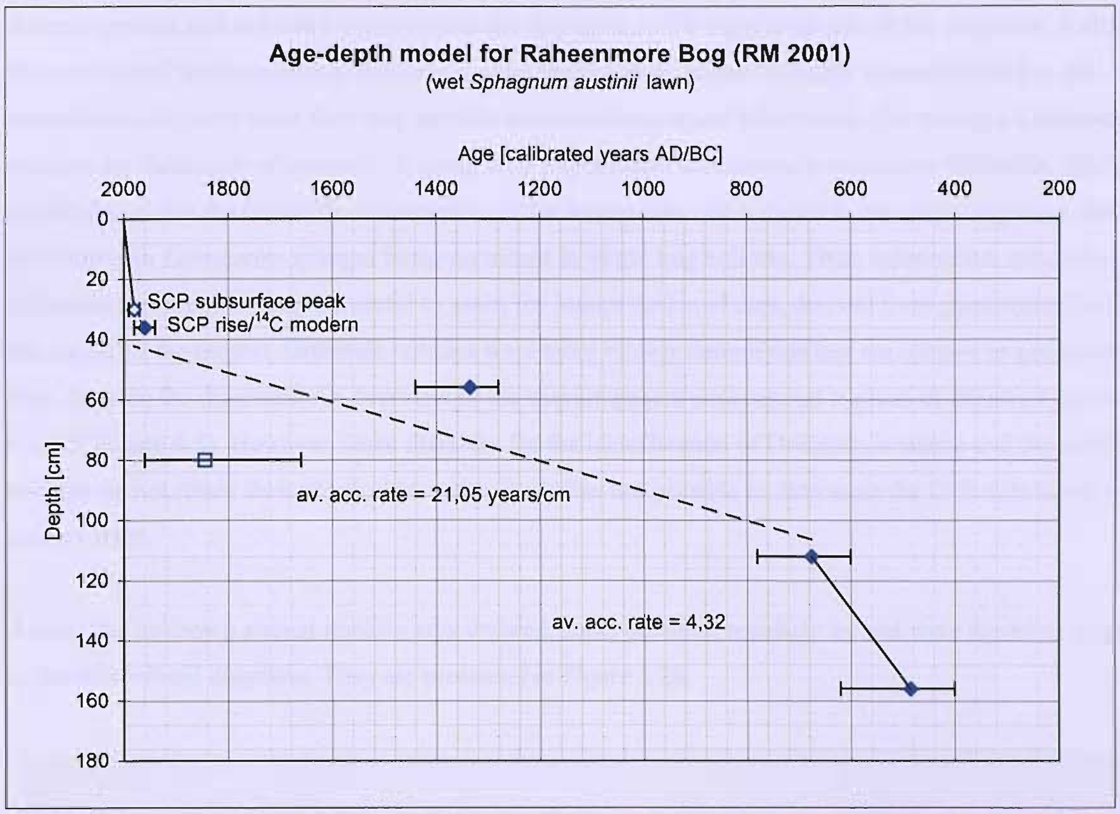


Figure 5.26: Age-depth model of RM 2001.

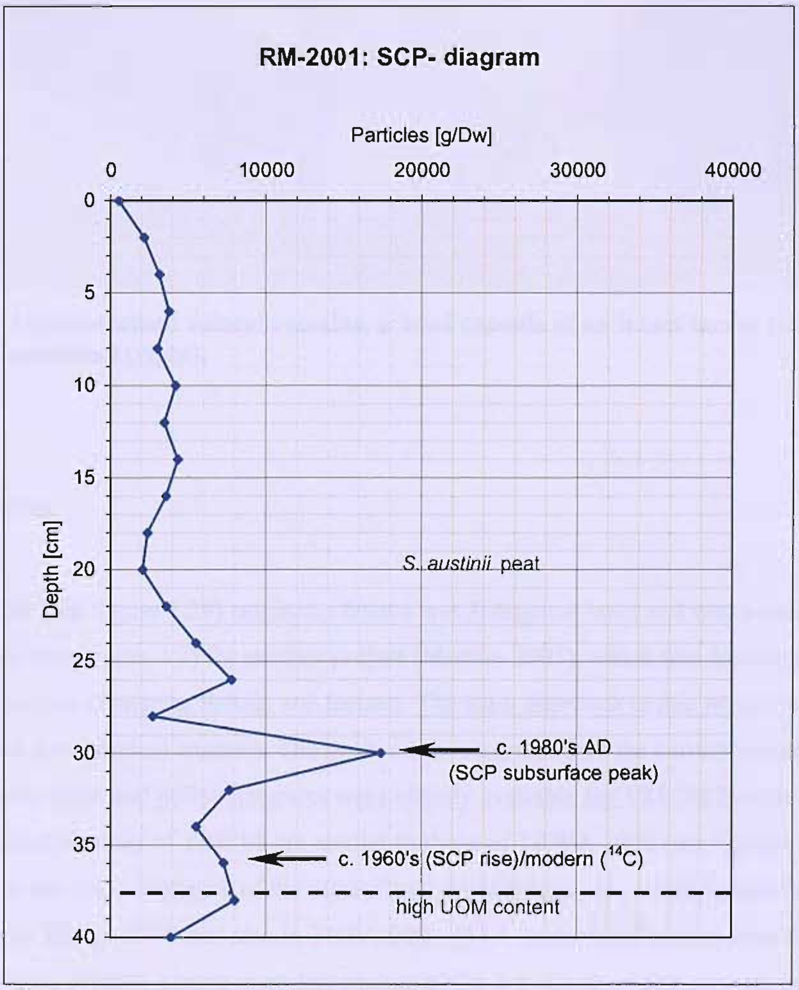


Figure 5.27: SCP diagram of RM 2001.

Animal remains and unknown macrofossils are displayed on the right hand side of the diagrams. Although the macrofossil analysis mainly focuses on plant macrofossils, animal remains where included in the macrofossil diagrams since they may provide additional ecological information (for example Cladocera remains are indicators of wetness). A group with a considerable indicator potential are Oribatida. Markkula (1986) found that the Oribatida communities of the hummocks and hollows in the virgin bog were markedly different with *Limnozetes sphagni* being dominant in virgin bog hollows. Thus, information about the Oribatida communities may be useful to assist the interpretation of data, derived from plant macrofossils. In the course of the project, Oribatida remains were more closely determined and the species or genera have been listed in the diagrams. An overview of the species/genera encountered is given in chapter 4 (section 4.4.3.5, Figure 4.8). However, since literature for the identification of Oribatida is scarce and the subfossil remains do not retain their physical integrity, it is often not possible to determine the Oribatida down to species level.

Among the unknown animal remains encountered, some occurred regularly by and were therefore displayed in the macrofossil diagrams. They are presented in Figure 5.28.

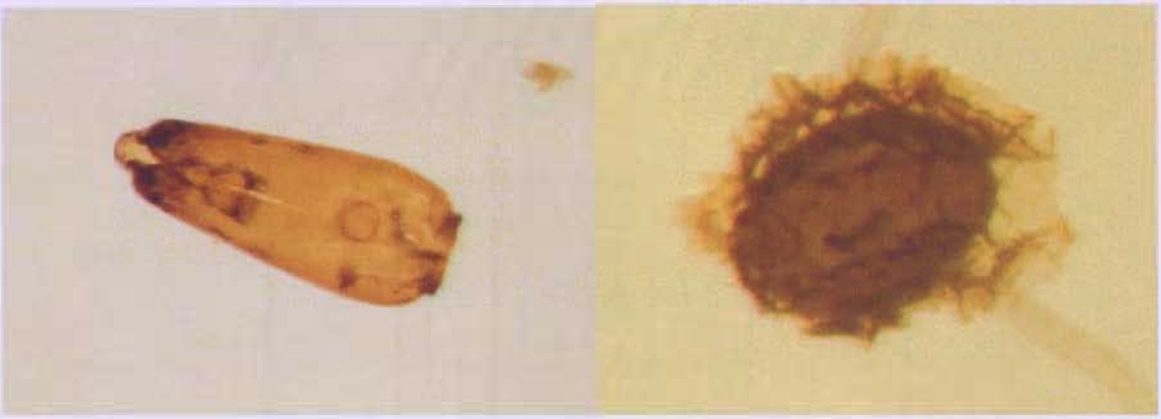
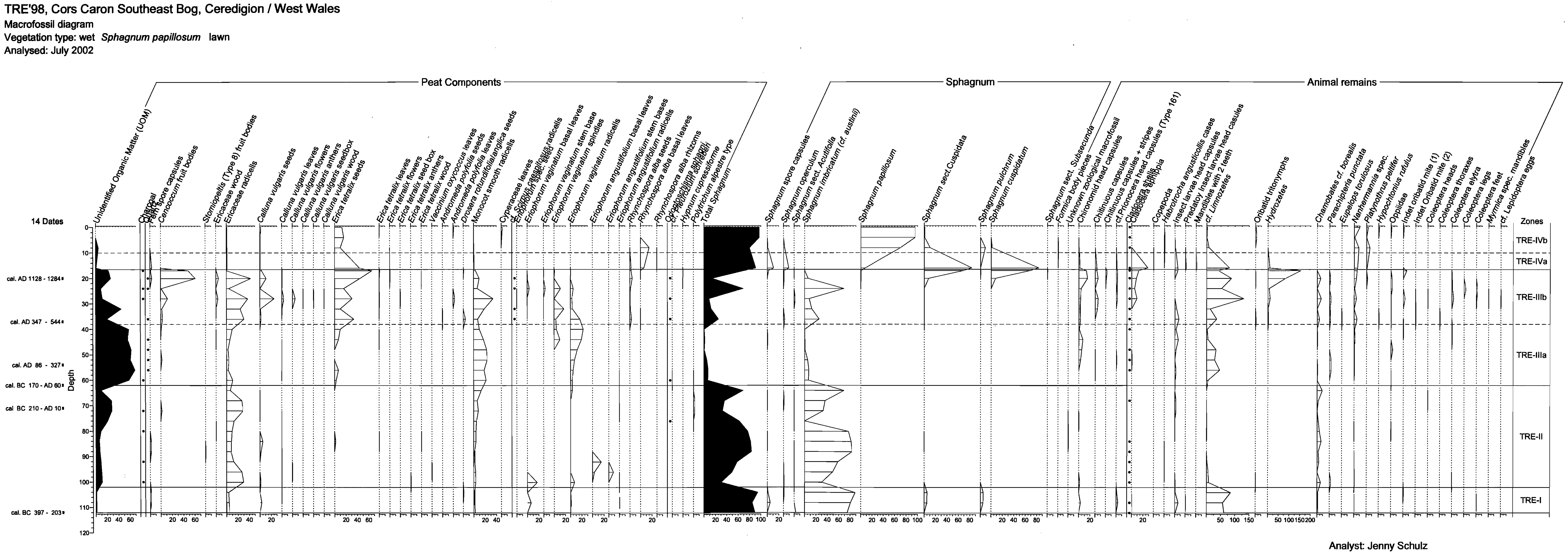


Figure 5.28: Undetermined animal remains, a head capsule of an insect larvae (left) and an unknown zoological macrofossil (right).

5.2.1 TRE'98

Profile TRE'98 (see Figure 5.29) originates from a wet *Sphagnum* lawn and was taken in 1998 from the Southeast Bog (see Figure 4.2) for another project (Morriss 2001), which was focusing on recent human impact and land use change in Britain and Ireland. The main approach in this project was pollen analysis combined with geochemical analysis. The profile was integrated into the current project for several reasons: (1) Radiocarbon dates and pollen diagrams were already available for TRE'98 from Morris (2001). (2) As the chronological features of TRE'98 are similar to those of TRWA 2000 (see Figures 5.3 and 5.7) it was investigated to see if the sequence of the macrofossil assemblages too, would reflect the general bog development in TRWA 2000 and also in TNEA 2000. (3) A macrofossil record from the Southeast Bog was needed in order to provide a more complete picture of the bog development patterns on Cors Caron (see also



TRE'98, Cors Caron Southeast Bog, Ceredigion / West Wales
Macrofossil diagram
Vegetation type: wet *Sphagnum papillosum* lawn
Analysed: July 2002

Analyst: Jenny Schulz

Figure 5.29: Macrofossil diagram of TRE '98.

chapter 4 section 4.3). The profile has been divided into five zones, according to the changes in the macrofossil assemblages.

TRE-I (112-102 cm): The bottom zone is characterised by the dominance of *S. austinii*, accompanied by very little *S. cf. pulchrum*. The other components of the macrofossil assemblage are very infrequent, such as unidentifiable organic matter (UOM) along with Ericaceae and Monocotyledons rootlets. Amid the animal remains, the relatively high numbers of *cf. Limnozetes* mites are notable. Some *Limnozetes* species such as *L. sphagni* occur in high amounts in virgin bog pools (Markkula 1986). Although the species here could not be identified, the high *Limnozetes* numbers together with *S.* pulchrum as an associate with *S. austinii* point towards a wet environment. The bottom of the profile has been radiocarbon dated to *c.* cal. 397-203 BC.

TRE-II (102-62 cm): Zone TRE-II is also dominated by *S. austinii* but in the bottom and top levels of the zone *S. austinii* reverses and UOM amounts along with those of Ericaceae rootlets increase. Monocotyledon rootlets are generally at low values but increase slightly throughout the zone. The numbers of *cf. Limnozetes* declined to traces levels. The zone ends at cal. BC 170-60 AD.

TRE-III (62-16,5 cm): The following sub-zone **TRE-IIIa (62-38 cm)** is marked by a steep decline in *S. austinii* whereas the frequency of UOM increases rapidly and remains dominant. The change towards the upper sub-zone has been dated to cal. 347-544 AD. In **TRE-IIIb (38-16,5 cm),** a reversing trend is visible with increasing *S. austinii* remains. Generally, the numbers of *Erica tetralix* seeds and *cf. Limnozetes* are higher in this zone with an increasing tendency towards the top of the zone. Shortly before the end of the zone peat at 20 cm depth was dated to cal. 1128-1284 AD. In the very top level of this zone a steep increase in *S. cuspidatum* forms the transition towards the top zone.

TRE-IV (16.5-0 cm): In this zone *Sphagnum* forms the bulk of the macrofossils. At the bottom zone, **TRE-IVa (16.5-14 cm)** it is *S. cuspidatum* which is dominant, giving way to *S. papillosum* in the top sub-zone **TRE-IVb (14-0 cm)**. Most of the other macrofossils decline substantially and are only present as traces.

5.2.2 TNEA 2000

This profile (see Figure 5.30) originates from a mixed, wet *Sphagnum* lawn at the summit of the Northeast Bog (see Figure 4.2). The macrofossil assemblage features a highly humified peat layer between less humified peat layers rather like the previously described profile from the Southeast Bog. The core was taken in order to obtain a macrofossil record from the North eastern part of the mire complex and to compare it with the record of TRWA 2000.

TNEA-I (84-74 cm): The bottom zone is characterised by the prevalence of *S. cf. austinii*, which declines towards the top of the zone. It is accompanied by some UOM, Ericaceae rootlets and seeds as well as Monocotyledon rootlets. In the top level higher quantities of *E. angustifolium* leaves occur.

Page 113 missing

TNEA-II (74-54 cm): Zone TNEA-II is dominated by *Sphagnum*. Most other macrofossils have declined and occur only in small amounts. The lower sub-zone, **TNEA-IIa (74-62 cm)** is still dominated by *S. austinii*; however, at the transition to **TNEA-IIb (62-54 cm)**, which is dated cal. 597-690 AD, there is an abrupt change in the prevalence of *Sphagnum* towards *S.* s. *Acutifolia.*

TNEA-III (54-14 cm): After the start of this zone at 52 cm depth and at about cal. 690-893 AD, *Sphagnum* decreases to very low levels. It has been replaced by equal amounts of UOM and Monocotyledon rootlets. Additionally, there are somewhat higher quantities of *E. vaginatum* rootlets and Ericaceae remains. The upper sub-zone, **TNEA-IIIb (54-26 cm)**, starts at 26 cm depth at cal. 1018-1182 AC and shows some differences to the previous zone **TNEA IIIa (26-14 cm)**. Such differences includes the disappearance of *S. austinii* at the core location and the emergence of modest quantities of *S. papillosum* associated with traces of *S. tenellum* and *S. cuspidatum.*

TNEA-IV (14-0 cm): In the uppermost zone the amounts of UOM and Monocotyledon rootlets decline and then dissapear. The content of *Sphagnum* increases to dominance, consisting of *S. papillosum*, *S. tenellum* and *S. pulchrum* along with *S. cuspidatum.* These species are accompanied by *R. alba*, *O. sphagni* and *Kurzia pauciflora. E. tetralix* seeds reach their maximum in this zone as well as the numbers of Oribatida and *Habrotrocha angusticollis.*

5.2.3 TRWA 2000

This profile originates from a wet *Sphagnum papillosum* lawn on the Cors Caron Cors West Bog within the Regeneration complex (see Figures 4.2 and 4.10) and is shown in Figure 5.31. In contrast to the profiles of the Southeast and Northeast Bogs the phase of highly humified peat in this core is much shorter, less pronounced and starts later than in all other dated cores. However, the changes within this profile are numerous, leading to its division into six major zones.

TRWA-I (152-101 cm): The bottom zone is generally dominated by *S. cf. austinii*, but differences in the quantities of UOM, *Cenococcum* fruit bodies and Monocotyledon remains justify a division into two sub-zones. In **TRWA-Ia (152-129 cm)** *S. cf. austinii* is prevalent, joined at the top levels by *S. papillosum* and *S.* s. *Cuspidata.* The amounts of UOM, Monocotyledon rootlets and *E. vaginatum* rootlets are high in this sub-zone but decline within the top levels parallel with the appearance of the other *Sphagnum* species/sections. Among the animal remains; Chironomid head capsules and Oribatida are continuously present. **TRWA-Ib (129-101 cm)** is characterised by higher *S. cf. austinii* values and the dominance of this species reaching 80-90 % of the assemblage. Other *Sphagnum* species/sections occur only as traces. Towards the end of TRWA-Ib *S. cf. austinii* declines somewhat and *E. angustifolium* rootlets increase along with the numbers of *Cenococcum* fruiting bodies, which are generally higher than in the previous sub-zone.

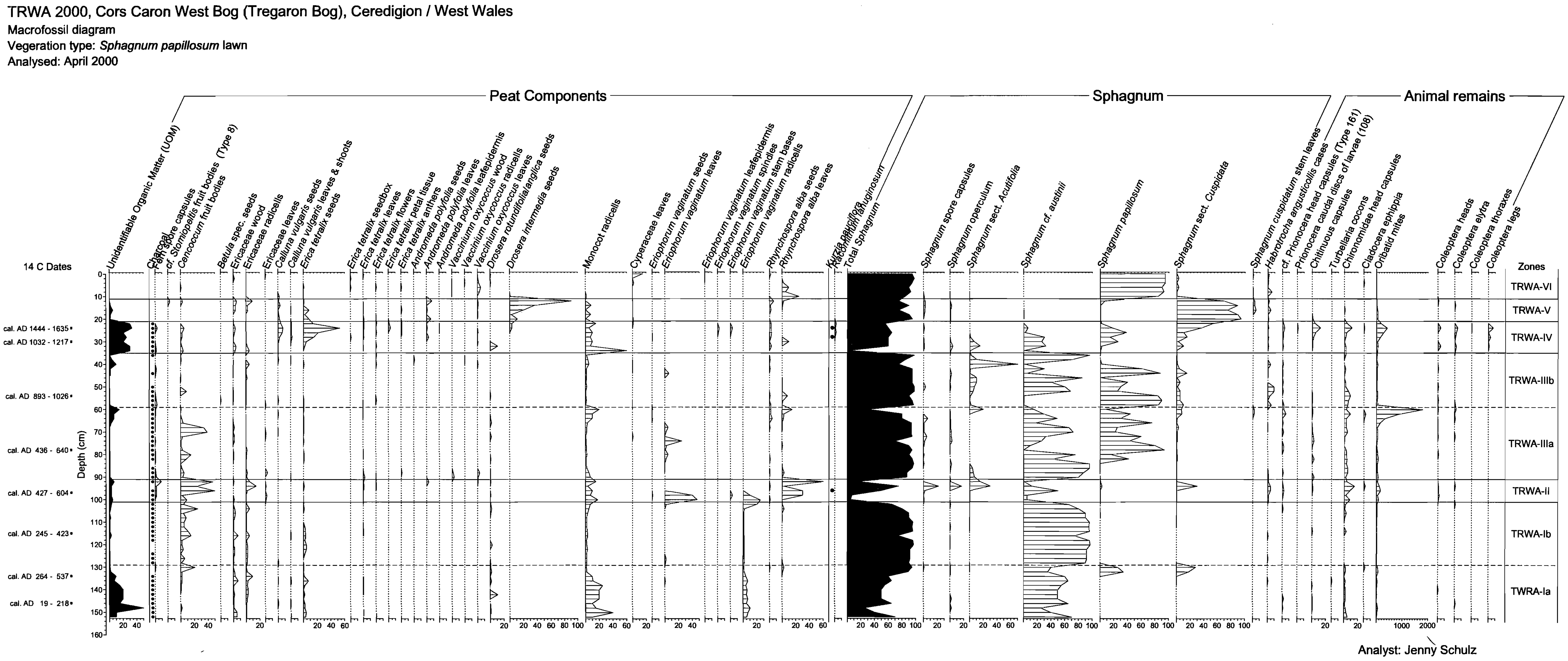


Figure 5.31: Macrofossil diagram of TRWA 2000.

TRWA-II (101-91 cm): In zone TRWA-II the *Sphagnum* content fluctuates but it is generally lower than in the previous zone. At the bottom of the zone *E. vaginatum* remains dominate and in the upper part basal leaves of *R. alba* are frequent. The higher *Sphagnum* content in the upper levels of TRWA-II consist of *S. austinii* and *S.* s. *Acutifolia* and *S.* s. *Cuspidata*. The quantities of Monocotyledon rootlets, UOM and *Cenococcum* fruit bodies are higher in this zone than in the neighbouring zones above and below TRWA-II.

TRWA-III (91-35 cm): Zone TRWA-III is characterised by high values of aggregate *Sphagnum*, dominated by *S. cf. austinii* and *S. papillosum*. UOM, Ericaceae and Monocotyledon rootlets occur only in small quantities. The entire zone is marked by frequent changes in occurrence between *S. cf. austinii* and *S. papillosum*. However, in **TRWA-IIIb (59-35 cm)** the quantities of *S.* s. *Acutifolia* and *S.* s. *Cuspidata* rise somewhat compared to **TRWA-IIIa (91-59 cm)**. At the transition between the two sub-zones the amounts of UOM, Monocotyledon rootlets along *R. alba* remains and oribatid mites increase.

TRWA-IV (35-21 cm): In this zone significant changes occur in the macrofossil assemblage. The amount of *Sphagnum* is lower than in most other zones, whereas the quantities of UOM and Monocotyledon rootlets increase, along with the numbers of *E. tetralix* seeds. It is also noteworthy that some *Racomitrium lanuginosum* occurs within this zone, which occupies the top of hummocks in raised bogs. Another important change occurs in the *Sphagnum* assemblage, where *S. cf. austinii* declines to be replaced by *S. papillosum* and *S.* s. *Cuspidata*.

TRWA-V (21-11 cm): In zone TRWA-V *S.* s. *Cuspidata* is completely dominant. The high numbers of *Drosera intermedia* seeds are very distinctive in this zone. The other macrofossil components in TRWA-V occur only in very low quantities.

TRWA-VI (11-0 cm): In the top zone an abrupt change in the dominating *Sphagnum* species towards *S. papillosum* has occurred, which also forms the current living vegetation cover. It is associated with leaves of *R. alba* and *Vaccinium oxycoccus*. Other macrofossil types are only present as traces.

5.2.4 TWC 2000

Core TWC 2001 originates from the margin of the crown, which is at the current time occupied by *Molinia caerulea* (see Figure 4.2). The macrofossil diagram, presented in Figure 5.32, was expected to be at least similar to TRWA 2000, but turned out to be quite different. Apart from two zones the bulk of the record is dominated by very highly humified radicell peat. However, the changes occurring in the macrofossil record allow a division of the diagram into seven zones, which are described in the sections underneath.

TWC–I (160-150 cm): The bottom zone is characterised by an assemblage of UOM and Monocotyledon rootlets, increasing upwards together with Ericaceae remains and *E. vaginatum* rootlets, which decrease during the course of the zone. There are traces of *S.* s. *Acutifolia* at the very bottom of the diagram.

TWC-II (150-138 cm): TWC–II differs from the neighbouring zones by the presence of some *S. austinii* and slightly increased Ericaceae remains. The UOM amount falls and then increases again at the top of the zone. Monocotyledon and *E. vaginatum* rootlets are somewhat reduced in TWC-II.

TWC–III (138-114 cm): In this zone *S. austinii* has declined back to trace levels, whereas UOM amounts dominate throughout the zone, accompanied by Monocotyledon- and *E. vaginatum* rootlets. In the upper levels of TWC-III *Cenococcum* fruit bodies become frequent. Ericaceae remains have reduced compared with the previous zones. In the top level Monocotyledon rootlets and Acari numbers form significant peaks marking the transition to the following zone at cal. BC 502-208.

TWC–IV (114-91 cm): Zone TWC – IV is characterised by the complete dominance of *S. austinii*, reducing the rest of the macrofossil assemblage almost to trace levels. In the course of the zone the content of *S. austinii* reverses slightly in parallel with a rise in Monocotyledon rootlets.

TWC–V (91-22 cm): The transition to TWC-V is similar to the transition from TWC–III to TWC–IV. A peak in Monocotyledon rootlets and Acari numbers occurs at cal. BC 383-171. Throughout the zone UOM dominates, associated with increased amounts of Monocotyledon- and *E. vaginatum* rootlets. In the whole of TWC–V high *Cenococcum* fruit body numbers correlate with increased seed numbers of *C. vulgaris* and *E. tetralix*. *Sphagnum* occurs only in traces mostly consisting of *S.* s. *Acutifolia*.

TWC–VI (22-10 cm): Sub-zone TWC–VI differs from TWC–V by increased amounts of UOM and Monocotyledon rootlets and the decline of *E. vaginatum* rootlets to trace levels. The numbers of oribatid mites are high through this sub-zone.

TWC–VII (10-0 cm): Zone TWC–VI starts with the presence of *S. papillosum*, which is displaced in the uppermost sample level by remains of *R. alba*, associated with *M. caerulea*, which occurs in the present living vegetation cover at the core location.

5.2.5 TWD 2000

This core has been taken from a *S. cuspidatum* hollow on the northern edge of the bog crown (see Figure 4.2). It is presented in Figure 5.33.Despite the distance of about one kilometre this profile is strikingly similar to the previous TWC-2001. It is divided into five zones.

TWD-I (160-138 cm): The bottom zone of core TWD 2000 is characterised by a substantial amount of UOM along with higher amounts of Ericaceae wood, Monocotyledon rootlets and *E. vaginatum* rootlets. *Sphagnum* occurs only as traces.

TWD-II (138-74 cm): Zone TWD-II has generally higher UOM amounts along with continuously higher values of Monocotyledon rootlets. The presence of Ericaceae wood and rootlets is somewhat lower than in

the previous zone, whereas *E. tetralix* seed numbers rise and are higher in the upper part of the zone, where *Cenococcum* fruit bodies are very frequent. Remains of *E. vaginatum* dominate several levels at the bottom and top of TWD-II. By contrast, *R. alba* remains are more abundant in the middle of the zone. There the *R. alba* is associated with traces of *Sphagnum* and its spore capsules and lids. The top sample level marks the transition to the following zone with Monocotyledon rootlets and oribatid mites peaking at cal. BC 761-404. These changes are similar to zone TWC-III (Figure 5.32).

TWD-III (74-45 cm): TWD-III is dominated by *S. austinii,* which increases with fluctuations towards the top of the zone. Monocotyledon rootlets are slightly reduced in this zone, whereas UOM occurs only in very small amounts. At the top level the frequency of *S. austinii* reverses and the number of *cf. Limnozetes* mites rises substantially.

TWD-IV (45-14 cm): The transition to zone TWD-IV at cal. BC 397-119 is characterised by an increase in Monocotyledon rootlets, *E. tetralix* seeds and an increase in UOM. The quantities of *S. cf. austinii* decline and at the top of the zone and the species then disappears from the record.

TWD-V (14-0 cm): In the top zone, which also forms the living vegetation cover, *S. cuspidatum* dominates. At the transition, in the bottom level of zone TWD-V, the numbers of *E. tetralix* seeds and Acari become abundant along with the increasing content of *S. cuspidatum.*

5.2.6 Short cores

In addition to the *c.* 150 cm long cores, covering the late Holocene, four short cores were taken from the West Bog of Cors Caron in order to reconstruct the very recent vegetation succession of several vegetation units, which have not been covered yet by the longer cores. The vegetation at the core locations involves a *S. magellanicum* hummock (TWE 2002), a *S. caespitosus* tussock (TWF 2002), the *Molinia* area of the West Bog centre (TWG 2002) and one of the former bog pools which is currently vegetated with *S. pulchrum* and *Narthecium ossifragum.*

5.2.7 TWE 2002

Profile TWE 2002, shown in Figure 5.34, has been taken from one of the rather rare *S. magellanicum* hummocks. When excavating the monolith from the core location (Figure 4.2), a sharp contrast between the fresh *Sphagnum* peat and the dark underlying peat was visible which is also reflected in the macrofossil diagram of TWE 2002 (transition from zone TWE-IIIb to TWE-III in Figure 5.34).

TWE-I (46-50 cm): This zone is marked by the decline and near disappearance of *S.* s. *Acutifolia* whereas at the same time the UOM quantities rise substantially. There are few remains of Ericaceae species but somewhat more Monocotyledon rootlets and *E. vaginatum* rootlets.

TWE-II a (46-26 cm): In this sub-zone the trend of high UOM values, together with the presence of few Ericaceae remains and Monocotyledon rootlets continues. In addition, to the *E. vaginatum* rootlets, further remains of this species are present as stem bases, spindles and basal leaves. In this zone fruit bodies of *Cenococcum* are also frequent and occasionally the fruit bodies of *cf. Stomiopeltis* (Type 8) occur. In the entire zone TWE-II *Sphagnum* occurs only as traces. The second sub-zone, **TWE-II b (26-22 cm)** can be separated from the previous one by the increase in UOM and a decline in the amount of Monocotyledon rootlets. Remains of *E. vaginatum* disappear in this sub-zone. Among the animal remains there is a notable increase in numbers of *Nanhermannia* spp. coincident with the maximum in UOM frequencies. It is also noteworthy, that most of the UOM at this level consists of many small pellets, which may be droppings from the soil fauna.

TWE-III (22-0 cm): At the bottom of this zone the macrofossil assemblage changes dramaticly. The UOM amounts decline steeply and occur only in traces throughout the rest of the zone. *Sphagnum magellanicum* rises to dominance, accompanied by small quantities of *Odontoshisma sphagni*, *Calypogeia sphagnicola* and *Hypnum cupressiforme*. At the bottom of the zone the amounts of Ericaceae rootlets rise somewhat but decline towards the top of the zone. This is accompanied by significant rises in numbers of *E. tetralix*, which decrease in coincidence with the decline of the Ericaceae rootlets.

5.2.8 TWF 2002

TWF 2002 (see Figure 5.35) was placed in a *Scirpus caespitosus* stand within the former Scirpetum to investigate the history of this vegetation type. The peat underneath the *S. caespitosus* tussock was highly humified, amorphous and very tough, requiring considerable physical effort to excavate the monolith.

TWF–I (48-45 cm): The bottom zone of this profile is characterised by the dominance of *Sphagnum. S.* s. *Acutifolia.* The taxon then declines in the upper level, whereas *S. austinii* appears in higher frequencies later in the zone. The rest of the macrofossil assemblage is roughly equally shared between UOM, Ericaceae rootlets and Monocotyledon rootlets. *E. vaginatum* rootlets occur in small quantities.

TWF-II (45-29 cm): In the second zone *S. austinii* remains dominate, whereas most of the other components of the macrofossil assemblage decline in frequency. The seed numbers of *E. tetralix* are an exception. They rise slightly at the bottom of the zone and increase significantly at its top level. At the same level the amount of UOM also rises at the expenses of *S. austinii.*

TWF-III (29-6 cm): At the beginning of zone TWF-III *S. austinii* declines dramatically and is only present as traces throughout the zone along with minimal amounts of other *Sphagnum* species. UOM dominates from the bottom to the top of this zone, accompanied by higher amounts of *Cenococcum* fruit bodies and somewhat higher quantities of Monocotyledon rootlets. In this zone there are more remains of Monocotyledons and Ericaceae present than in the previous one. The increase in *E. tetralix* seed numbers is also notable. Amid the zoological sub-fossils the numbers of *Nanhermannia* and *cf. Limnozetes* are significantly higher than in all other zones.

TWF-IV (6-0 cm): In the transition towards the top zone the UOM frequencies reverse to small amounts and also the frequencies of *E. tetralix*. The remains of most Monocotyledons, which were frequently present in the previous zone, disappear and give way to *S. caespitosus* litter, which dominates zone TWF-IV.

5.2.9 TWG 2002

TWG 2002 was taken from a location within the former Molinietum and has been sampled through a *M. caerulea* tussock. It is presented in Figure 5.36. The highly humified dark peat material below the *Molinia* tussock was even more tough than that of TWF 2002, causing difficulties during sampling.

TWG-I (46-34 cm): The bottom zone of this profile is characterised by an abundance of *Sphagnum*, mostly represented by *S. papillosum* and *S.* s. *Acutifolia*. The rest of the macrofossil assemblage is composed by UOM, rootlets of *E. vaginatum* and Monocotyledons as well as Ericaceae. In this zone the highest quantities of *Nanhermannia* spp. occur, accompanied also by frequent *cf. Limnozetes*.

TWG-II (34-18 cm): In this zone a substantial change occurs in the dominating macrofossils. The amounts of UOM and Monocotyledon rootlets rise significantly, whereas *Sphagnum* remains decline to trace levels and then disappears from the record. *E. vaginatum* basal leaves and spindles become very abundant. The bottom level of this zone differs somewhat from the main part of it and therefore TWG-II was divided into two sub-zones. **TWG-IIa (34-30 cm)** differs from **TWG-IIb (30-18 cm)** because it contains fewer Monocotyledon rootlets and high numbers of *cf. Limnozetes* mites. At the same level oribatid tritonymphs are also present in moderate numbers.

TWG-III (18-0 cm): The uppermost zone is differentiated from the previous one by declining amounts of UOM, but very abundant *Cenococcum* fruit bodies and rising quantities of Monocotyledon rootlets. Also increasing are the numbers of *C. vulgaris* and *E. tetralix* seeds along with a modest presence of Ericaceae rootlets. The top layer is dominated by living stem bases and roots of *M. caerulea*.

5.2.10 TWH 2002

This core (presented in Figure 5.37) has been taken from a hollow, which has been assumed to be one of the former bog pools mentioned by Godwin and Conway (1938) and also recognisable on the aerial photographs of 1947 and 1948. Its current vegetation consists mostly of *Narthecium ossifragum* and *S. pulchrum*. The ground in this hollow was notably quaking and soft. The material below the rooted horizon was half liquid and appeared to be pool mud. When taking the monolith out of the ground this had to be carried out quickly in order to prevent its content from flowing out. This has to be taken into account when looking at the UOM content of this profile.

TWH-I (48-33 cm): The bottom zone of this profile is dominated by *S. austinii*, which declines towards the top of the core, where traces of other *Sphagnum* species appear such as *S. papillosum*, *S. pulchrum* and *S. cuspidatum*. Along with the decrease in *S. austinii*, the UOM content rises continuously and gains dominance in the top level of TWH-I. In the same level also, seed numbers of *E. tetralix* rise significantly, but the amount of Ericaceae rootlets remains very low. Monocotyledon rootlets rise somewhat at the bottom of the zone and remain present in moderate quantities throughout TWH-I.

TWH-II (33-27 cm): In the second zone the UOM amounts reach the maximum correlating with a rise in *Cenococcum* fruit body numbers. The quantities of *Sphagnum* drop at the start at the zone but increase again in the upper part of the zone. *S. austinii* is reduced to traces and gives way to *S. papillosum*, which is the dominating *Sphagnum* species in this level. Seed numbers of *E. tetralix* are generally higher than in the previous zone and seeds of *C. vulgaris* appear for the first time in the profile. Whereas there are no drastic changes within the macrofossil assemblage of TWH-II, the upper level differs from the lower by a steep increase in many animal remains such as Chironomid head capsules, Cladocera ephippia and the numbers of *cf. Limnozetes* and oribatid tritonymphs which indicate a wetter environment.

TWH-III (27-21 cm): Zone TWH-III is characterised by slightly declining quantities of UOM and an modest increase in *Sphagnum*. The dominant *Sphagnum* species changes again, this time towards *S. cuspidatum*. The animal remains, which increased at the end of the previous zone, stay in high numbers throughout this one. Additionally, the numbers of *Nanhermannia* spp. increase slightly. Unique in this zone are the extremely high numbers of *Juncus acutiflorus* seeds, which occur in traces throughout most of the profile, but were encountered in other profiles only very occasionally. *Juncus acutiflorus* thrives in a very wet environment (Ellenberg 1992).

TWH-IV (21-0 cm): With the transition towards zone TWH-IV the amounts in UOM decline to smaller quantities whereas Monocotyledon smooth rootlets increased substantially. In the *Sphagnum* assemblage, which is present in moderate quantities, there occurs another change in species from *S. cuspidatum* towards *S. pulchrum*, which is also dominant at the core location within the living vegetation cover.

5.2.11 CFA 2000

The first profile of this site was cored through a wet *Sphagnum cuspidatum* lawn and is presented in Figure 5.38. The macrofossil diagram of this profile reveals fluctuations in *S. austinii* which indicate that it did not always dominate the macrofossil record in the late Holocene.

CFA-I (160-94 cm): This zone is generally characterised by varying but mostly high content of *Sphagnum* s. *Sphagnum* and lower amounts of UOM, Monocotyledon rootlets and *Erica tetralix* seed numbers. Sub-zone **CFA-Ia (160-146 cm)** is dominated by *S. papillosum* accompanied by *S. cuspidatum* at the bottom level. There is very little *S. cf. austinii* and only small amounts of UOM. Other macrofossil remains include seeds of *Rhynchospora alba, Drosera rotundifolia/anglica*, *Oxycoccus palustris*, *Andromeda polifolia* and

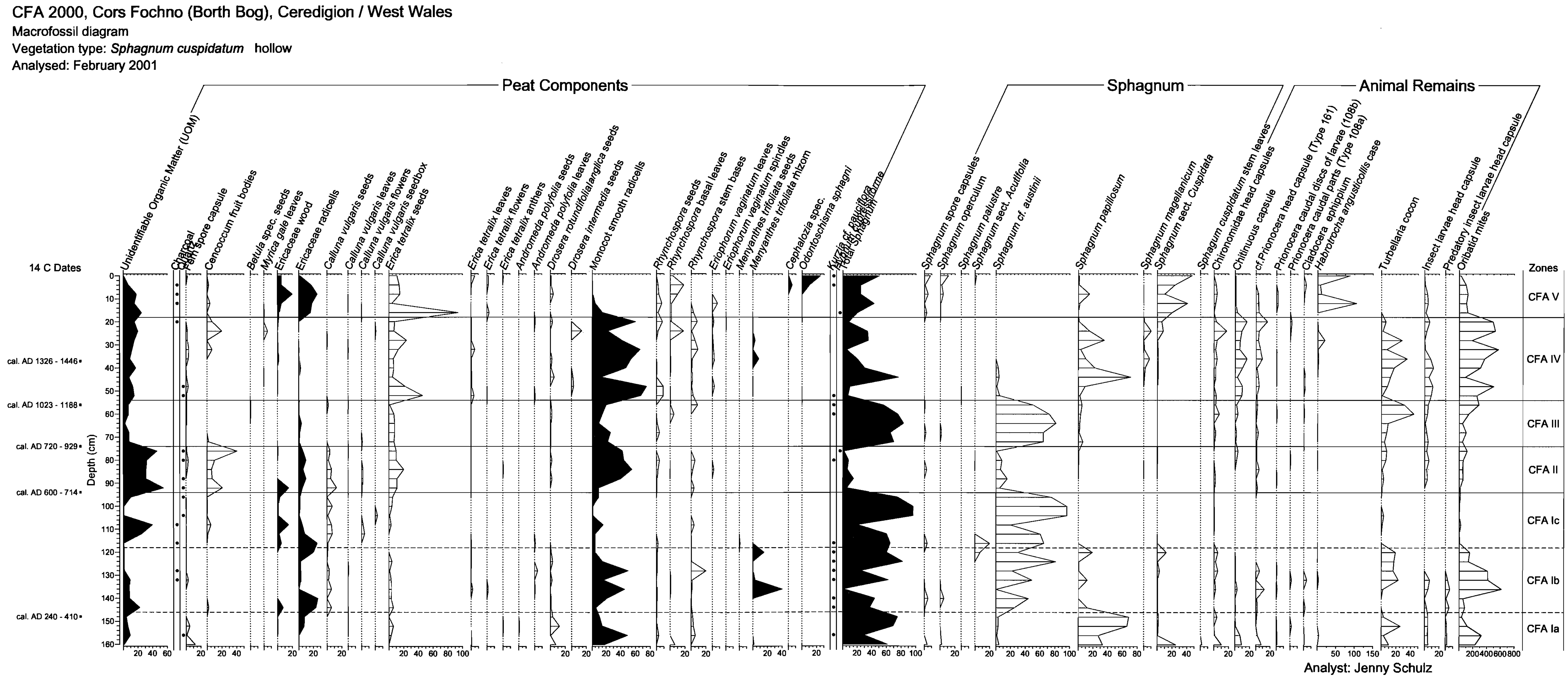


Figure 5.38: Macrofossil diagram of CFA 2000.

Erica tetralix. Furthermore, the whole range of animal remains is present. Peat at 148 cm depth dates *c.* cal. 240-410 AD. Two centimetres above this level a change in the macrofossil assemblage marks the start of the second sub-zone. In **CFA-Ib (146-118 cm)** the amount of *S. cf. austinii* increases continuously but with strong fluctuations towards dominance whereas *S. papillosum* declines sharply. *S.* s. *Cuspidata* quantities are very low, but constantly present, rising slightly towards the top of sub-zone CFA-Ib. *Kurzia pauciflora* is present, with one exception, in all levels of sub-zone CFA-Ib. Higher amounts of *Monocotyledon* rootlets, *Menyanthes trifoliata* rhizomes and *Rhynchospora alba* stem bases are recorded during the decline of *S. cf. austinii*. All types of animal remnants remain present with higher numbers of Oribatida than in the previous zone. *S. cf. austinii* dominates sub-zone **CFA-Ic (118-94 cm)** with one interruption by higher levels of UOM, Ericaceae wood and Monocotyledon rootlets accompanied by some *Cenococcum* fruit bodies. *S.* s. *Cuspidata* is not present by the beginning of this zone.

CFA-II (94-74 cm): At the start of Zone CFA-II, at cal. 600-714 AD, *S. cf. austinii* has steeply declined and stays low throughout the entire zone. At the same time the quantities of UOM, *Cenococcum* fruit bodies, and Monocotyledon rootlets increase considerably, Ericaceae rootlets, *E. tetralix* and *C. vulgaris* seeds rise to slightly higher values. In the middle of this zone small quantities of *S.* s. *Acutifolia* , *S. papillosum* and *S.* s. *Cuspidata* appear and at the end some *Hypnum cupressiforme* is also present.

CFA-III (74-54 cm): At the beginning of zone CFA-III, dated at cal. 720-929 AD, *S. cf. austinii* has regained dominance. *Rhynchospora alba* and *S. papillosum* are present in small amounts and *Sphagnum* s. *Cuspidata* in traces. The values of UOM, *Cenococcum* fruit bodies and Monocotyledon rootlets fall to low levels. Chironomid and Prionocera head capsules are present in small numbers whereas those of Turbellaria cocoons and Oribatida increase throughout zone the zone, which ends just above the 56 cm level, dated cal. 1023-1188 AD.

CFA-IV (54-18 cm): This zone is characterised by several fluctuations between high quantities of Monocotyledon rootlets and *Sphagnum*. UOM rises somewhat but stays at moderate levels, whereas Ericaceae rootlets and wood occur only as traces. Zone CFA-IV starts with a sudden increase of Monocotyledon rootlets and a simultaneous retreat of *S. cf. austinii* remains followed by high *S. papillosum* values together with few *S. cf. austinii* and declining amounts of Monocotyledon rootlets. At 38 cm, in the middle of this zone (cal. AD 1326-1446), *S. cf. austinii* disappears from the record at the core site and some *S. magellanicum* appears for the first time. Then *Sphagnum* values decline again accompanied by a rise in Monocotyledon rootlets and *Menyanthes trifoliata* rhizomes followed by a increase of *S. papillosum* values along with *R. alba* leaves. Both peaks of *S. papillosum* occur with *Drosera intermedia* seeds and the peak of Monocotyledon rootlets along with Oribatida are very similar and almost simultaneous. At the top of the zone *S. papillosum* declines, whereas Monocotyledon rootlets gain high values again and *S.* s. *Cuspidata* starts to rise from traces to low values.

CFA-V (18-0 cm) : The uppermost zone contains moderate amounts UOM and higher values of *Sphagnum*, Ericaceae rootlets and wood along with a sharp increase in *E. tetralix* seeds. The *Sphagnum* consists mainly of *S.* s. *Cuspidata* indicating the onset of wetter conditions. At the top where the macrofossils turn into the living vegetation cover the percentage of liverworts increases considerably. The start of the SCP record at the bottom of this zone indicates that it developed in modern times.

5.2.12 CFB 2001

Core CFB 2001 was taken from a big hummock formed by *S. austinii* in order to investigate the development of this species at localities, where it still occurs (see Figure 4.3). This profile, shown in Figure 5.39, revealed that *S. austinii* dominated the macrofossil record only intermittently at spots where it currently forms the vegetation cover.

CFB-I (120-70 cm): The lowermost zone is characterised by a high content of *Sphagnum*. The values of Monocotyledon rootlets are moderate and the amount of UOM low. Ericaceae remains occur only in traces. Most animal remains reach their highest numbers in this zone. In Sub-zone **CFB-Ia (120-88 cm)** the bulk of *Sphagnum* consist of *S. papillosum,* interrupted between 96 and 100 cm depth, by a peak of *S. cf. austinii. S.* s. *Cuspidata* occurs only in small quantities as well as UOM. Monocotyledon rootlets remain in moderate quantities throughout CFB-Ia. In this sub-zone the remains of *R. alba* are present along with occasional *Eriophorum angustifolium* and *M. trifoliata*, species, which generally indicate a very wet environment. The numbers of many animal remains vary considerably but most have their highest abundance in this sub-zone together with peaks in UOM, which consists of pool mud at this level. At the base of the zone the rotifer *Habrotrocha angusticollis* occurs in high numbers at the same level as the biggest peak of *S.* s. *Cuspidata.* Oribatid mites and tritonymphs reach their greatest quantities together with *R. alba* remains, *M. trifoliata* and Monocotyledon rootlets at the same levels where aggregate *Sphagnum* is lowest. In sub-zone **CFB-Ib (88-70 cm)** a change occurs towards higher *S. cf. austinii* quantities, whereas the amount of *S. papillosum* drops significantly and *S.* s. *Cuspidata* is also reduced. Monocotyledon rootlets and *D. rotundifolia/anglica* seed numbers increase in abundance. The zone ends just above 72 cm depth, which is dated cal. AD 1000-1161.

CFB-II (70-68 cm): The changes from the previous zone to CFB-II are significant. The *Sphagnum* content declines steeply. *S. cf. austinii* remains only as traces and *S. papillosum* drops to very low values along with *S.* s. *Cuspidata.* However *S.* s. *Acutifolia* appears for the fist time at the core location, accompanied by *Aulacomnium palustre* and *Hypnum cupressiforme.* The bulk of the macrofossil assemblage is formed by UOM, Monocotyledon- and Ericaceae rootlets. From the base of the zone higher quantities of Ericaceae rootlets start to form a continuous presence until the top of the core in common with the numbers of *Nanhermannia* spp.

CFB-III (68-50 cm): Zone CFB-III is characterised by a sudden rise to dominance of *S. cf. austinii* along with a decrease of UOM, *Cenococcum* fruit bodies, Ericaceae rootlets and Monocotyledon rootlets to lower values. *S. papillosum* and *S.* s. *Cuspidata* are absent but *S.* s. *Acutifolia* remains with low quantities. The zone ends just above 50 cm depth, which is dated cal. 1667-1951 AD.

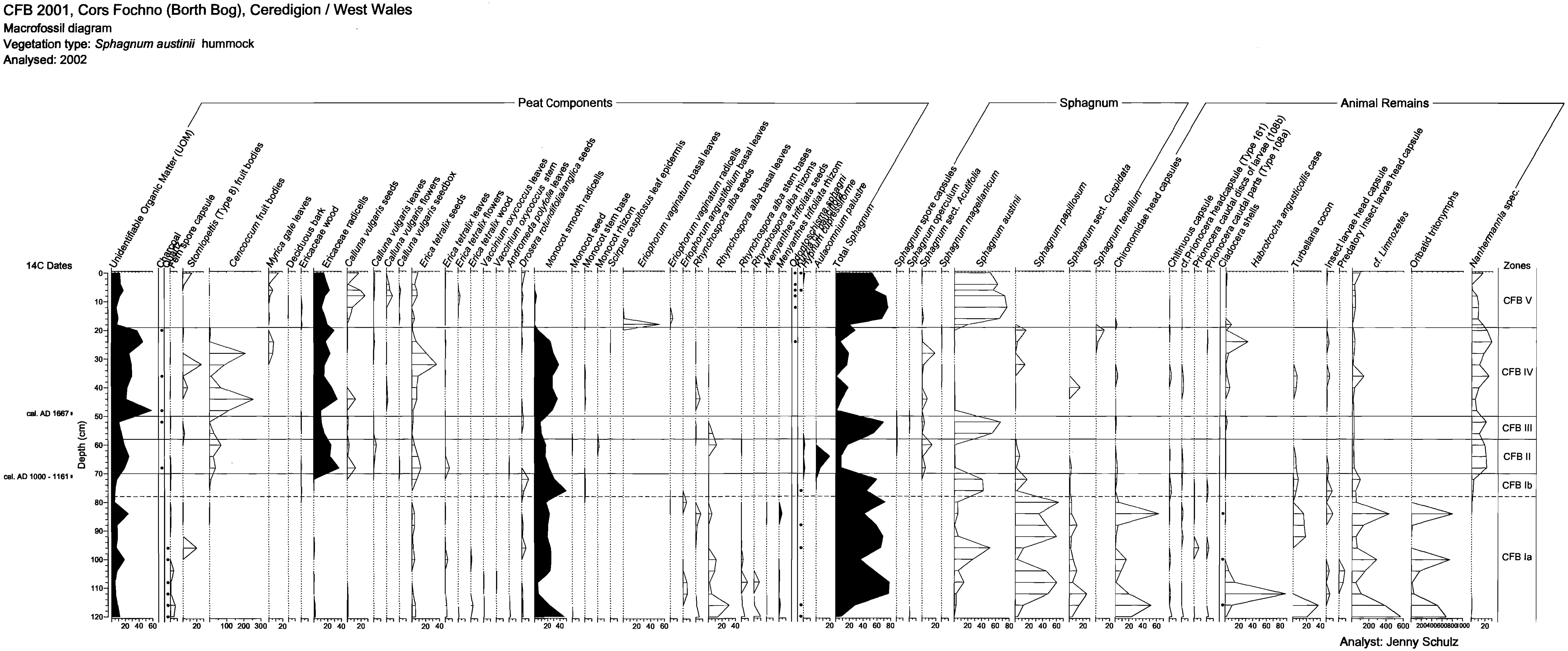


Figure 5.39: Macrofossil diagram of CFB 2001.

CFB-IV (50-18 cm): At the start of this zone *S. cf. austinii* declines very steeply and occurs only as traces in the zone, whereas UOM and *Cenococcum* values reach their maximum values. Likewise, Ericaceae rootlets and Monocotyledon rootlets increase in frequencies. *Sphagnum* remains low throughout the zone consisting mainly of *S.* s. *Acutifolia, S. papillosum* and *S.* s. *Cuspidata. S. magellanicum* appears for the first time but only as traces. In the top part of the zone *Myrica gale* leaves occur for the first time. *Nanhermannia* and *cf. Limnozetes* mites are continuously present and cases of *H. angusticollis* reache higher numbers in this zone. *H. angusticollis* is generally associated with *Sphagnum.*

CFB-V (18-0 cm): In transition to zone CFB-V there is again an abrupt change in the macrofossil record. At the base of the zone basal leaves of *Eriophorum vaginatum* are dominant but UOM and Monocotyledon radicell amounts drop significantly. The latter occur only in smaller amounts in this zone. *S. austinii* suddenly reappears and gains dominance near the top of the core and it is associated with *Odontoshisma sphagni.* Ericaceae rootlets remain at moderate levels, whereas numbers of *C. vulgaris* seeds and flowers reach their maximum in this zone. The SCP record indicates that this remarkable recovery of *S. austinii* occurred in very recent times, most probably within the early decades of the 20th century.

5.2.13 CFC 2001

This core was also taken from a wet *Sphagnum* lawn (see Figure 3.3) in order to investigate if there are correlations in the development with core CFA 2000. It is shown in Figure 5.40.

CFC-I (112-58 cm): CFC-I is dominated by *Sphagnum* of the sections *Sphagnum* and *Cuspidata,* which occur at the base of the zone at high values and decrease slightly throughout the zone. Monocotyledon rootlets start at low values and rise continuously until the zone top. Ericaceae quantities are low as well as UOM with the exception of the level at 92 cm depth. All levels with low *Sphagnum* content have higher quantities of UOM, Monocotyledon rootlets, *Eriophorum angustifolium*, *R. alba* or *M. trifoliata.*The most animal remains are also located within zone CFC-I, but others like *Nanhermannia* spp. gain higher numbers only above this zone. Sub-zone **CFC-Ia (112-90 cm)** is characterised by the highest *Sphagnum* quantities. This is the only zone, where *S. austinii* reaches higher amounts. Among *Sphagnum* first *S. pulchrum* and later *S. papillosum* are dominant. High numbers of Oribatid tritonymphns, *cf. Limnozetes* mites, Cladocera ephippia and also Chironomids correlate with heigh quantities of *Sphagnum.* The following sub-zone, **CFC-Ib (90-66 cm)** starts with high quantities of *S. papillosum,* which decreases in the course of the zone and rises again in its upper part where the number of *D. rotundifolia* seeds reaches a maximum. *S. austinii* is not present in this sub-zone but *S. magellanicum* occurs consistently in low quantities throughout sub-zone CFC-Ib. At the level where the *S. papillosum* content is lowest *R. alba* leaves are more abundant. In the upper part of the zone *S. pulchrum* reaches higher values, together with spore capsules and operculi. Monocotyledon rootlets increase steadily through the zone. Ericaceae rootlets and UOM content remain few. Low, Ericaceae rootlets rise slightly.

CFC 2001 Cors Fochno (Borth Bog), Ceredigion / West Wales
Macrofossil diagram
Vegetation type: mixed *Sphagnum* hollow
Analysed: July 2002

Figure 5.40: Macrofossil diagram of CFC 2001.

CFC-II (58-42 cm): The second zone, starting at cal. 1000-1210 AD, is characterised by low *Sphagnum* amounts and the dominance of UOM, which reaches its maximum at the top of the zone together with the fruit bodies of *Cenococcum*. Ericaceae rootlets, *E. tetralix* seeds and *Stomiopeltis* fruit bodies increase moderately. At the bottom level of zone CFC-II Chironomids, Cladocera ephippia, *cf. Hydrozetes* and *cf. Limnozetes* reach a maximum and then decrease significantly in this zone. Other oribatid species like *Nanhermannia* and *Chamobates* spp. start to register a continuous presence from the bottom of CFC-II onwards.

CFC-III (42-34 cm): This zone is marked by a reversal in UOM content and *Cenococcum* fruit body numbers in parallel with a sudden rise in aggregate *Sphagnum* along with *H. angusticollis*. At the base of the zone, *S.* s. *Acutifolia* reaches high quantities for the first time and at the top *S. magellanicum* appears and gains dominance. This is the only zone, where *S. magellanicum* reaches high values. Monocotyledon and Ericaceae rootlets remain at moderate values but the numbers of *C. vulgaris* seeds reach their maximum within this zone.

CFC-IV (34-26 cm): In zone CFC-IV *Sphagnum* declines and the UOM content increases again to high amounts. *S. magellanicum* disappears from the record within this zone and *S. papillosum* is also present for the last time at the core location. Ericaceae and Monocotyledon rootlets occur continuously at lower levels throughout zone CFC-IV. The lower level in this zone at 32 cm has been dated cal. 1670-1960 AD.

CFC-V (26-0 cm): During the time span represented by the uppermost zone UOM and Monocotyledon rootlets decrease continuously towards present days and *Sphagnum* dominates the zone. Ericaceae remain consistently at moderate values but drop in the two top sample levels. Sub-zone **CFC-Va (26-18 cm)** is characterised by a fall in UOM amounts and the dominance of *S.* s. *Acutifolia,* which reaches its second maximum along with high numbers of *R. alba* seeds. Quantities of Ericaceae rootlets and *E. tetralix* seeds are moderate and Monocotyledon rootlets are slightly less than in the previous zone. With the beginning of sub-zone **CFC-Vb (18-0 cm)** there is a significant change in the composition of aggregate *Sphagnum. S.* s. *Acutifolia* has decreased and becomes associated with *S.* s. *Cuspidata* and *R. alba* leaves. At the same time the numbers of *H. angusticollis* cases rise steeply to their maximum at the bottom of the zone and decline then steadily towards the top. Within the living vegetation cover *O. sphagni* becomes significant.

5.2.14 CFD 2001

This profile was taken from a hummock that is presently occupied by *Myrica gale* (see Figure 4.3 for core location). The purpose of this core was to investigate the history of *M. gale*, which recently became problematic because it often occupies the top of higher hummocks and is therefore a potential threat to the remaining hummocks of *S. austinii*. The macrofossil diagram presented in Figure 5.41 suggests that *S. austinii* was indeed out competed at this locality by *M. gale*.

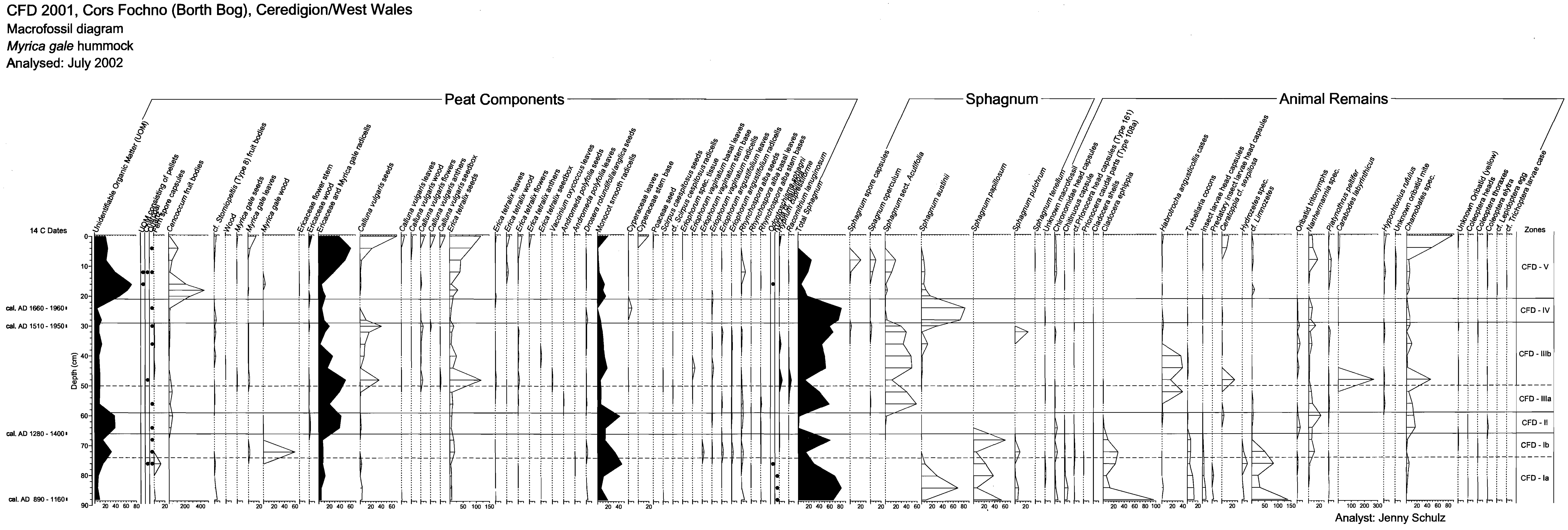


Figure 5.41: Macrofossil diagram of CFD 2001.

CFD-I (88-66 cm): The bottom zone is characterised by high *Sphagnum* quantities, moderate amounts of Monocotyledon rootlets and UOM, as well as low values of Ericaceae rootlets and *E. tetralix* seed numbers. The first sub-zone, **CFD-Ia (88-74 cm)**, is dominated by *S. austinii* and *S. papillosum*, accompanied by small amounts of *S. pulchrum*, *D. rotundifolia* seeds and liverworts. However towards the top *Sphagnum* declines and Monocotyledon rootlets increase. The UOM content is low but raises somewhat towards the top. The numbers of Cladocera ephippia, and *cf. Limnozetes* are greatest in this sub-zone and indicate very wet conditions. In **CFD-Ib (74-66 cm)** the UOM content is slightly higher than in the previous sub-zone. Monocotyledon rootlets decline towards the top of the zone and *S. austinii* is not present. *S. papillosum* becomes dominant and it is associated with some *S. pulchrum*. The dominance of *Myrica gale* wood at 72 cm is notable.

CFD-II (66-59 cm): In contrast to the last zone *Sphagnum* occurs here only as traces of *S. austinii* and *S.* s. *Acutifolia,* which appears for the first time in this record. The content of UOM, Ericaceae and Monocotyledon rootlets increases considerably. *Cenococcum* fruit bodies and *Chamobates* are also present at higher numbers than in the preceding zone. In contrast, the quantities of Cladocera ephippia and *cf. Limnozetes* decline to traces levels.

CFD-III (59-29 cm): *Sphagnum* s. *Acutifolia* is dominant in most of this zone. UOM and Monocotyledon rootlets decline and remain at low levels; Ericaceae rootlets rise first and then decline in the course of the zone. *H. angusticollis* reaches high numbers. Sub-zone **CFD-IIIa (59-50 cm)** starts with dominance by *S.* s. *Acutifolia*. UOM and Monocotyledon rootlets declined and remain at low levels, whereas Ericaceae rootlets amounts are relatively high. In the bottom level of sub-zone **CFD-IIIb (50-29 cm)** *S.* s. *Acutifolia* decreases at the same time as a slight rise of *Hypnum cupressiforme* and *Racomitrium lanuginosum* occurs. Likewise the amounts of *C. vulgaris* and *E. tetralix* seeds rise significantly together with the appearance of other remains belonging to these species and Ericaceae rootlets. In the same level the oribatid mites *Carabodes cf. labyrinthicus* and *Chamobates* spp. reach high numbers. After that *S.* s. *Acutifolia* values increase again and Ericaceae seeds and rootlets decline but stay at higher values than in the previous sub-zone. *S. austinii* reappears in this zone and increases in frequency towards the top. Close to the top of the zone *S. pulchrum* occurs for the last time in this core.

CFD-IV (29- 21cm): This zone is characterised by a change in the prevalence of *Sphagnum* species. *S.* s. *Acutifolia* declines to traces, whereas amounts of *S. austinii* increase steeply. UOM, Ericaceae and Monocotyledon rootlets values are low, as well as other Ericaceae remains.

CFD-V (21-0 cm): At the bottom of zone CFD-V *S. austinii* decreases to very low quantities and then disappears shortly before the upper zone boundary. The amount of UOM and *Cenococcum* fruit bodies increase significant in parallel with the decline in *S. austinii*. The numbers in *Cenococcum* fruit bodies remain high throughout CFD-V. Halfway though the zone *S.* s. *Acutifolia* amounts rise along with numbers of spore capsules and operculi but all *Sphagnum* species disappear at once shortly beneath the surface. The quantities of orange rootlets, including *M. gale* and Ericaceae rootlets along with *C. vulgaris* and *E. tetralix* seeds increase towards the top.

5.2.15 RM 2001

This profile originates from a wet *Sphagnum* s. *Sphagnum* lawn on Raheenmore Bog (see Figure 4.4) and is presented in Figure 5.42. This core was taken in order to compare the macrofossil record of a relatively intact raised bog, which still contains *S. austinii* in its present vegetation, with the Welsh study sites. In the field it was not possible to identify the *Sphagnum* (s. *Sphagnum*) species at the core location. However, with the start of the laboratory work it turned out that the living *Sphagnum* cover consists entirely of *S. austinii*, which also dominates the uppermost 40 cm of peat. Altogether the macrofossils of this core are extremely well preserved. The preservation of most *Sphagnum* remains, including *S.* s. *Acutifolia*, which had branches, branch leaves and stem leaves still attached to the plants, enabled identification down to species level.

RM-I (156-110 cm) The bottom zone is characterised by high quantities of aggregate *Sphagnum* (80-90 %). Most other peat components have very low values. **RM-Ia** In sub-zone RM-Ia *S.* s. *Acutifolia* dominates along with some *S. austinii* at the bottom level and *Kurzia cf. pauciflora* over the entire sub-zone. UOM and Monocotyledon rootlets occur only as traces and Ericaceae rootlets at very low frequencies. **RM-Ib** In the second sub-zone the aggregate *Sphagnum* content remains equally high as in RM-Ia. However, the composition of the species/sections varies considerably. At the bottom level *S.* s. *Cuspidata* is dominant, accompanied by some *S.* s. *Subsecunda*. Then there is a sudden change to *S. austinii* and the next level changes abruptly again to *S.* s. *Acutifolia*. The second half of the sub-zone is characterised by a combination of *S. austinii* and *S.* s. *Acutifolia* with *S. austinii* amounts rising first and then declining. The *S.* s. *Acutifolia* graph runs exactly in the opposite way. It decreases after the first maximum in this sub-zone and rises towards its end. UOM values are slightly higher in RM-Ib. Amid the animal remains numbers in *cf. Limnozetes* increases and Turbellaria cocoons along with Chironomid head capsules appear in the top half of RM-Ib. Also in the second sub-zone, *R. alba* seeds and Monocotyledon rootlets rise slightly.

RM-II (110-82 cm): In Zone RM-II a change to significantly higher UOM values occurs simultaneously with a strong decrease in aggregate *Sphagnum* quantities. *S.* s. *Acutifolia* reaches the highest values, accompanied by *S. austinii*, *R. lanuginosum*, *K. cf. pauciflora* in the base of the zone and *S.* s. *Cuspidata* in the top half of the zone. Ericaceae rootlets rise in the course of RM-II and decline before its top. The amount of Monocotyledon rootlets and *Cenococcum* fruit bodies are also higher than in the previous zone. At the top level *E. angustifolium* occurs in considerable amounts. Among the animal remains oribatid tritonymphs reach their maximum in this record at the bottom and top levels. The occurrence of *cf. Limnozetes*, Turbellaria cocoons and Chironomid head capsules is similar with greater numbers both at the bottom and top of RM-II.

RM-III (82-66 cm): Zone RM-III is dominated by *S.* s. *Cuspidata* accompanied by *S.* s. *Subsecunda*. UOM, Monocotyledon and Ericaceae rootlets occur only in traces indicating very wet conditions.

RM-IV (66-54 cm): At the transition to zone RM-III there is an abrupt change in the prevalence of *Sphagnum* from *S.* s. *Cuspidata* and *S.* s. *Subsecunda* to *S.* s. *Acutifolia* together with *S. austinii*. The amount

of aggregate *Sphagnum* declines at the bottom of RM-III, whereas the quantities of UOM, Ericaceae and *E. vaginatum* remains along with *Cenococcum* fruit bodies increase. Monocotyledon rootlets are still very low. Towards the top of the zone *Sphagnum* rises to dominance again.

RM-V (54-38 cm): At the bottom of RM-V aggregate *Sphagnum* declines suddenly and is absent in the course of the zone. At the top there are some traces of *S.* s. *Acutifolia* and *S. magellanicum*. UOM amounts are at first moderate and rise considerably towards the top. The graphs of Monocotyledon rootlets, *cf. Limnozetes* and *Platynothrus peltifer* change in the opposite way. Early in the zone their values are highest and decline throughout the zone. Likewise, at the bottom level there are higher numbers of Chironomid head capsules and oribatid tritonymphs. The numbers of *C. vulgaris* and *E. tetralix* seeds rise to their maximum in zone RM-V. Some remains of *E. vaginatum*, *E. angustifolium* and *R. alba* are present.

RM-VI (38-0 cm): At the beginning of the uppermost zone *S.* s. *Acutifolia* and *S.* austinii appear again, *S.* s. *Acutifolia* is dominant. Shortly after the appearance of *Sphagnum, S. austinii* gains dominance and *S.* s. *Acutifolia* values decrease to very low levels. *O. sphagni* is often associated with *Sphagnum*. UOM occurs only as traces and Ericaceae and Monocotyledon rootlets are found in small amounts. In the bottom half of the zone *H. angusticollis* occurs in higher numbers.

5.3 Results of the Detrended Correspondence Analysis (DCA)

The DCA results for each core are represented in the Figures 5.44 to 5.70. Figure 5.43 represents the key to the DCA diagrams. An introduction to DCA is given in chapter 4 (section 4.6.1). There are mostly two diagrams presented here for each core, first the DCA diagrams, which show axes 1 and 2, which represent the largest eigenvalues. The second diagram shows mostly the axis 1 scores (the largest ecological gradient) plotted against depth. In some cases axis 2 was chosen for the second diagram, if the first axis did not indicate a clear ecological gradient. However, DCA did not always yield useful results. The cores in this project are rather short and do not contain the full ecological range a core of several metres may include. This limits the use of DCA especially for the short cores. Thus, DCA results yielding no useful information were left out.

Legend to the DCA diagrams:

○ Species scores

◆ Sample scores

Figure 5.43: Legend to the DCA diagrams.

5.3.1 DCA of Cors Caron

5.3.1.1 TRE'98

The results of the DCA for TRE'98 are presented in the Figures 5.44 and 5.45. The species distribution in the first DCA diagram (Figure 5.44) shows on the left species thriving in rather wet conditions such as *S. cuspidatum*, *S. pulchrum*, *S. papillosum* and *Rhynchospora alba*. On the right side of the diagram are species, which tolerate lower water levels, like *S.* s. *Acutifolia*, *Calluna vulgaris* and *Eriophorum vaginatum*. *S. austinii* too is placed at the right side of the diagram. The eigenvalue is 0.92, which is quite high and indicates a dominant ecological gradient. Regarding the species distribution, this gradient appears to be a wetness-dryness gradient, which is also shown in the second DCA diagram (Figure 5.45). Most of the samples are concentrated on the right side of Figure 5.44 where the species composition indicates the dryer end of the gradient. A small number of the samples are placed on the left, together with the species preferring wetter conditions. There is a clear division between the samples in 'wet' and 'dry' parts of the gradient. However, the smaller fluctuations within the graph shown in Figure 5.45 do not clearly indicate the significant change at 62 cm depth. Where *S. austinii* steeply declines and UOM starts to dominate the macrofossil assemblage (see Figure 5.29). This could be due to the fact that both, *S. austinii* and UOM are located at the 'dry' end of the first DCA diagram. The same fact could also explain why zone TRE-1 is not indicated as wetter although the macrofossil assemblage points towards a wet environment.

5.3.1.2 TNEA 2000

The first DCA diagram of TNEA 2000 (see Figure 5.46) shows a species distribution with indicators (*S.* s. *Cuspidata*) for higher wetness on the left end and indicators for lower water tables on the right (for example *S.* s. *Acutifolia*). However, in the middle part of the diagram the orientation of species and macrofossil types is less clear like those of *Calluna vulgaris* and *E. vaginatum*. In general, the gradient on axis 1 seems to be a wetness gradient but less pronounced than in the previous profile. It is shown also in Figure 4.47 with axis 1 scored against depth. Although the samples are spread more evenly along axis 1 than in TRE'98, the majority are likewise placed towards the 'dryer' end of the diagram. Another similarity with TRE'98 is, that here too, *S. austinii* dominated zones are placed 'dryer' than UOM dominated ones in the second DCA diagram (Figure 5.30).

5.3.1.3 TRWA 2000

The species distribution on the first DCA diagram (Figure 5.48) is similar to the previous profiles. Species demanding or tolerating high water tables are located on the left side of the diagram and species with higher tolerance to lower water tables on the right. Samples are spread throughout the gradient with concentrations towards *S. austinii*, *S. papillosum* and *S.* s. *Cuspidata*. The species distribution indicates too that axis 1 represents a wetness gradient although smaller than in the previous profiles (as the lower eigenvalue of 0.64 indicates). This could be interpreted as water table fluctuations in the summit part of the West Bog which

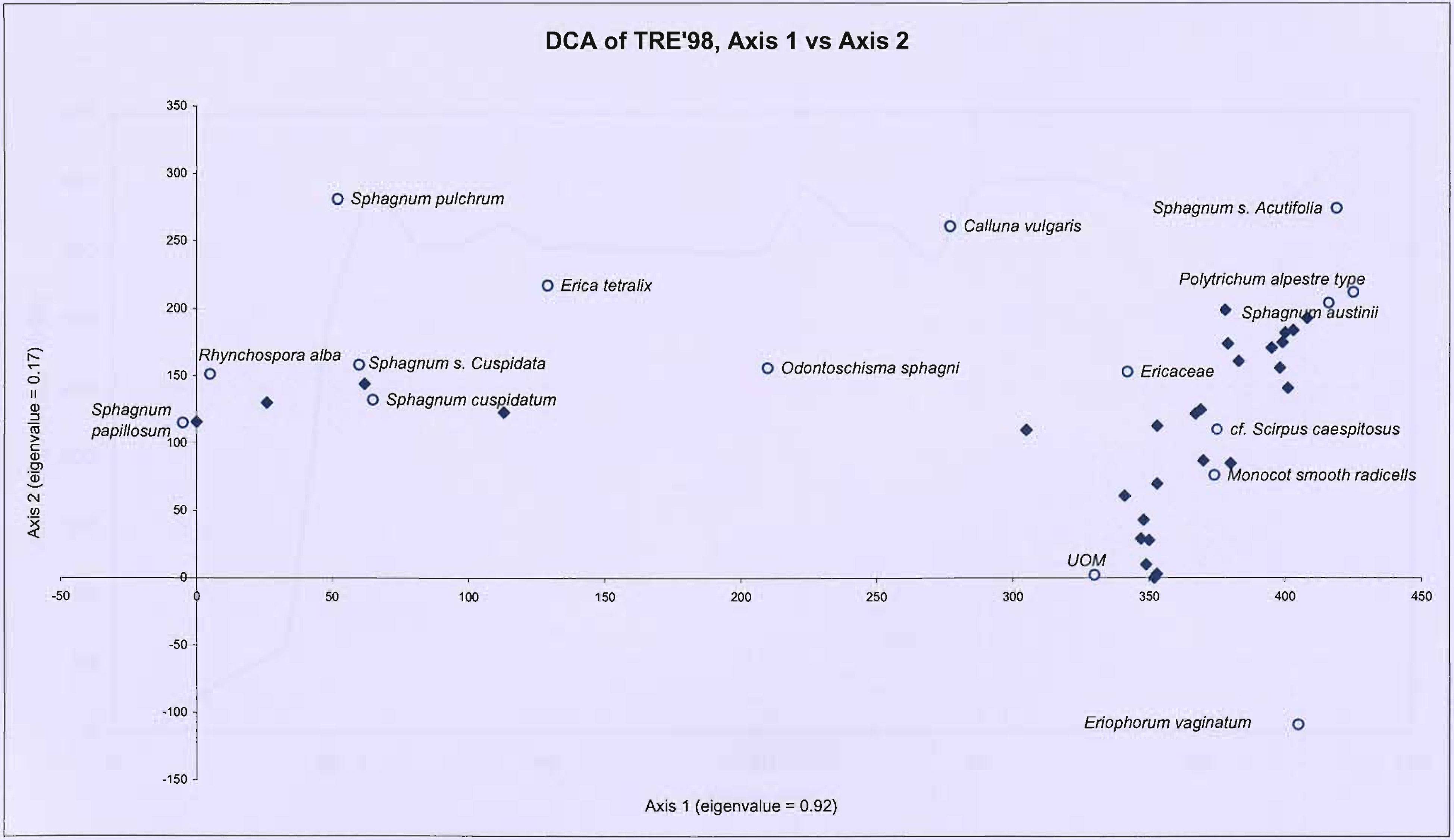


Figure 5.44: DCA of Cors Caron, core TRE'98 (detrended by segments and down weighting of rare species).

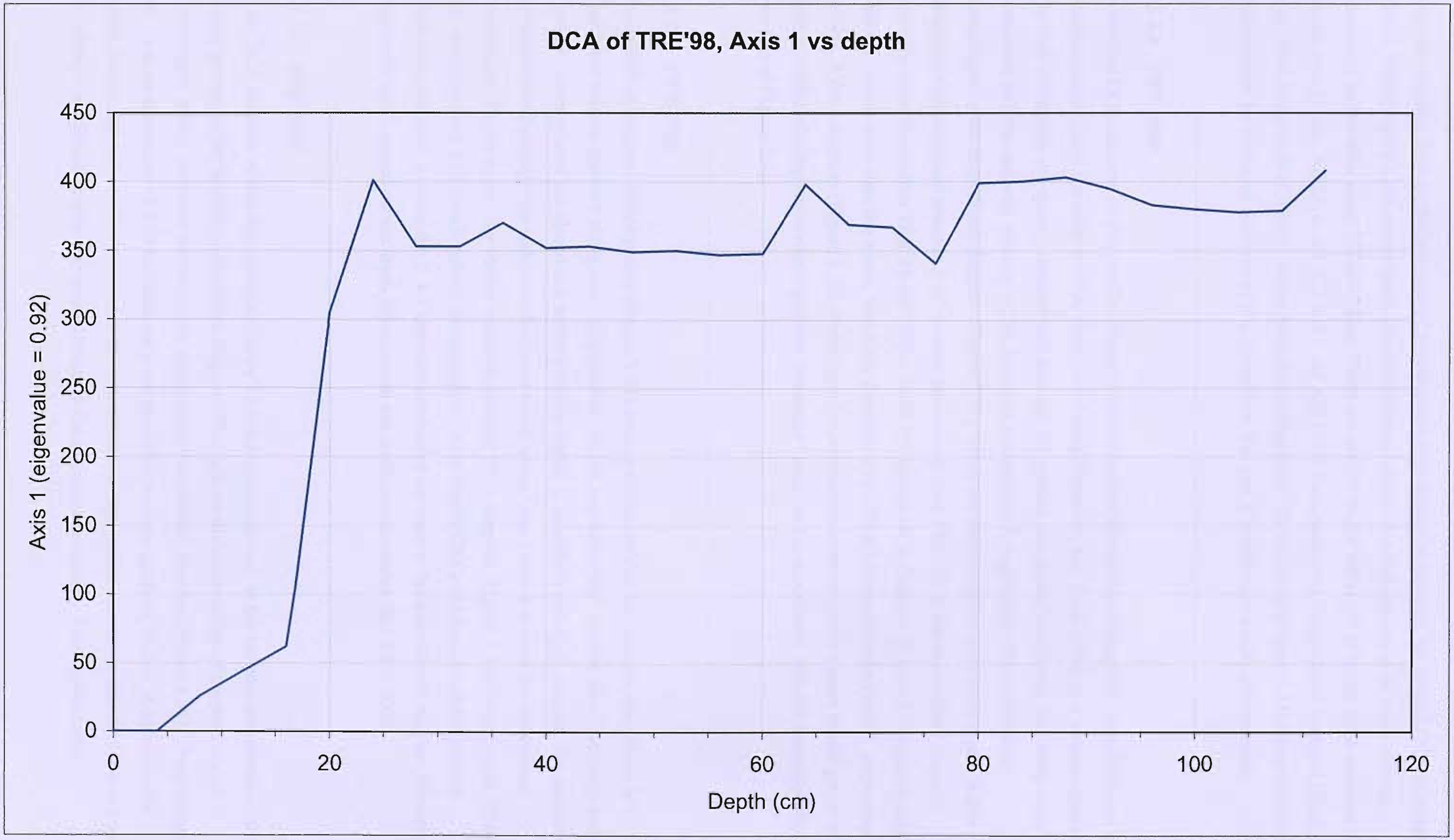


Figure 5.45: DCA of core TRE'98, Axis 1 vs depth.

were less extreme than on the summits of the other two peat domes. In contrast, the second DCA diagram of TRWA 2000 (Figure 4.49) shows much more fluctuations down core and appears to be more climate-sensitive than the other cores of Cors Caron. There are several major wet shifts of which three correlate with known ones (*c.* cal. AD 21, *c.* cal. 525 and *c.* cal AD 1500) from northwest England and Scotland (Hughes *et al.* 2000, Hughes *et al.* 2001). In the macrofossil diagram of TRWA 2000 (Figure 5.31) these shifts are characterised by increased amounts of *S.* s. *Cuspidata*, but also *S. papillosum* and *R. alba* remains.

5.3.1.4 TWC 2000

In the first DCA diagram of this profile (Figure 5.50) the species distribution along axis 1 also indicates a wetness gradient as in the other profiles from Cors Caron. However, axis 2 too points to a wetness gradient. The bulk of samples are clearly concentrated amongst the species and macrofossil types indicating dryer conditions with the majority close to UOM, Monocot rootlets and *E. vaginatum.* This reflects the assemblages in the macrofossil diagram (Figure 5.32), which are dominated by those three types. A few samples are concentrated towards *S. cf. austinii* dominating zone TWC-IV in the macrofossil diagram. However, as in the profiles TRE'98 and TNEA 2000, the second DCA diagram (Figure 5.51) places zone TWC-IV, much dryer than the zones, which are dominated by UOM, Monocot rootlets and *E. vaginatum* rootlets. A third diagram (Figure 5.52) where Axis 2 is scored versus depth yields a more useful graph which seems to reflect the dryness-wetness gradient somewhat better (and in accordance with the macrofossils) than that of Figure 5.51.

5.3.1.5 TWD 2000

The first DCA diagram of this profile (Figure 5.53) structurally resembles the previous one. There is a significant wetness gradient along axis 1 (eigenvalue = 0.88), but some 'dry' species like *C. vulgaris* and *Hypnum cupressiforme* are placed in a wetter position than *S.* s. *Acutifolia* and *S. cf. austinii.* The samples are concentrated amongst the indicators for lower water tables, which also dominate the macrofossil assemblages (Figure 5.33). The variety within the second DCA diagram (Figure 5.54) is very small. There is only one major wet shift which reflects the change at 14 cm from UOM and Monocotyledon rootlets dominated peat layer towards the *S.* s. *Cuspidata* dominated top zone in the macrofossil diagram. However, a trial with axis 2 scored versus depth did not yield any useful results rather like TWC 2000.

5.3.1.6 TWE 2002

In the DCA diagram of this short profile (Figure 5.55) the species as well as the samples are placed in two distinct groups on the opposite sides of the diagram. This reflects the composition of the macrofossil assemblages, which dominate the two major zones in the macrofossil diagram (Figure 5.34). The gradient on axis 1 has an eigenvalue of 0.89 but does not point towards a wetness gradient. Rather, it describes the abrupt change and different composition in the macrofossils in this profile. However, this profile is not only very short, it exhibits also only one major change in the macrofossil diagram. This explains why,

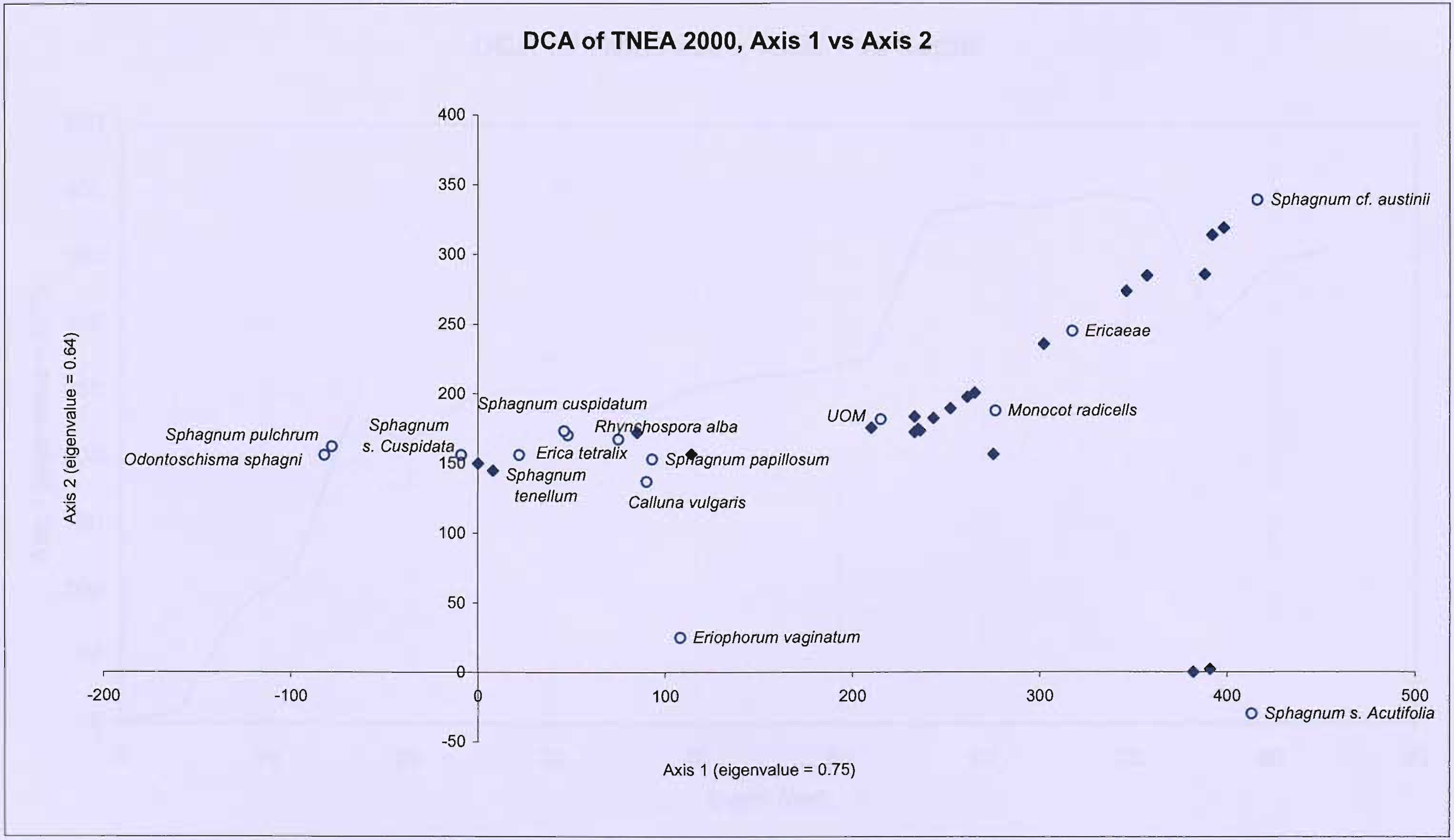


Figure 5.46: DCA of Cors Caron, core TNEA 2000 (detrended by segments and down weighting of rare species).

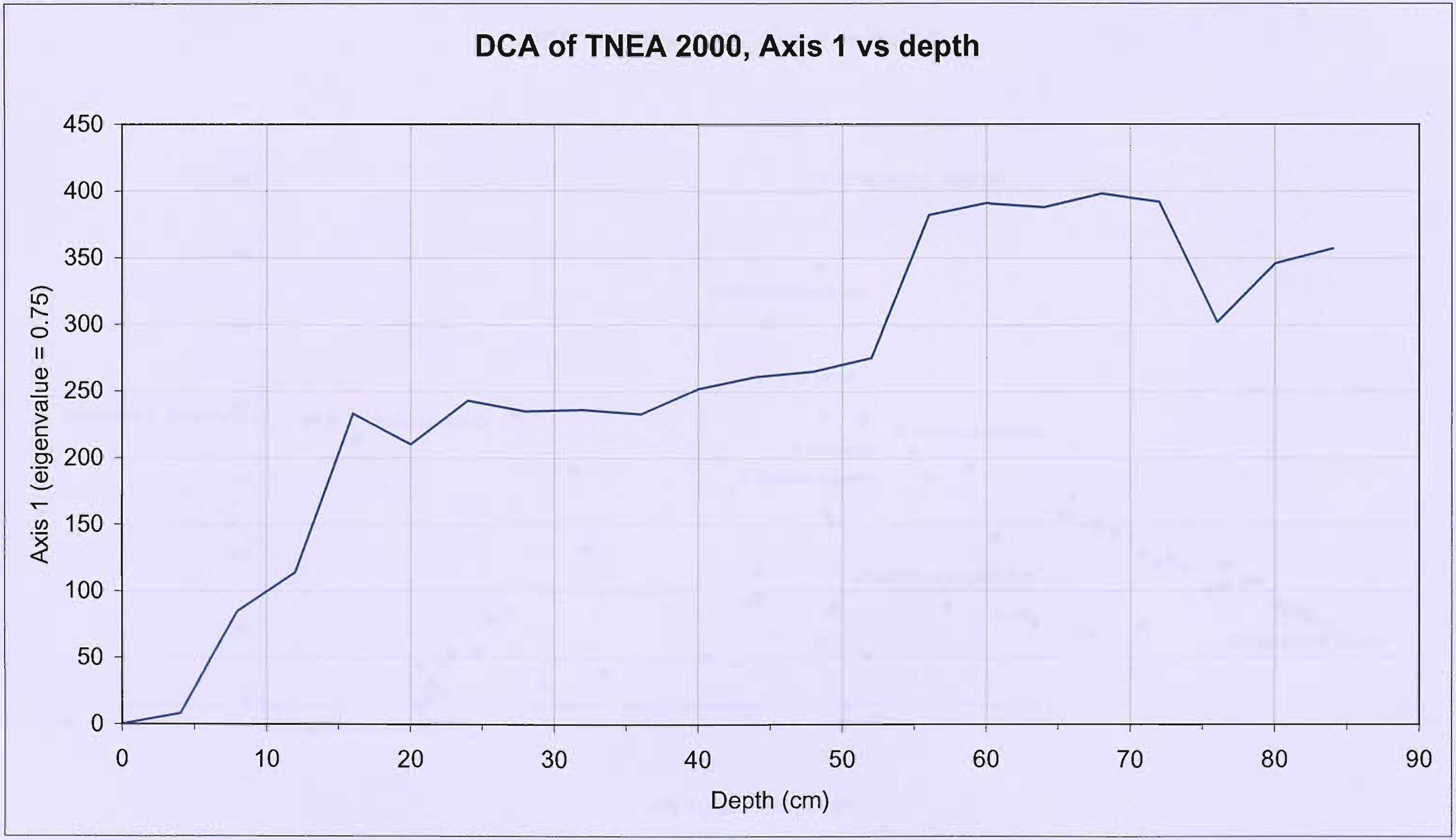


Figure 5.47: DCA of core TNEA 2000, Axis 1 vs depth.

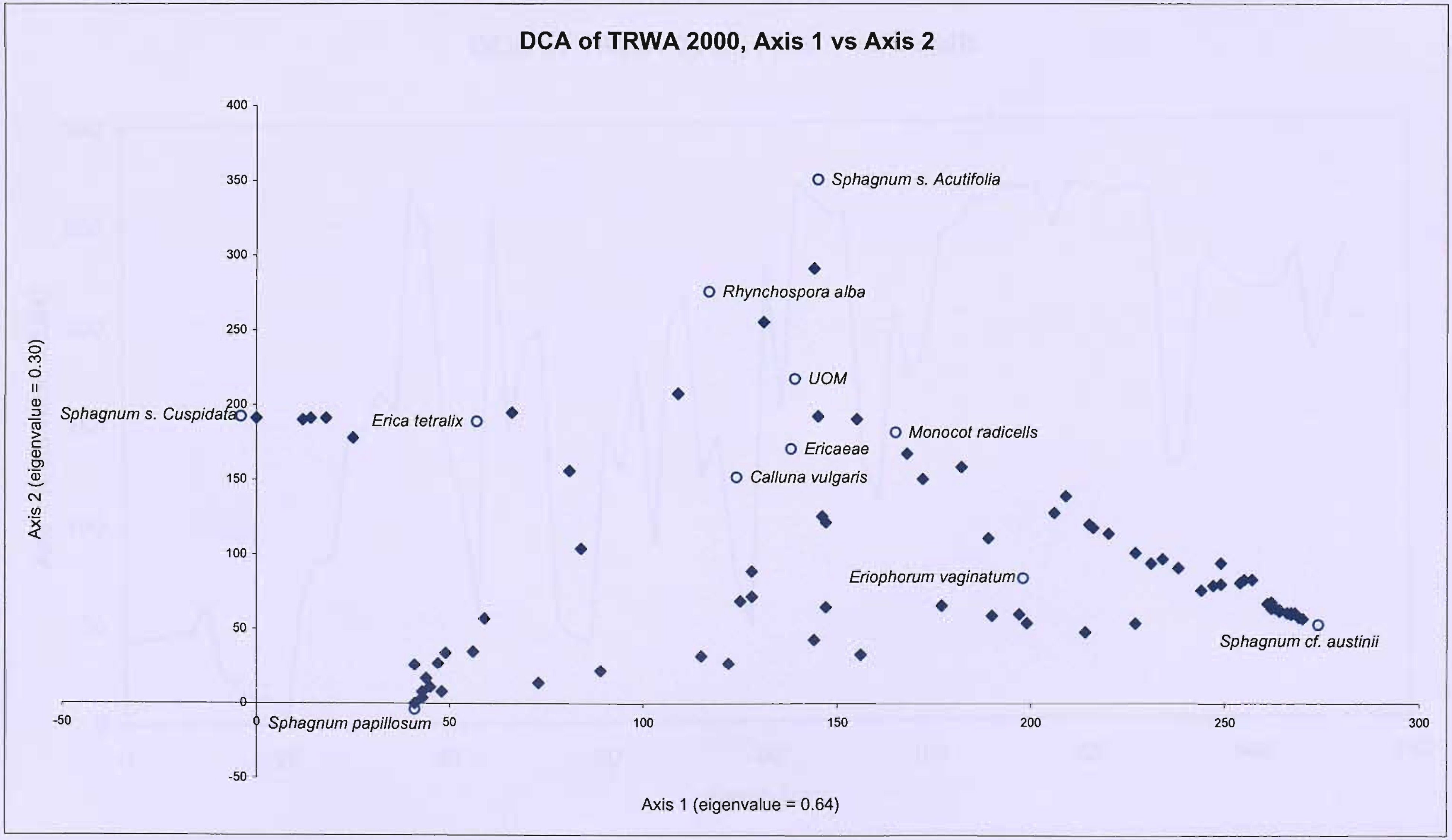


Figure 5.48: DCA of Cors Caron, core TRWA 2000 (detrended by segments and down weighting of rare species).

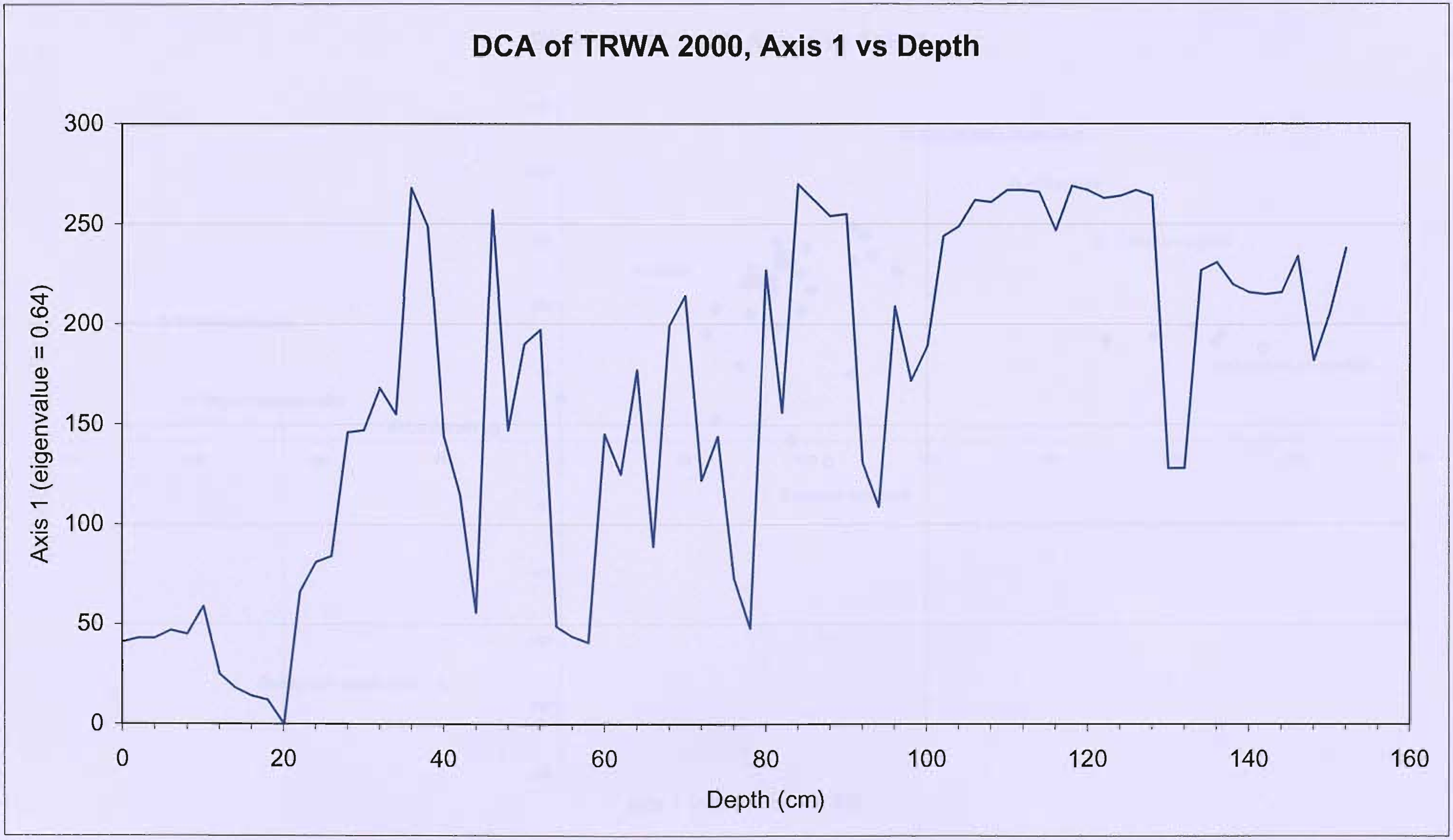


Figure 5.49: DCA of core TRWA 2000, Axis 1 vs depth.

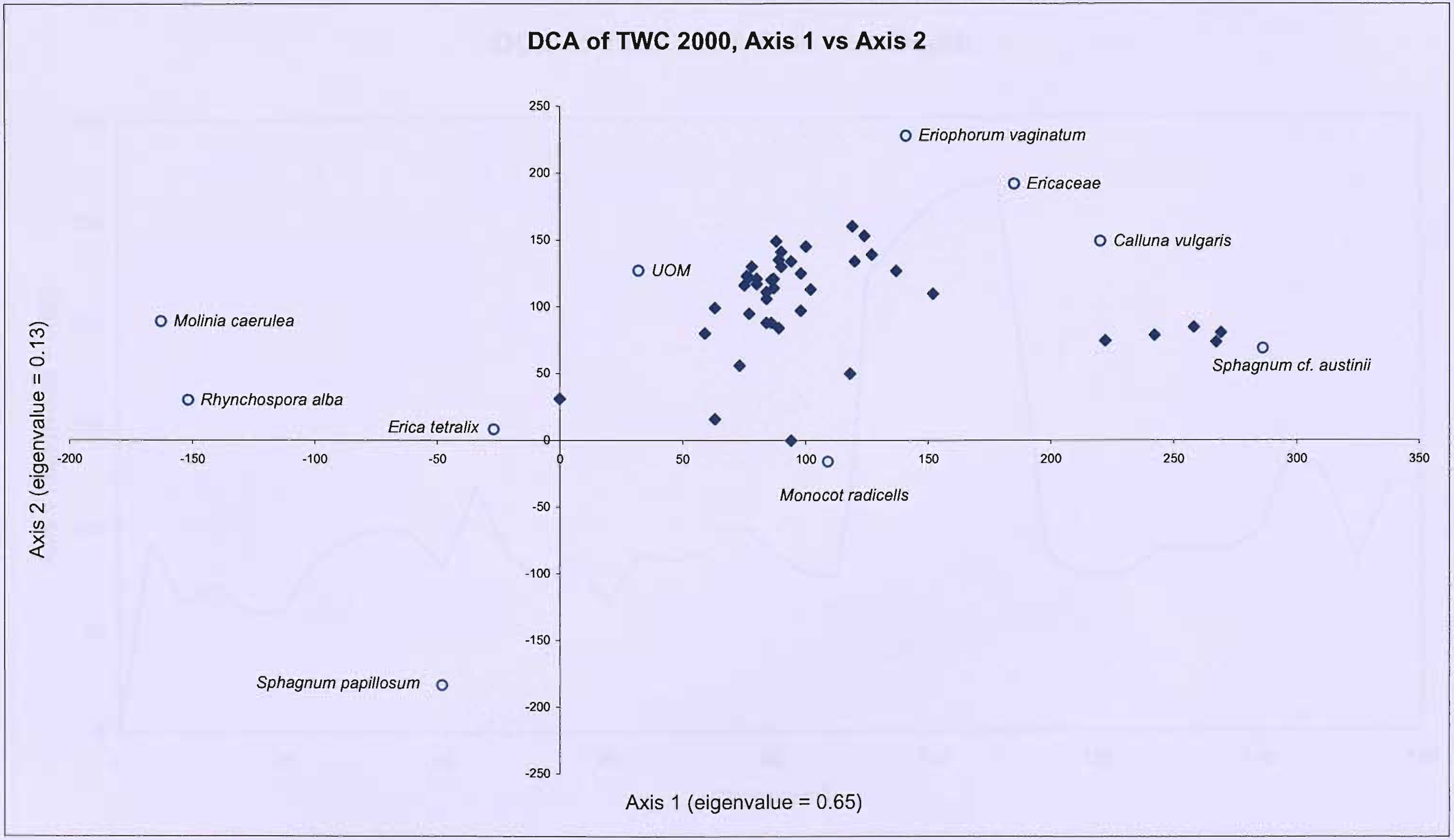


Figure 5.50: DCA of Cors Caron, core TWC 2000 (detrended by segments and down weighting of rare species).

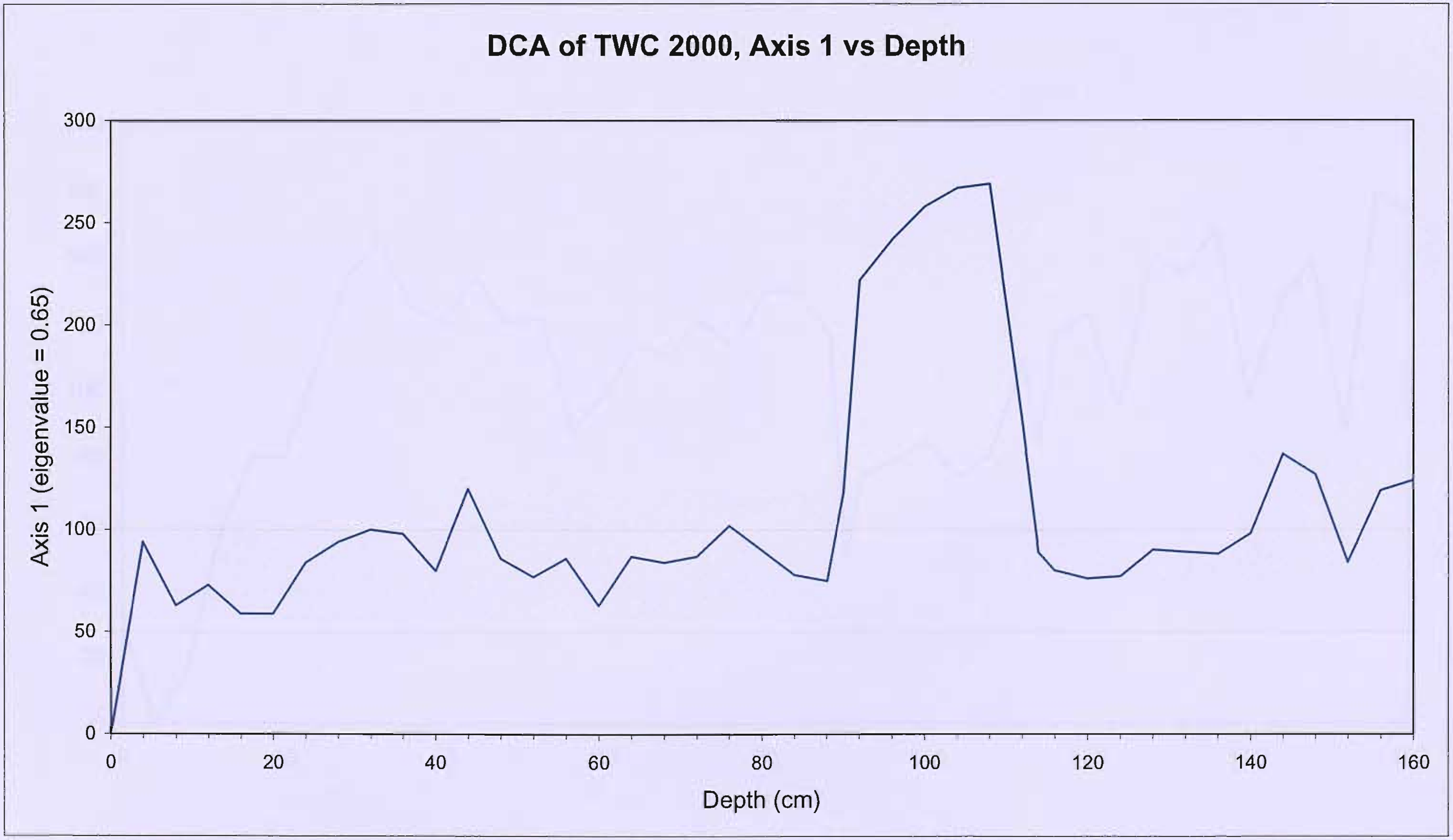


Figure 5.51: DCA of core TWC 2000, Axis 1 vs depth.

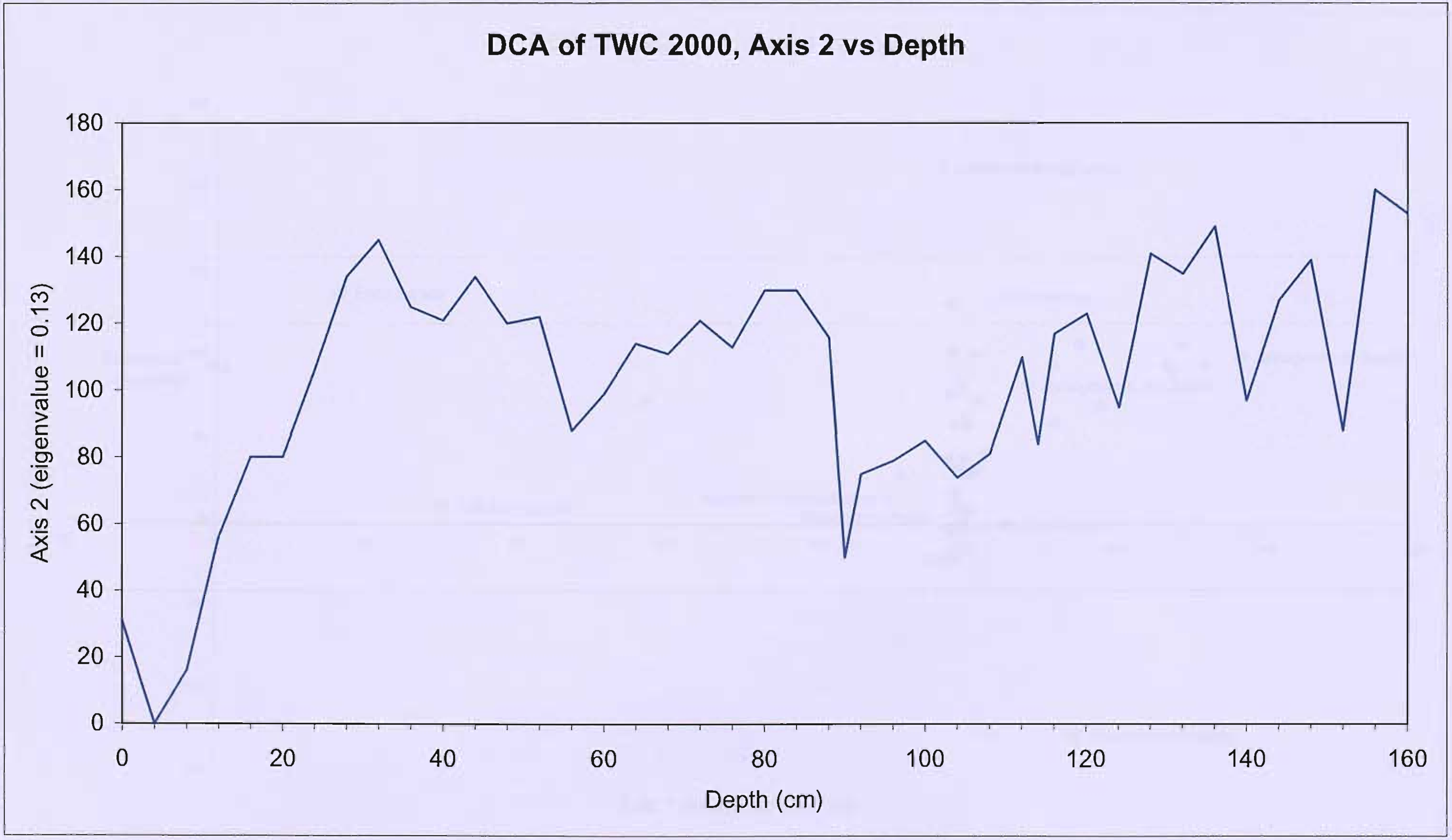


Figure 5.52: DCA of core TWC 2000, Axis 2 vs depth.

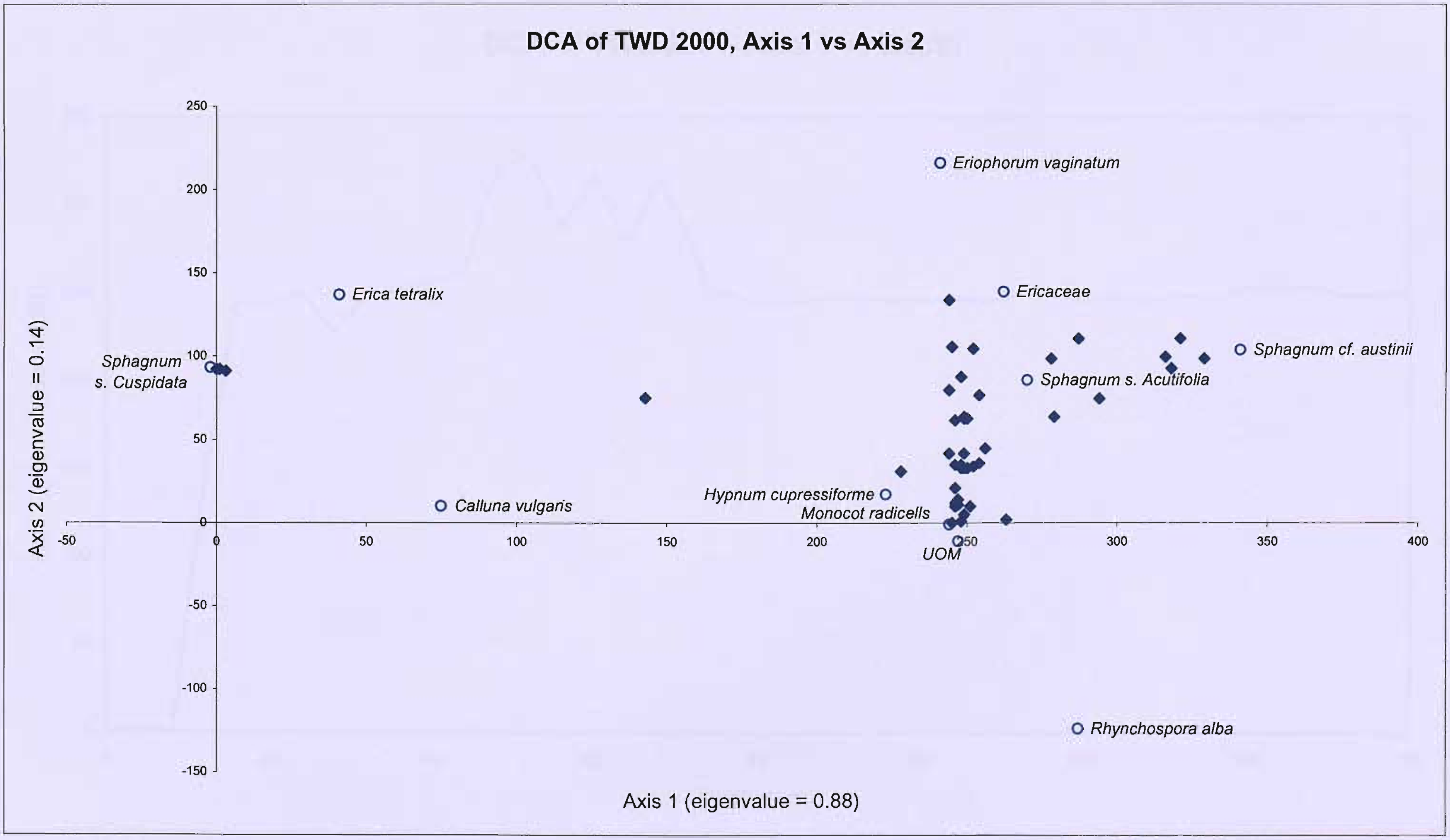


Figure 5.53: DCA of Cors Caron, core TWD 2000 (detrended by segments and down weighting of rare species).

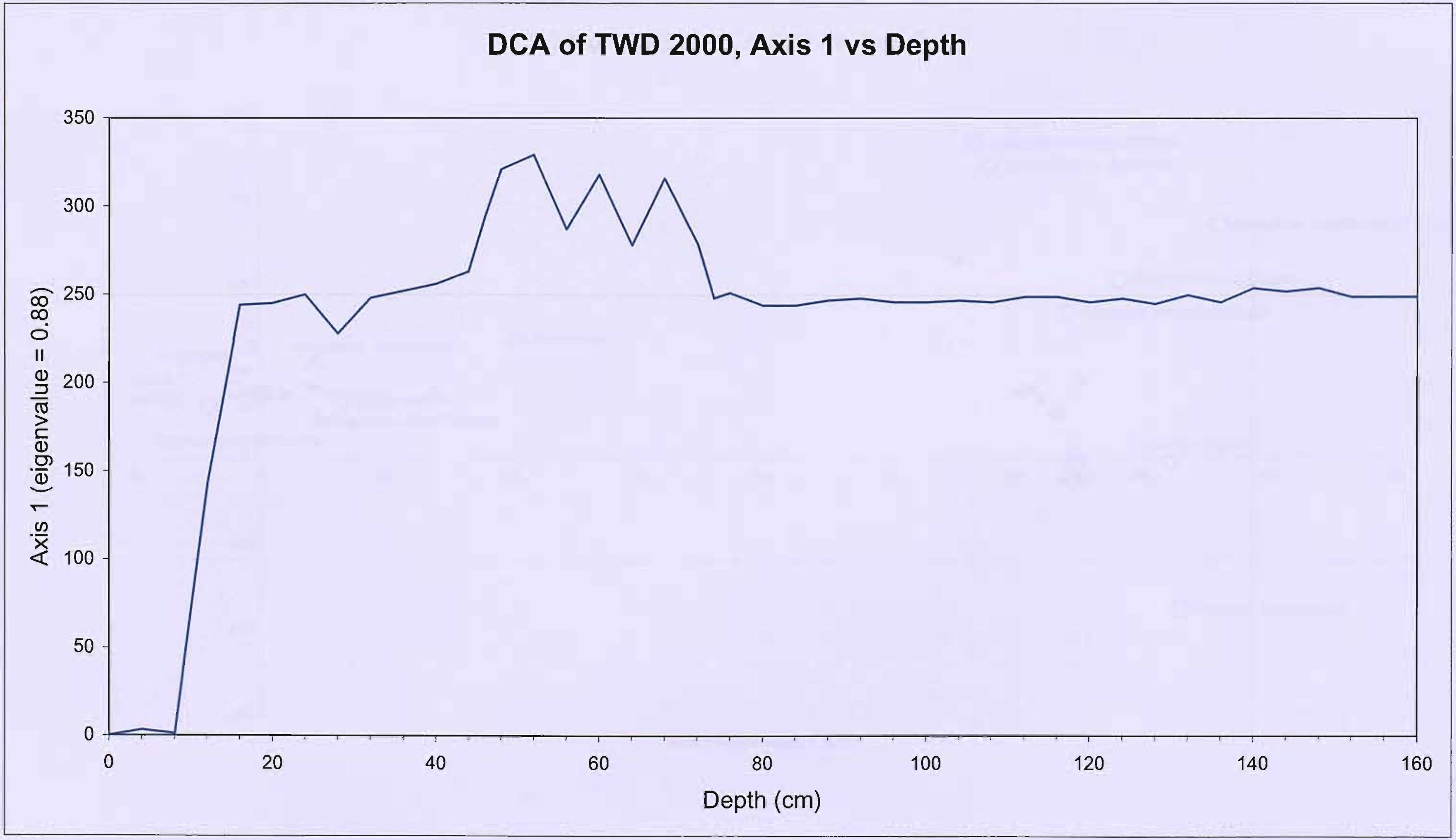


Figure 5.54: DCA of core TWD 2000, Axis 1 vs depth.

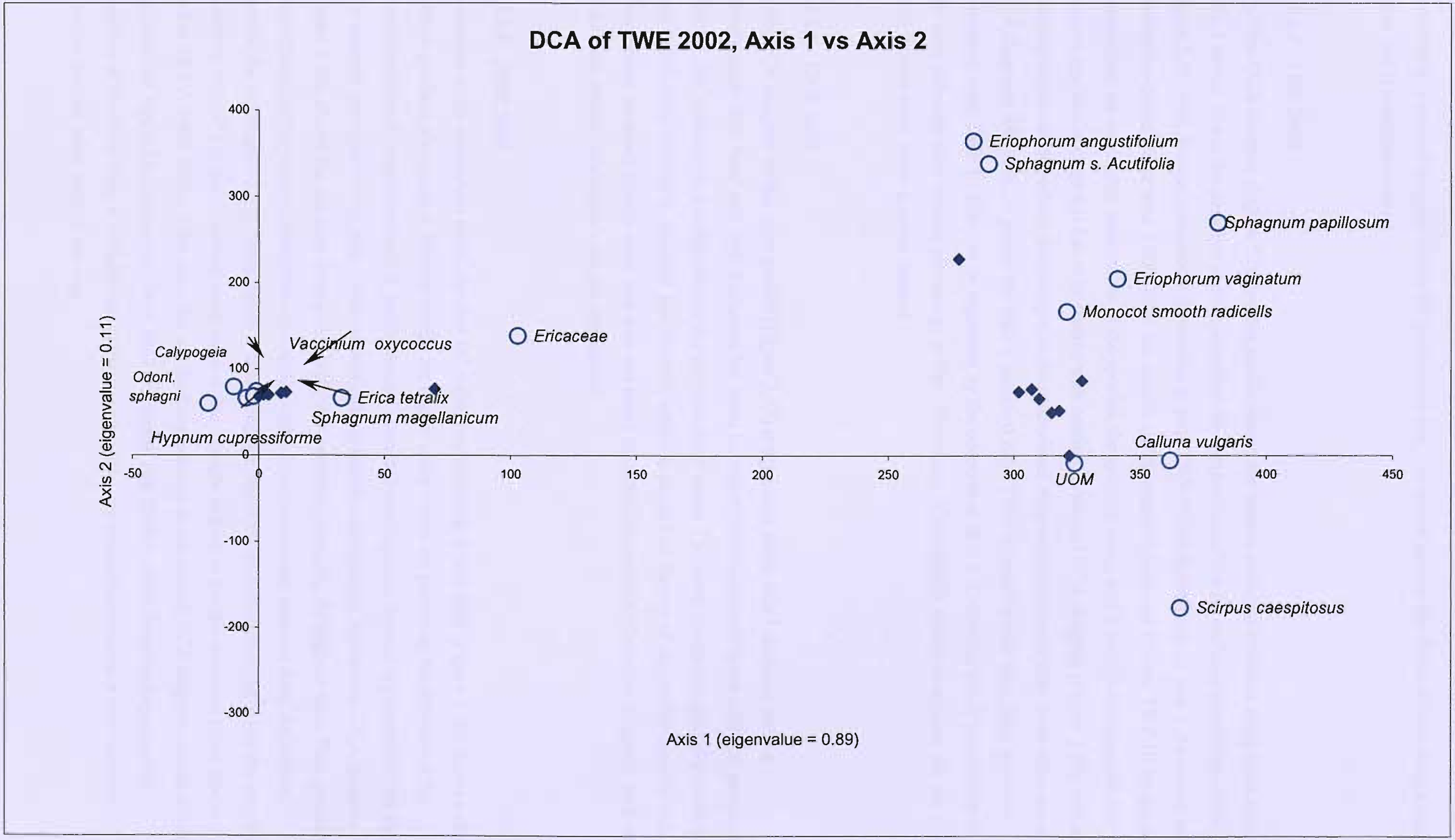


Figure 5.55: DCA of Cors Caron, core TWE 2002 (detrended by segments and down weighting of rare species).

expectantly, a second diagram where the gradient of axis 1 is scored against the depth did not yield a useful result and is therefore omitted.

5.3.1.7 TWF 2002

The first DCA diagram (Figure 5.56) of this profile shows the species widely distributed along both axes. Axis 1 seems, like in the previous profile, to reflect the composition of the macrofossil assemblages (see Figure 5.35) with *Scirpus caespitosus* (dominant in zone TWF-IV) on the left side of axis 1, Monocotyledon rootlets (co-dominant in zone TWF-III) in the middle and *S. austinii* (dominant in zone TWF-II) on the right. Considering the ecological preferences of the species, the gradient along axis 2 could be interpreted as a wetness gradient, though this has to be treated with caution. A second DCA diagram (Figure 5.57) with axis 2 scored versus depth, reflects the changes in the macrofossil diagram more clearly than most other second DCA diagrams. However, it places the highly humified zone TWF-III much wetter than the *S. austinii*-dominated zone TWF II. This can be explained by the occurrence of *S.* s. *Cuspidata* and *S. papillosum* in this zone although their volume percentage is tiny. The results of this profile demonstrate, that the use of DCA in very short cores is rather limited.

5.3.1.8 TWG 2002

In the DCA diagram of this short profile (Figure 5.58) the gradient along axis I does not show a differentiation into 'wet' and 'dry' indicators but seem to reflect the macrofossils in the different zones (see Figure 5.36), similarly in the diagrams of the previous short cores. The three *Sphagnum* species present in zone TWG-II are located on the right and *Molinia,* which is present on the top of the profile is on the left. The gradient on axis 2 is very small and does not result in useful information. Therefore diagrams with one of the axes scored versus depth are not represented.

5.3.1.9 TWH 2002

In contrast to the other short cores, the first DCA diagram of profile TWH 2002 (Figure 5.59) shows a clear wetness gradient along axis 1. Species preferring higher water tables are placed on the left side of the diagram such as *S. cuspidatum* and *S. pulchrum* and species tolerating more dryness are located on the right. The samples are spread along axis 1 with no particular areas of concentration. The second DCA diagram (Figure 5.60), shows the gradient from axis 1 well, with wetness increasing throughout time. This gradient is also reflected in the range of *Sphagnum* species throughout the macrofossil diagram from the bottom towards the top (Figure 5.37). Since this is a short diagram, there are no radiocarbon dates but the very low quantities of SCP's in the *S. austinii* layer suggest that it might belong to the late medieval times like in profile TRWA 2000. If this is the case, the wet shift represented in the second DCA diagram would reflect the Little Ice Age (LIA). As profile TWH 2002 originates, like TRWA 2000, from the Regeneration Complex of the West Bog, it is likely that at this core location, the macrofossil record is more climate-sensitive than on other parts of the bog.

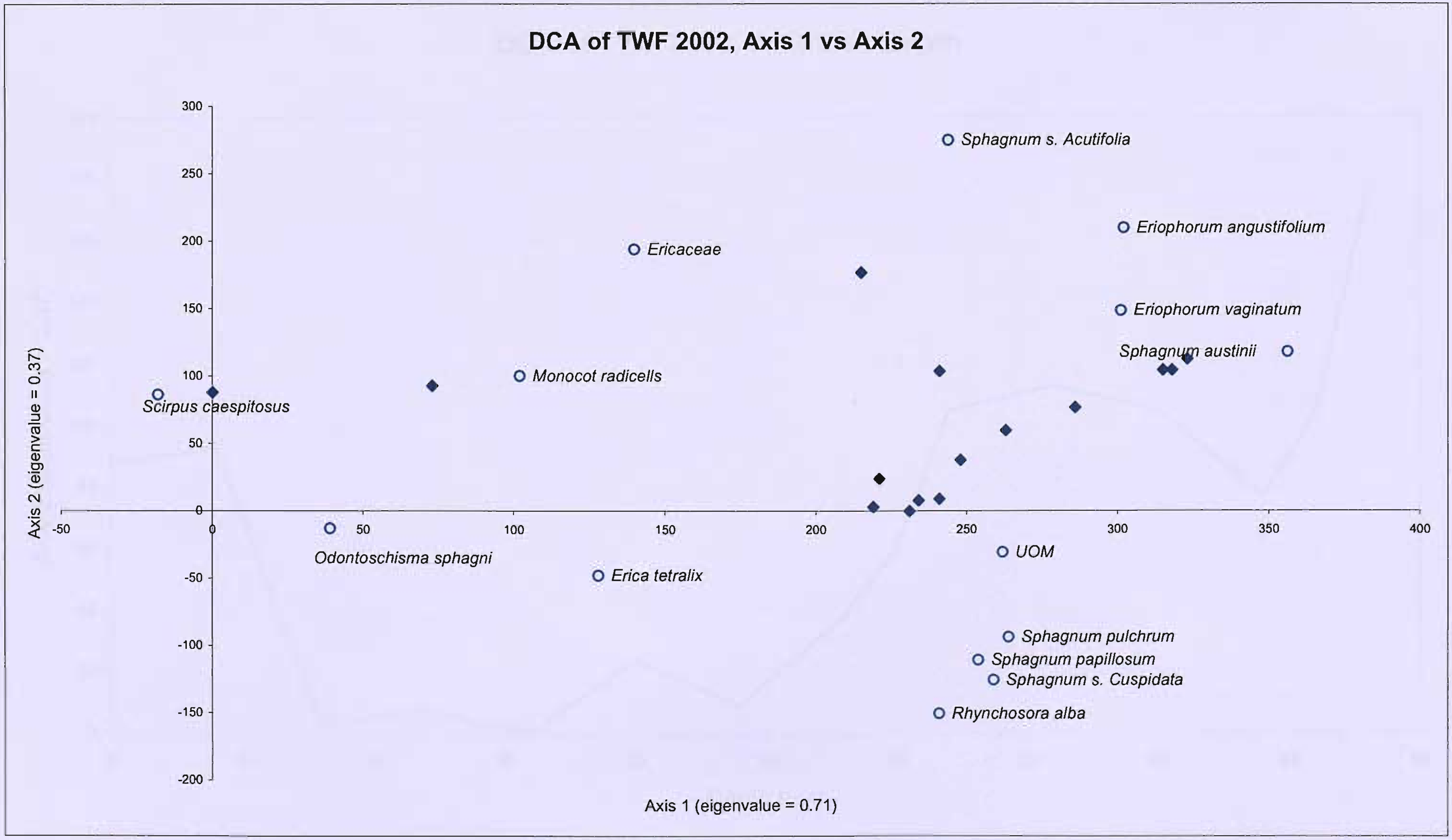


Figure 5.56 : DCA of Cors Caron, core TWF 2002 (detrended by segments and down weighting of rare species).

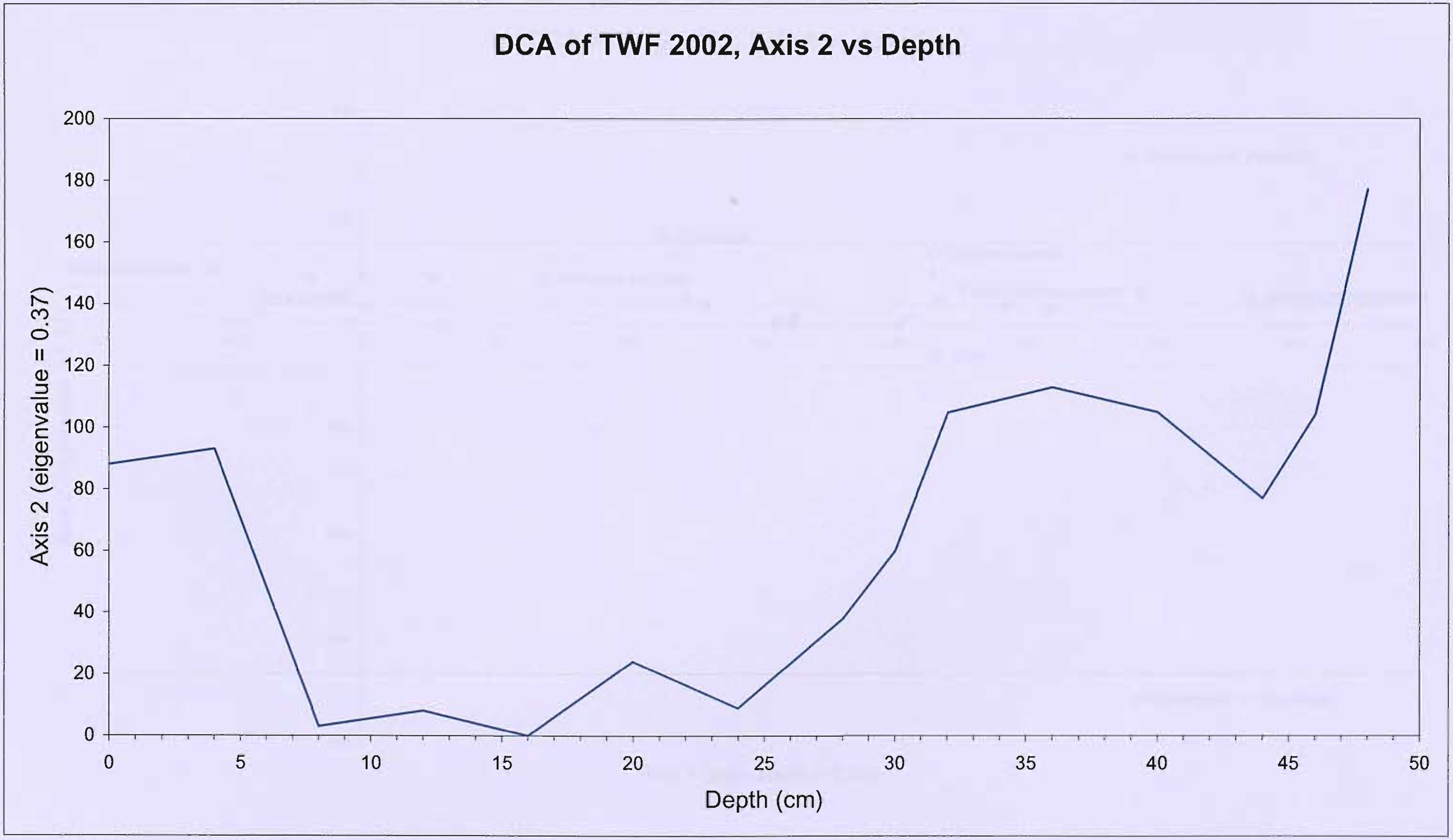


Figure 5.57: DCA of core TWF 2002, Axis 1 vs depth.

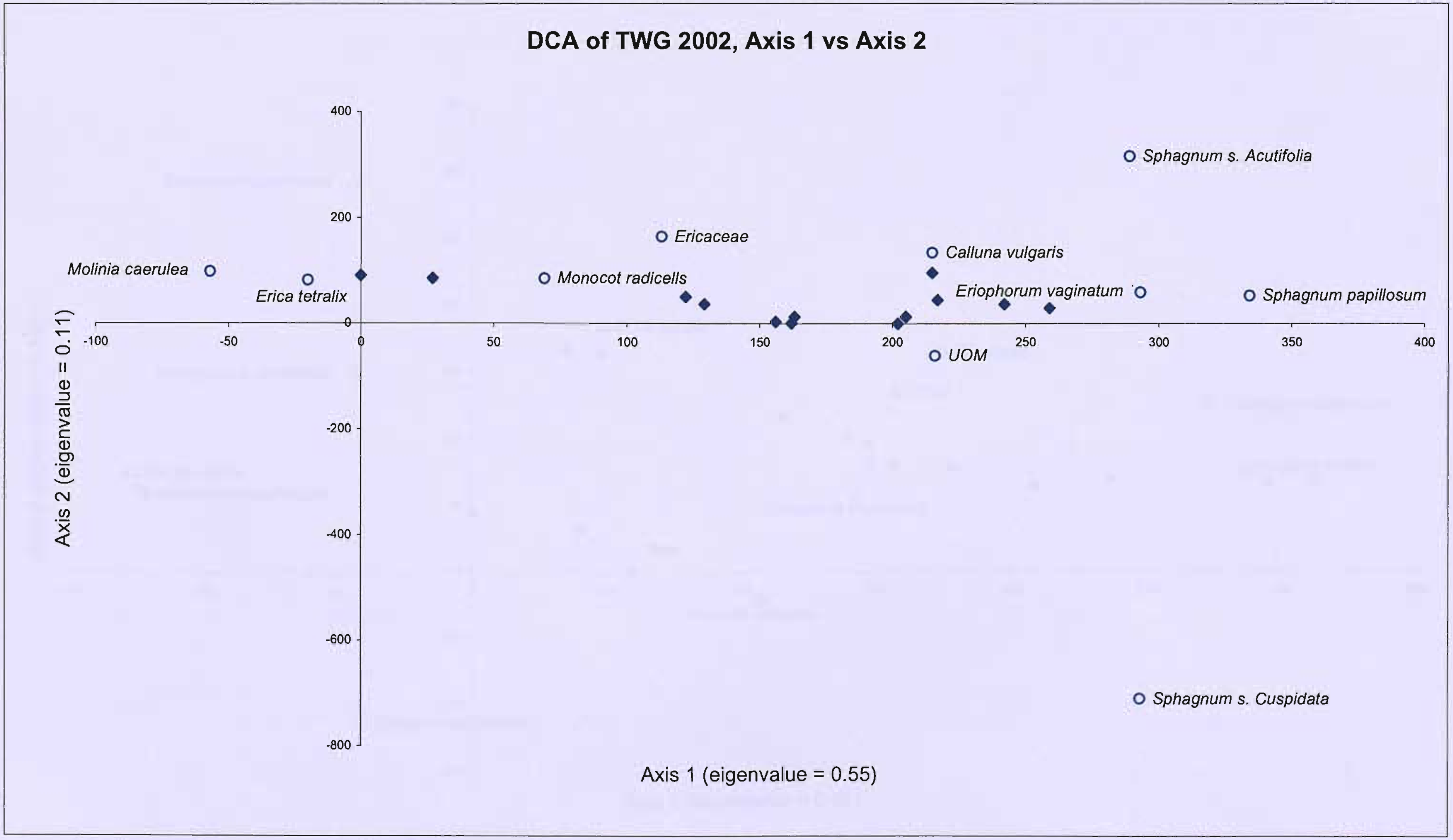


Figure 5.58: DCA of Cors Caron, core TWG 2002 (detrended by segments and down weighting of rare species).

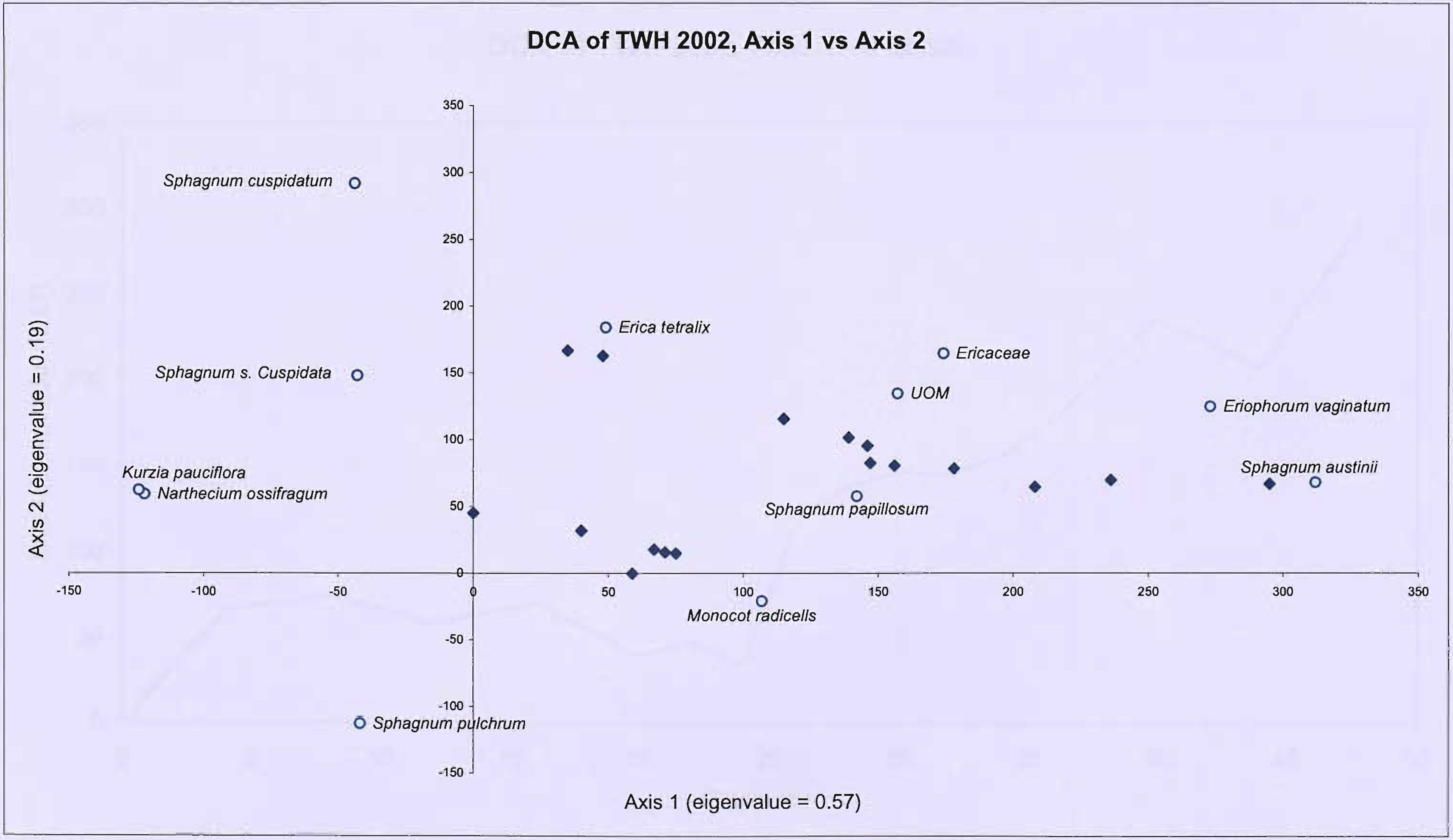


Figure 5.59: DCA of Cors Caron, core TWH 2002 (detrended by segments and down weighting of rare species).

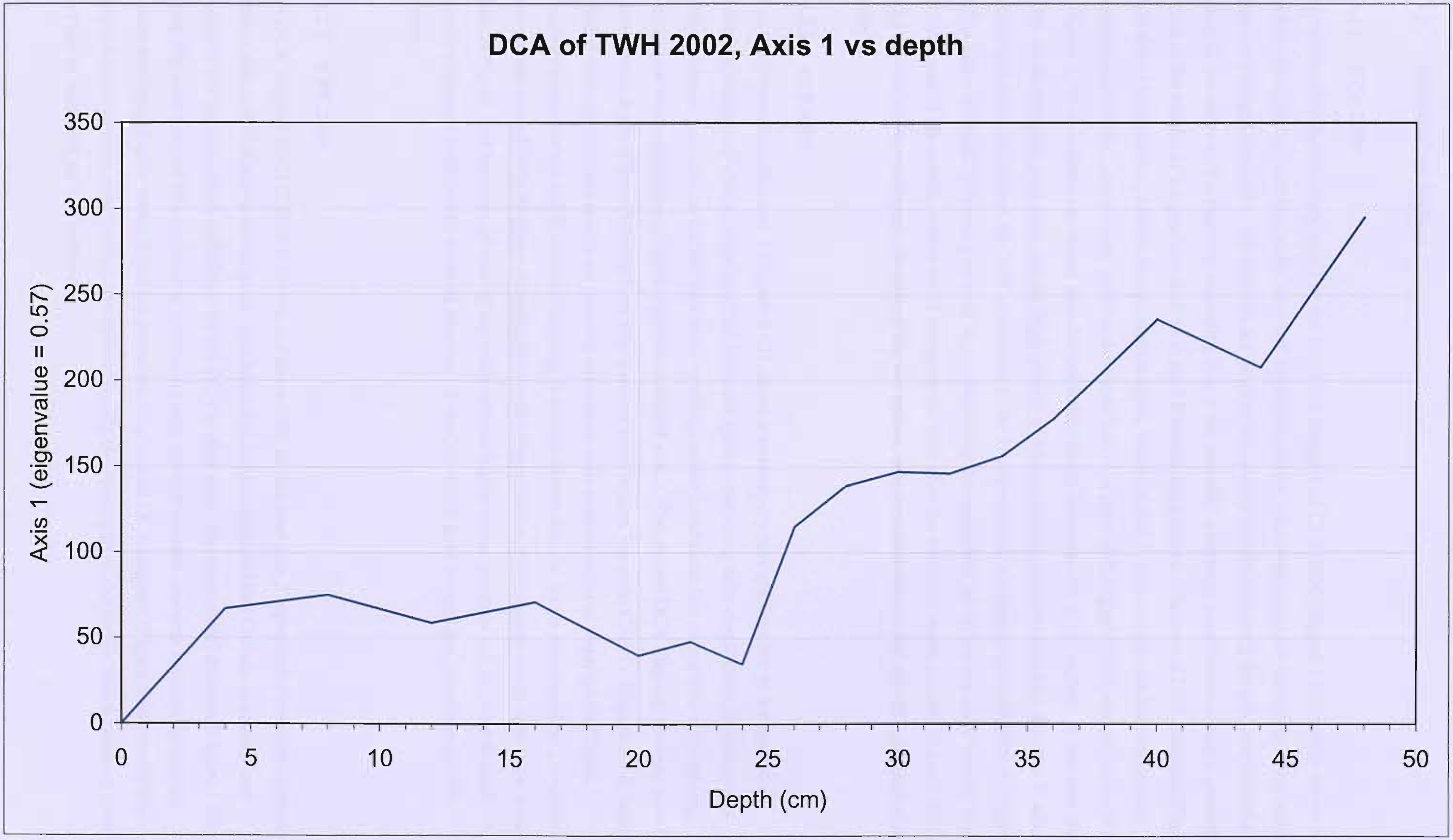


Figure 5.60: DCA of core TWH 2002, Axis 1 vs depth.

5.3.2 DCA of Cors Fochno

5.3.2.1 CFA 2000

The species distribution along axis 1 in the first DCA diagram of CFA 2000 (Figure 5.61) clearly shows a gradient from species thriving under very wet conditions on the left towards species tolerating lower water tables on the right hand side. The samples are more or less evenly distributed along the gradient. UOM is placed in the centre of the diagram, indicating that it has probably a bimodal distribution or that it generally occurs in the middle of the gradient such as in mud bottoms and hollows. The second DCA diagram (Figure 5.62) shows the wetness gradient scored against depth, which is also in accordance with the macrofossil record (Figure 5.38). Like in many profiles described before, a layer with higher UOM content (zone CFA-II in Figure 5.38) is indicated as wetter than the bordering layers dominated by *S. cf. austinii*. In this case the UOM could represent pool mud and the high amount of Monocotyledon rootlets could be those of *R. alba*, both of which would explain the 'wet' placement of the UOM variable. A climatic interpretation of Figure 5.62 is rather difficult. The youngest peat layer comprising the uppermost 30-40 cm is placed 'wetter' than the main part of the profile, which could represent the time after the medieval warm period. The dry shift at about 150 cm depth could mark the end of the wet period, which started after *c.* cal. AD 215 (Hughes *et al.* 2000).

5.3.2.2 CFB 2001

As in the previous profile, axis 1 (Figure 5.63) shows a wetness-dryness gradient but in the opposite orientation compared with all other profiles. Here the species tolerating drier conditions (for example *S. austinii*, *Myrica gale*) are on the left and those requiring wetter conditions (for example *S.* s. *Cuspidata*, *Eriophorum angustifolium*) are on the right hand side of axis 1. The second DCA diagram showing axis 1 scores versus depth (Figure 5.64) reflects this gradient more or less, but zone CFB-IV (Figure 5.39), which contains macrofossil types which are genrally associated with somewhat lower water tables (UOM, Monocotyledon rootlets and Ericaceae remains), is placed wetter than the layers dominated by *S. austinii*. To interpret the second DCA diagram climatically would be speculative. For example is not clear if the wetter phase in Figure 5.64 between 20 and 50 cm really reflects higher water tables or not. In order to track climatic changes a multi-proxy analysis approach is needed which goes beyond the objectives for this project.

5.3.2.3 CFC 2001

The DCA diagram of CFC 2001 is shown in Figure 5.65. In this case axis 2 represents a resnalbe wetness gradient although Calluna is out of space. The latter fact can be explained that Calluna is a rather rare species in this profile, which is difficult for the DCA to deal with. The macrofossil diagram (Figure 5.40) shows that dwarf shrubs like *Calluna* or *Myrica* are only present in small amounts whereas *Sphagnum* species preferring higher water tables are prevalent. The second DCA diagram (Figure 5.66) shows that there is a trend towards drier surface conditions towards the upper part of the profile which reverses at the top back to increased surface wetness.

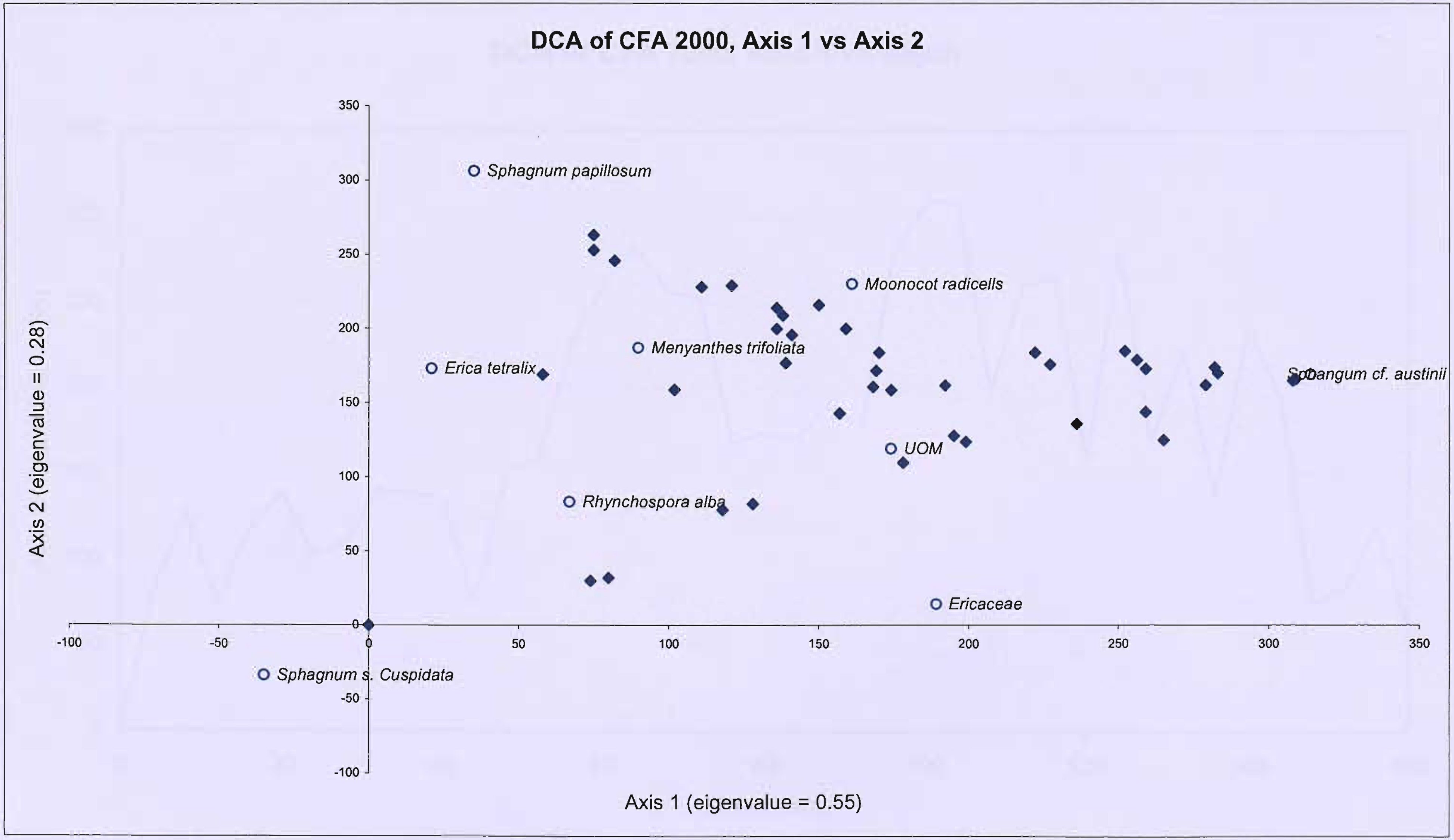


Figure 5.61: DCA of Cors Fochno, core CFA 2000 (detrended by segments and down weighting of rare species).

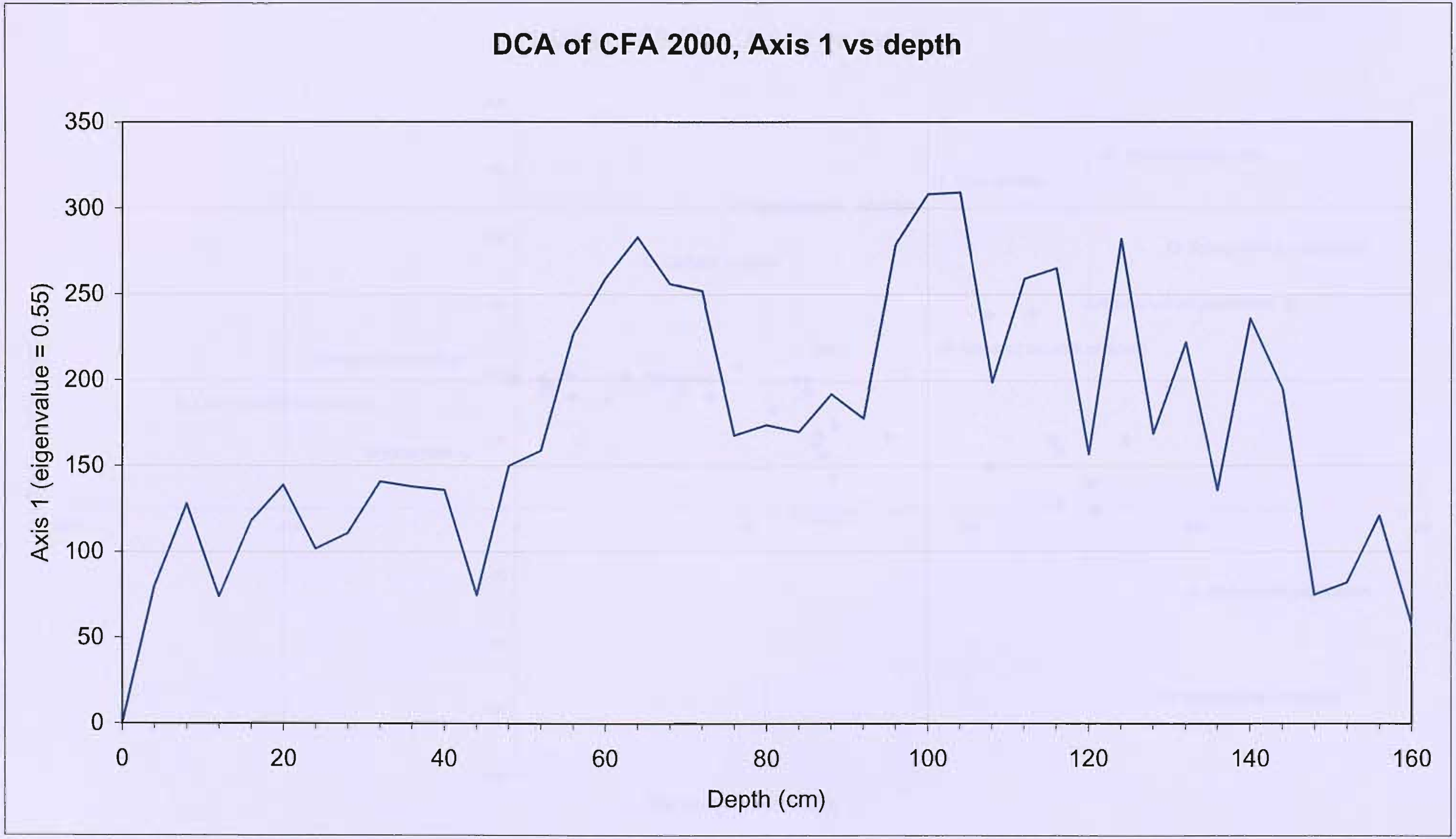


Figure 5.62: DCA of core CFA 2000, Axis 1 vs depth.

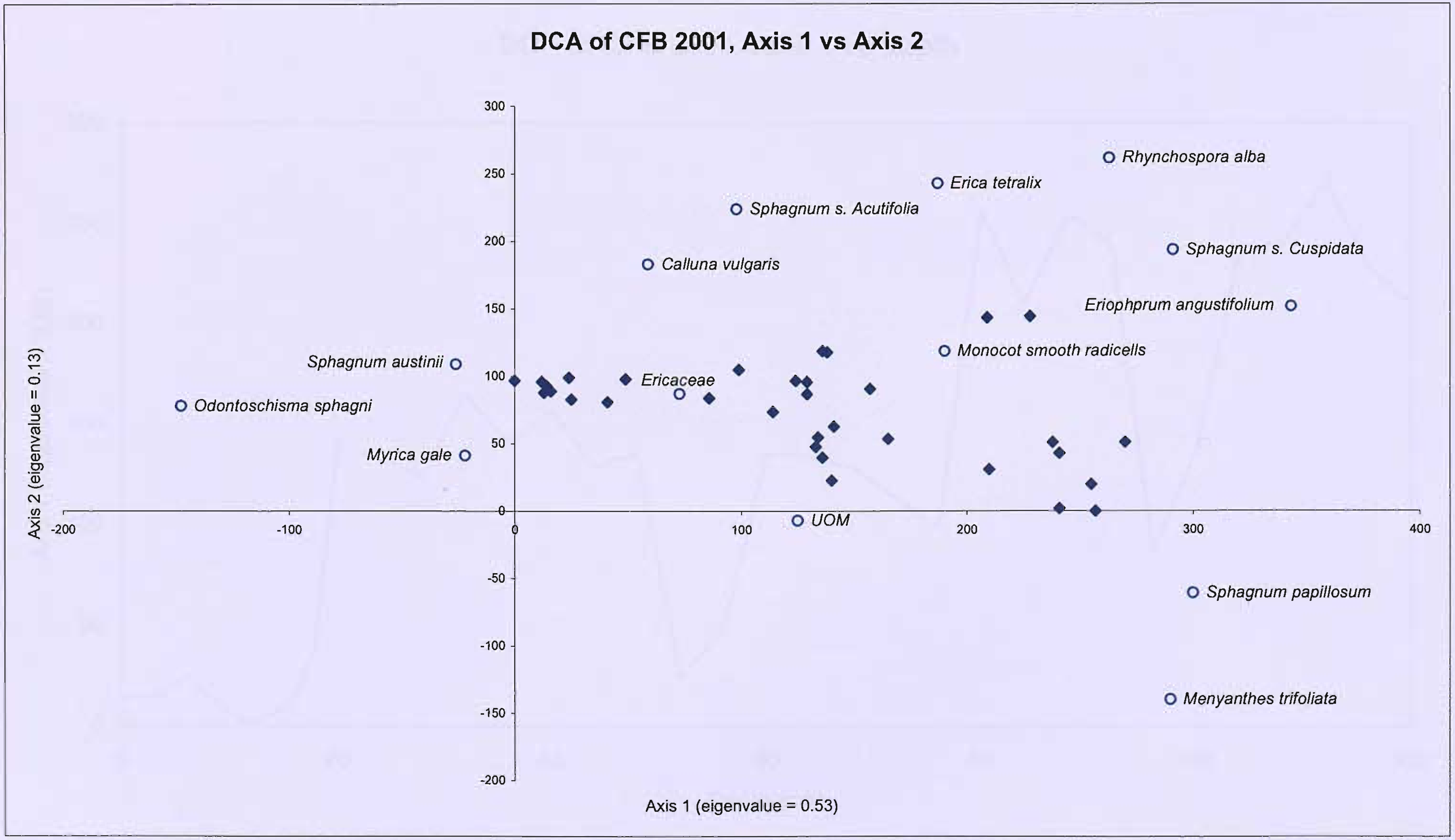


Figure 5.63: DCA of Cors Fochno, core CFB 2001 (detrended by segments and down weighting of rare species).

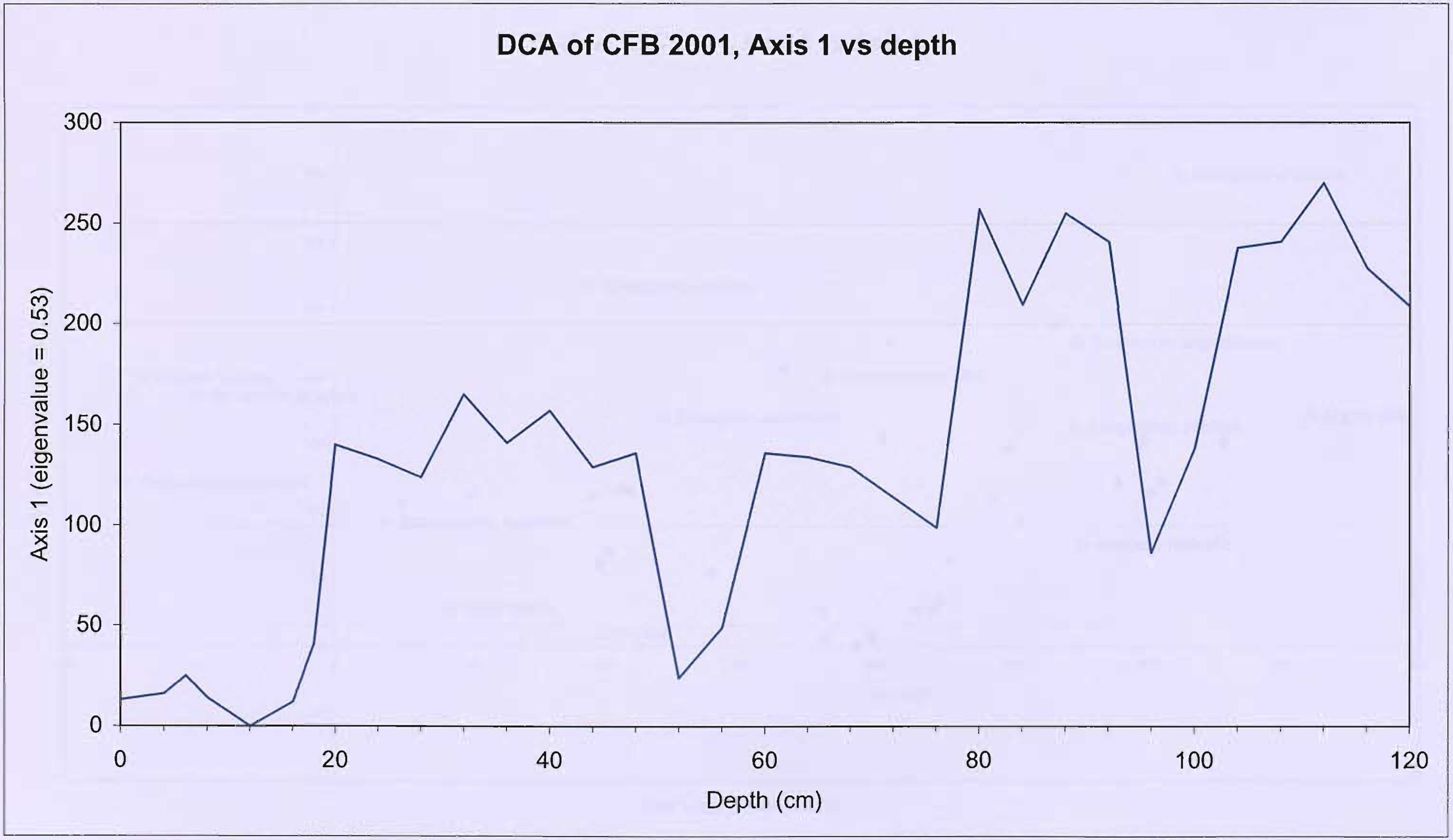


Figure 5.64: DCA of core CFB 2001, Axis 1 vs depth.

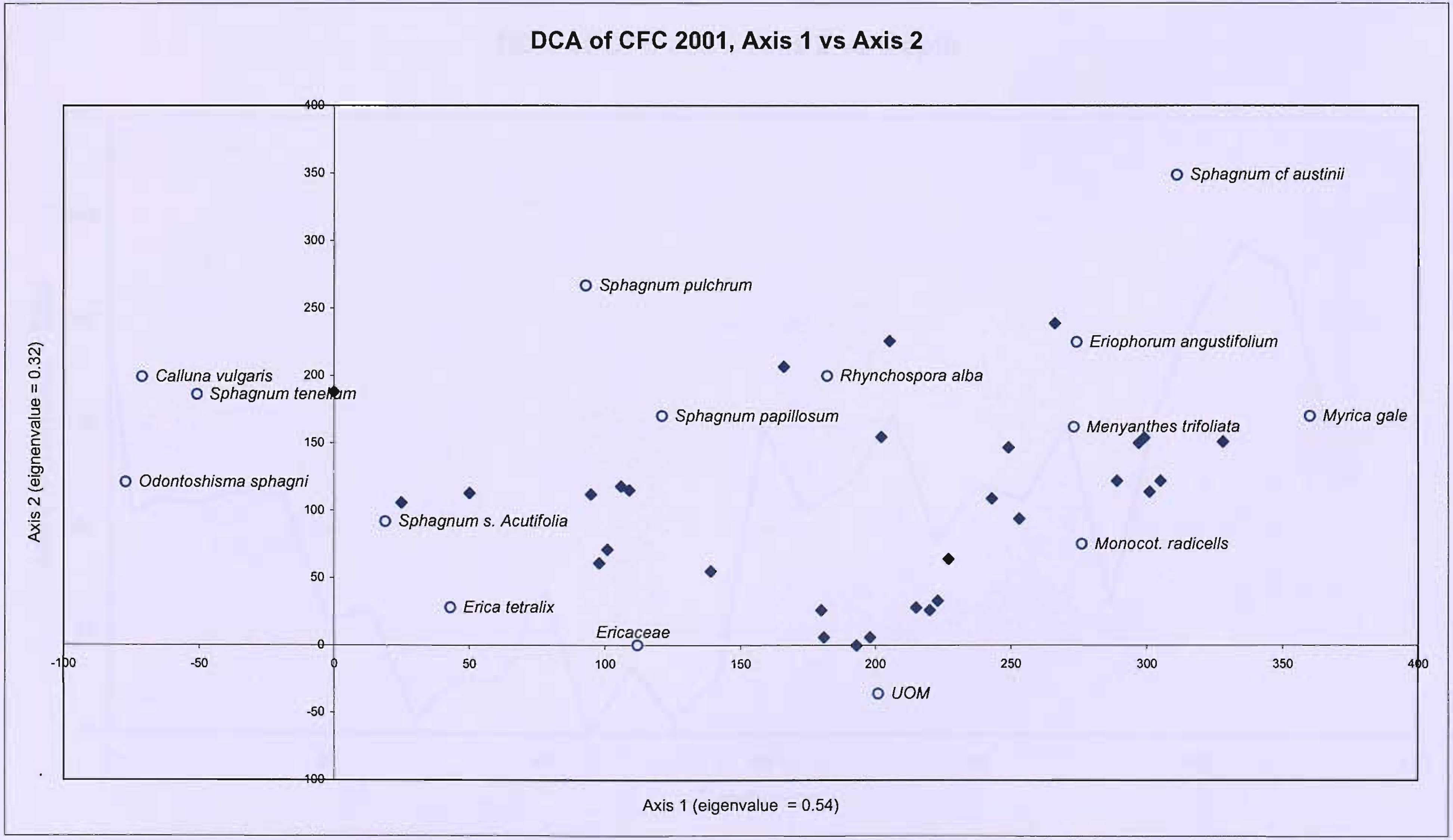


Figure 5.65: DCA of Cors Fochno, core CFC 2001 (detrended by segments and down weighting of rare species).

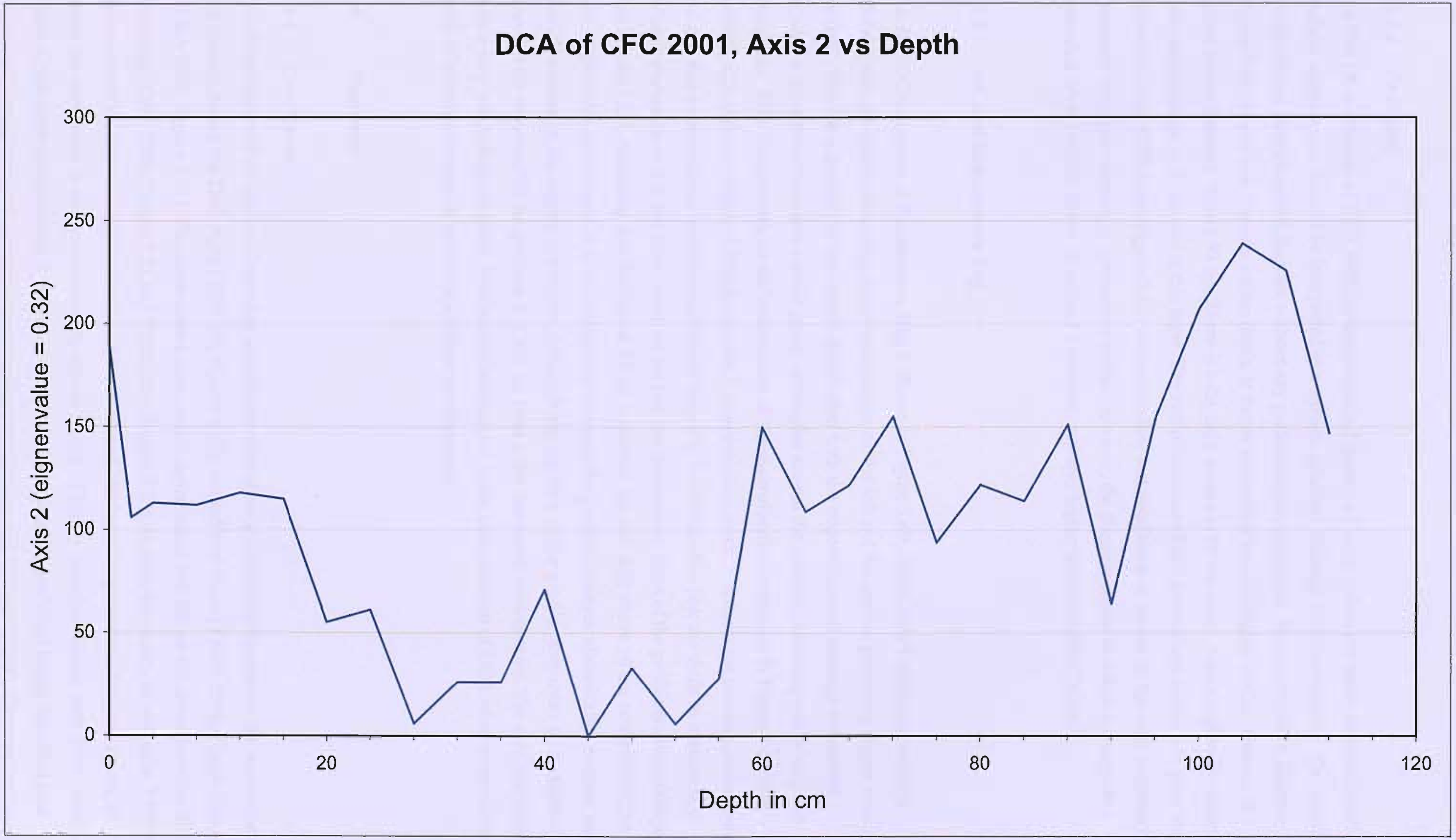


Figure 5.66: DCA of core CFC 2001, Axis 2 vs depth.

5.3.2.4 CFD 2001

The first DCA diagram of CFD 2001 is represented in Figure 5.67. Axis 1 does not show an identifiable gradient whereas axis 2 could be interpreted as a wetness gradient although with reservations. The samples are distributed over the entire diagram without any particular concentrations. The second DCA diagram (Figure 5.68) shows axis 2 scores versus depth. It shows tendencies towards higher surface wetness at greater depths between 70 and 90 cm. There is a dry shift placed at 84 cm depth, which is possibly caused by a misinterpretation of *S. austinii* at this layer. The rest of the macrofossil assemblage within this level and also within zone CFD-I (see Figure 5.41) indicates rather wet conditions as shown by the high numbers of Cladocera ephippia and also *cf. Limnozetes* mites. However, the diagram seems to reflect a change to a somewhat dryer horizon above 70 cm and a tendency towards higher wetness below 70 cm.

5.3.3 DCA of Raheenmore Bog

The first DCA diagram of Raheenmore Bog is shown in Figure 5.69. There, axis 1 exhibits a wetness gradient with the species tolerating lower water tables on the left and the species preferring higher ones on the right. There is a division in the sample distribution with the majority spread amongst the species indicating dryer conditions and a small group of samples around the species, indicating wet to very wet conditions. This division reflects the composition of the macrofossil assemblages in Figure 5.42. The second DCA diagram (Figure 5.70) shows axis 1 scored against depth. It reflects the wetness gradient well and it is also in accordance with the macrofossil diagram. It is difficult to link the shifts to climatically induced change since it is not clear which of the two top radiocarbon dates of the profile are out of range (see Figure 5.26). Assuming that the date at 80 cm is correct, the wet shift above 90 cm could reflect the LIA. If the other date correct, it is not possible to interpret the gradient changes climatically. Another remark should be made on the degree of wetness. Although the top layer of the profile, dominated by *S. austinii* is placed at the dryer end of the gradient it is still far from a dry hummock environment. The core was taken from a very wet *Sphagnum* lawn. This should be regarded in the interpretation of DCA when expressions are made of what is a hummock and what a hollow environment.

5.4 Summary

5.4.1 Cors Caron

The chronologies of all of Cors Caron bog expanse profiles show a significant decrease in the accumulation rate starting during the Dark Ages (TRE '98, Figure 5.29)) to medieval times (TNEA 2000, Figure 5.30 and TRWA 2000, Figure 5.31). The same feature starts much earlier about 300 BC on the crown margins of the West Bog (TWC 2000, Figure 5.32 and TWD 2000, Figure 5.33). In these two cores, as well as in TRE'98, the accumulation rate was also lower than on the West and Northeast Bog summits. The peat layers, in which the slow down in peat growth occurs, consist mostly of highly humified radicell peat. They usually follow a peat layer dominated by *S.* (*cf.*) *austinii* and it seems plausible that these highly humified peat layers are identical to the 'Retardation layer', noticed by Godwin and Mitchell (1938). The onset of the slow

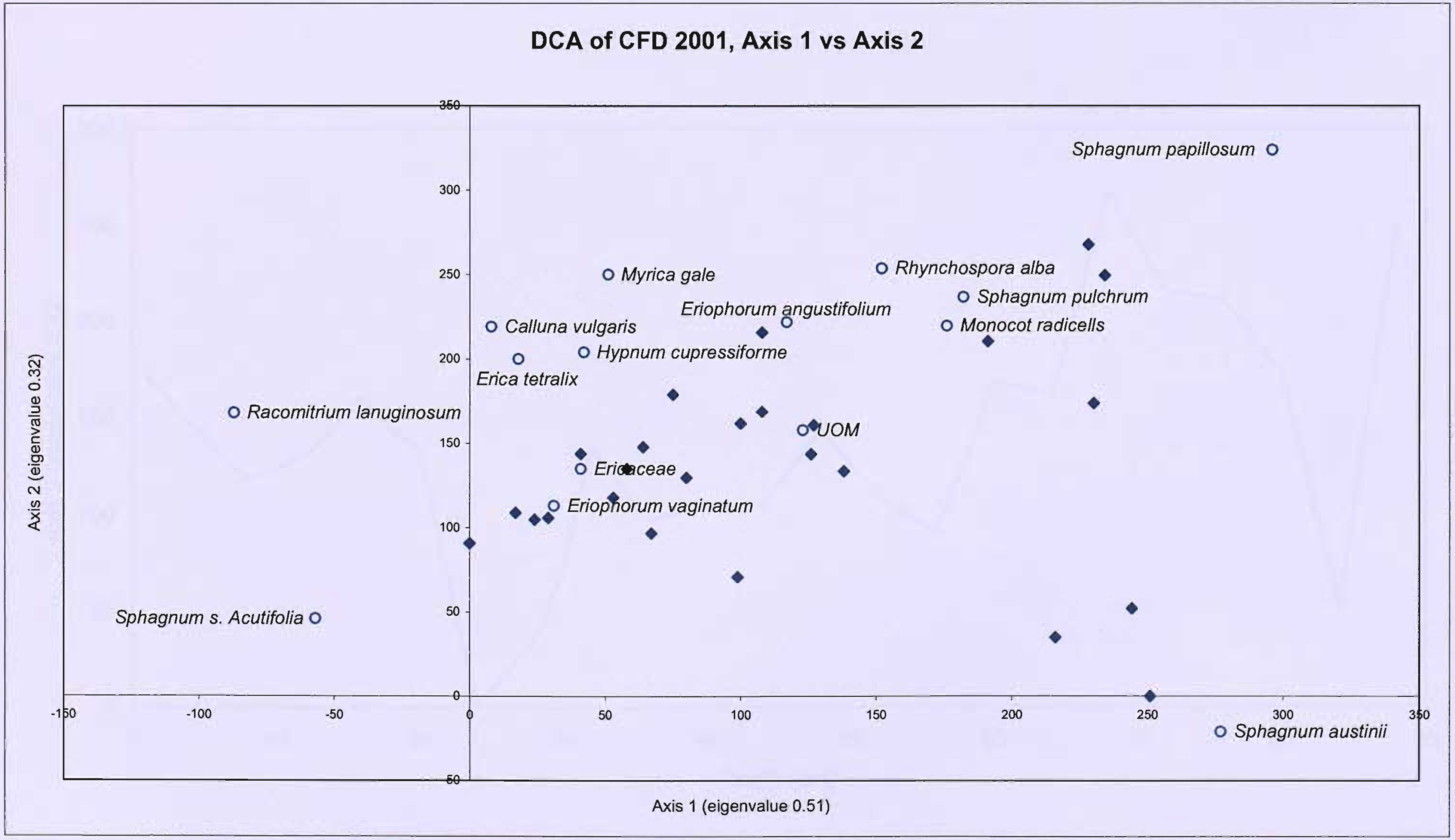


Figure 5.67: DCA of Cors Fochno, core CFD 2001 (detrended by segments and down weighting of rare species).

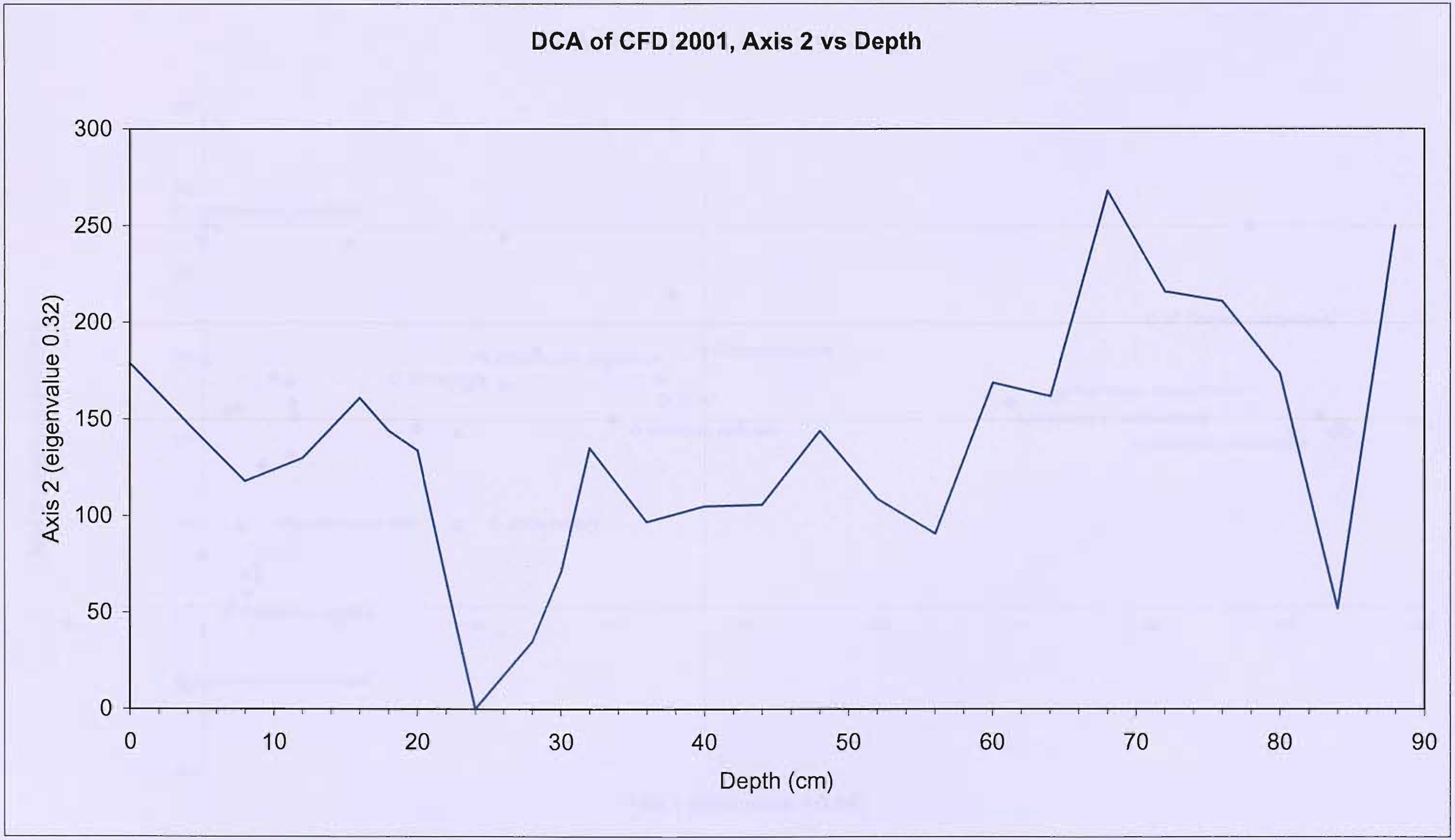


Figure 5.68: DCA of core CFD 2001, Axis 2 vs depth.

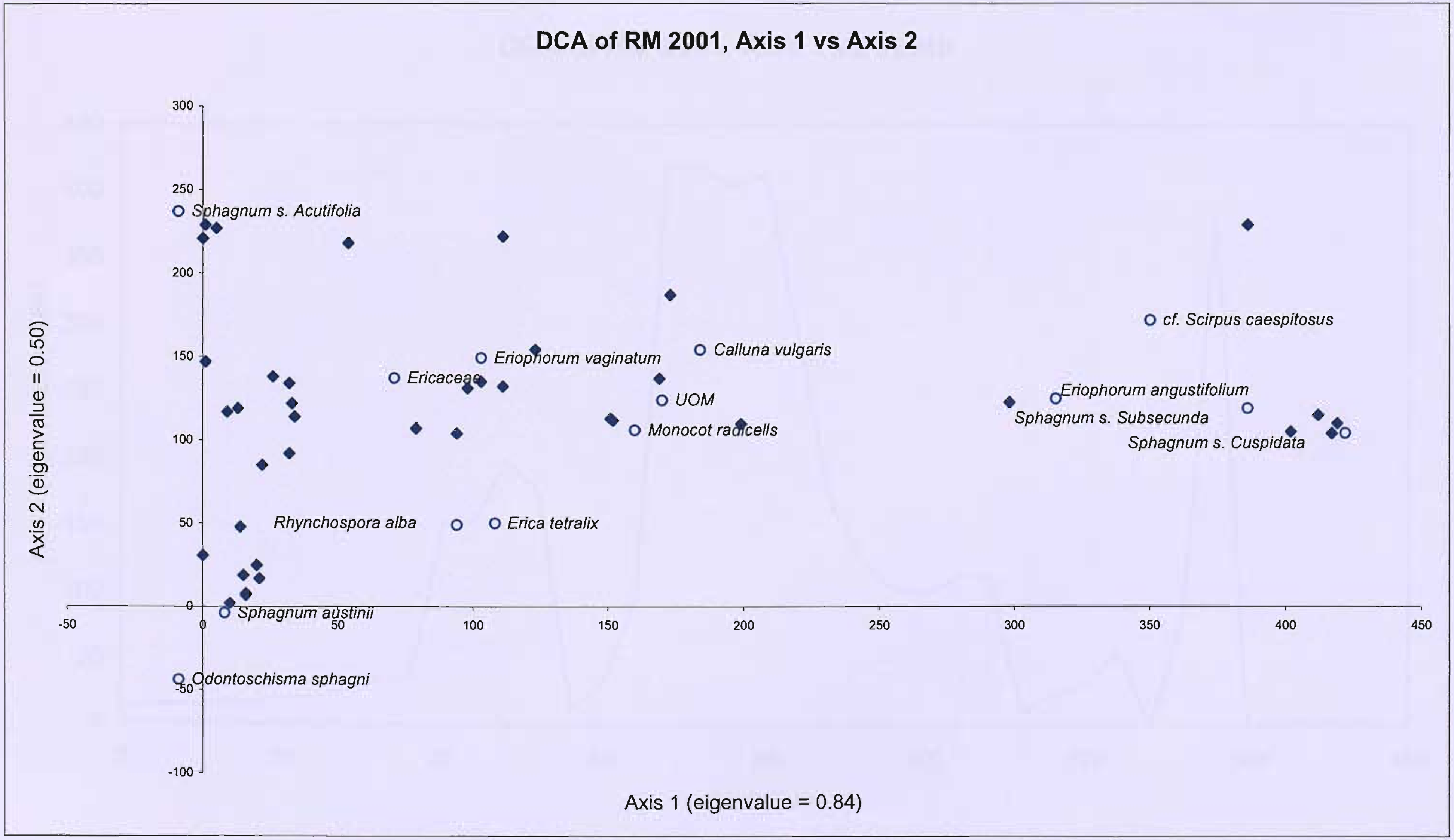


Figure 5.69: DCA of Raheenmore Bog, core RM 2001 (detrended by segments and down weighting of rare species).

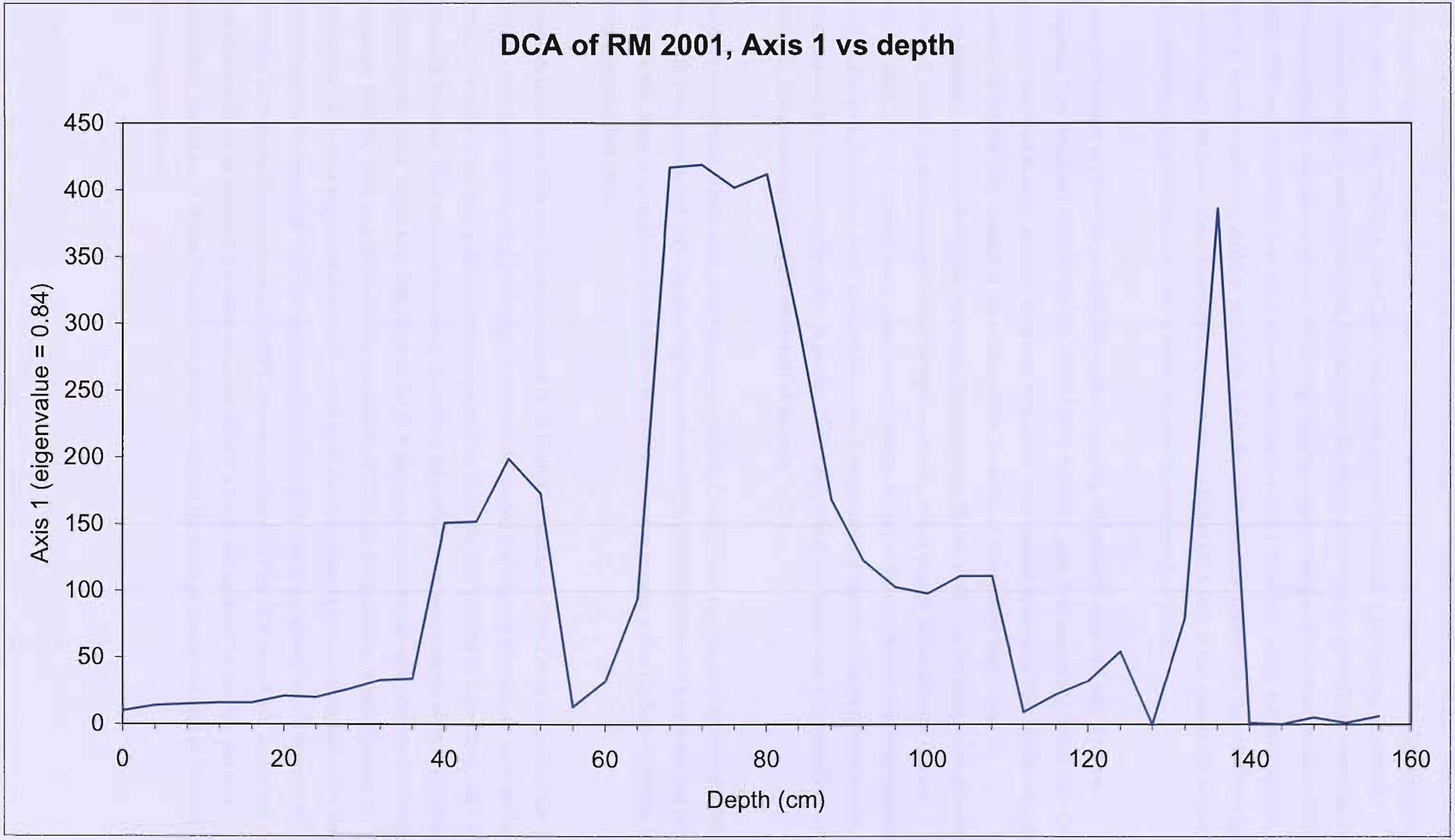


Figure 5.70: DCA of core RM 2001, Axis 1 vs depth.

down in peat accumulation at different times demonstrates that this feature is not synchonous. Thus, a single event as possible cause for this feature, like climatically induced change, is rather unlikely. Additionally, it can be concluded from the DCA, that Cors Caron seems generally unsuitable for tracking climatically induced changes in the macrofossil record. One reason for this could be that the macrofossil assemblages are often dominated by one species or type, which may mask the smaller changes. Exceptions are the profiles TRWA 2000 and TWH 2002 from the Regeneration Complex of the West Bog, which exhibit a higher degree of climate sensitivity. Another peculiarity is that the DCA does not differentiate the retardation layer as a particularly dry zone, which leaves two explanations: (1) Either DCA fails in this case or (2) the history and composition of the retardation layer is more complex than previously assumed.

S. austinii declines in all investigated profiles at the beginning of the highly humified peat layer and disappears from the record towards the end of the highly humified peat layer suggesting that at Cors Caron the species survived in small amounts for a long time under rather hostile conditions. This implies also that the cause for the loss of *S. austinii* at Cors Caron differ from that of other raised bogs where its disappearance is linked with climatic wet-shifts (Mauquoy and Barber 1999a). In the lower parts of most profiles, *S. austinii* is associated with other *Sphagnum* species, which usually thrive in lawns and wet hollows, such as *S.* s. *Cuspidata* and *S. papillosum*. Towards the top of the core this association disappears and *S.* s. *Acutifolia* becomes a more frequent associate. *S. magellanicum* appears in some profiles in very small amounts and remains unimportant. In profile TWE 2002, which was taken from a *S. magellanicum* hummock, this species dominates the upper half of the core.

There are two species, which are a matter of concern at Cors Caron. These are *Molinia caerulea* and *Betula* spec. Both have encroached onto the mire expanse, where they are naturally absent. The macrofossil record underpins that, there is no evidence that either of the two species was present within the bog vegetation over the investigated time span.

In modern times very little peat has accumulated in all of profiles sample at Cors Caron suggesting that the acrotelm, vital for balancing tbog hydrology, is not well developed and may not function properly on Cors Caron. As a result of the poor peat accumulation in modern times the SCP records of Cors Caron show an atypical SCP record. This concerns especially the 1970's subsurface peak, which seems often to be hidden in the autochtonic 'noise' of the bog. The shape of the SCP diagrams varies considerably, despite the fact that they are all from the same bog. Furthermore, the number of SCP's at the maximum in each diagram is inconsistent. It is rather peculiar that the SCP record in all dated profiles (and presumably also in the short profiles) apparently goes back well into medieval times. However, according to diagrams in Rose *et al.* (1995) the SCP record should start in the 1800's. This makes the use of the SCP record as a dating tool on Cors Caron difficult to interpret. The early presence of SCP's could be explained by the fact that coal deposited by the sea on S. Wales beaches was already collected by the local people and sold as 'seacoal' (anonymous reference).

5.4.2 Cors Fochno

The secondary DCA diagrams also reflect the pattern found on the macrofossil record of Cors Fochno. In profile CFA 2000, there is an overall trend towards increased surface wetness beginning about cal. AD 660. This is indicated by a gradual change in the dominating Sphagna from *S. cf. austinii* to *S. papillosum* and finally to *S. s. Cuspidata.* This trend is also clearly shown in the secondary DCA diagram of this profile. In contrast to CFA 2000, all other cores from Cors Fochno show an opposite trend. Species indicating wetter conditions occur at the lower parts of the profiles whereas species assemblages, which point to drier conditions are present towards the top. The secondary DCA diagrams reflect this tendency very well. However, the contrast between CFA 2000 and the other profiles of Cors Fochno demonstrates, that the chronology and macrofossil analysis of a single core may not necessarily reflect the development trends of an entire bog and has therefore to be interpreted with caution. The DCA results show, that either field stratigraphy or several other cores should back a single core from a raised bog, which is used to track climate changes.

It seems that there are some similarities between the two hollow cores and the two hummock cores. The age-depth models of the hollow profiles (Figures 5.17 and 5.21) show a decline in the overall accumulation rate and *S. austinii* disappears from the macrofossil record after the medieval times (see Figures 5.38 and 5.40). In contrast, the profiles originating from hummocks show an increase in the accumulation rates (Figures 5.19 and 5.21). In these profiles, *S. austinii* persists into recent times and is still present on one hummock (see Figures 5.39 and 5.41). In all profiles, *S. austinii* is less dominant and forms a less continuous record than on Cors Caron. Its appearance and disappearance in the macrofossil record is often in exchange with *S. papillosum.* The latter is also its most frequent associate within the investigated profiles. At this point, a remark should be made on *S. magellanicum.* In other raised bogs in Cumbria and northern Ireland *S. magellanicum* appears to be a main competitor and replaces *S. austinii* after the medieval times (Mauquoy and Barber 1999a,b, McMullen *et al.* 2004). On Cors Fochno, the situation mirrors that of Cors Caron; the species appears in three profiles but never reaches dominance.

Myrica gale has become more abundant on the present bog surface and is considered as a potential competitor to *S. austinii.* In the macrofossil record of Cors Fochno, *Myrica* is present in all four peat profiles. In CFD 2001 it appears for the first time in the medieval period and in CFC 2001 it is present from the bottom of the core onwards, (*c.* cal. AD 500 - present). This indicates that the species is not a recent invader and was part of the bog vegetation throughout the investigated time span. *Molinia caerulea* and *Betula* spec., however, are also a matter of concer on Cors Fochno, there is no evidence, that these two were present within the mire vegetation of Cors Fochno in the past.

5.4.3 Raheenmore Bog

The macrofossil record of Raheenmore Bog shows some similarities with that of Cors Fochno. Here too, *S. austinii* forms a discontinuous record. It disappears and reappears several times in exchange with other *Sphagnum* species (see Figure 5.42). The main associate of *S. austinii* in this profile is *S.* s. *Acutifolia* (often *S. rubellum* since its stem leaves could often be identified). The *Sphagnum* is in general exceptionally well preserved and strongly dominates most of the profile. Another feature that is in common with Cors Fochno is the presence of the living species in modern times. The age-depth model (Figure 5.26) and also the SCP record (Figure 5.27) indicate that the top layer of *S. austinii* peat has accumulated very fast. Within the age-depth model, one of the two upper dates is out of range, probably the one at 80 cm. The DCA shows a wet shift at this point, which could be the LIA. The DCA also shows, that the definition, of what is 'wet' and what 'dry' on a bog is relative. Although the DCA places the top layer of *S. austinii* peat at the 'dry' end of the gradient, the core was taken from a wet lawn.

6 Results of the work on the vegetation on Cors Caron

The vegetation survey conducted on Cors Caron West Bog in 1936/37 was one of the first 'modern' studies of raised bog communities in Britain. It employed, a systematic approach using transects and quadrats to investigate the phytosociological and morphological composition of a large area. The early date of the study provides a unique opportunity to study detailed changes in plant communities and species diversity over a 65 year period. As such the early vegetation records from Cors Caron are nationally important. Direct observational studies of the later stages of hydroseral succession are usually difficult because of the slow rates of change. Palaeoecological techniques offer a solution to this problem because the peat layers record a detailed history of past biodiversity. But plant macrofossil assemblages are subject to losses due to selective decay and there are often problems with the identification of plant remains to species level (see Chapter 2.3). The chapter will examine the change in mire biodiversity over the last 65 years and provide a comprehensive comparison of the vegetation of Cors Caron West Bog in 1936/37 and 2001/02.

The palaeoecological record is limited in that it is only possible to analyse a small number of cores. Most palaeoecological studies rely on one or sometime two cores from a site and the question of how representative these cores are of past communities often arises. This study has taken a larger number of cores (9) located in the different vegetation communities described by Godwin and Conway (1939) in attempt to provide a record of spatial differences in past mire communities. Although nine cores from the same study site is a much greater level of analysis than is normally attempted in palaeoecological reconstructions it still represents the equivalent of describing the modern vegetation communities with just 9 small quadrats. In this chapter the comparison of the 1936/37 vegetation survey by Godwin and Conway with the re-survey in 2001/02 provides a means to track changes in the spatial distribution of mire communities through time, across a large area. This kind of analysis is not feasible using palaeoecological core data.

The first part of the chapter presents the comparison between the original 1936/37 vegetation survey and the 2001/02 re-survey followed by a comparison of the 21st century data with the palaeoecological data. The re-survey was conducted covering a smaller, representative area, but in more detail than that recovered in the original survey. The second part of the chapter will analyse the patterns of vegetation distributions on the present mire surface. The inclusion of all species (excluding small liverworts) in the re-survey allows a more comprehensive assessment of the composition and quality of the present bog vegetation as well as providing a baseline for future ecological studies at Cors Caron.

6.1 Comparison of the vegetation data from Cors Caron in 1936/37 and 2001/02

The 1936/37 vegetation survey was arranged on transects located on a grid (Figure 4.9). The 2001/02 re-survey followed the same spatial structures to ensure that the results were comparable with the 1936/37 data, but used modern monitoring methods. As time and assistance during the fieldwork seasons covered by this project were limited it was decided to concentrate on the central offsets D-M. The full details of the methods employed in both surveys are provided in Chapter 4.4. Based on the transect survey, Godwin and Conway created a vegetation map (Figure 6.1) showing the distribution of 8 communities (e.g. Scirpetum). For each community the authors recorded example quadrats of 5×5 m to provide an in-depth description of the vegetation types. They also located individual quadrats to illustrate transitions between communities.

The presentation of the results starts with the transect data of both the 1936/37 survey and the re-survey conducted in 2001/02. This is followed by a descriptive comparison of the vegetation communities present in both surveys, illustrated by the past and modern quadrat data. For the comparison the community names and borders established by Godwin and Conway were used in order to specify the local distribution of plant species in the past and present. As the only publication cited in the following sections will be Godwin and Conway (1939) it will be referred to as Godwin and Conway in this chapter to keep the explanations short.

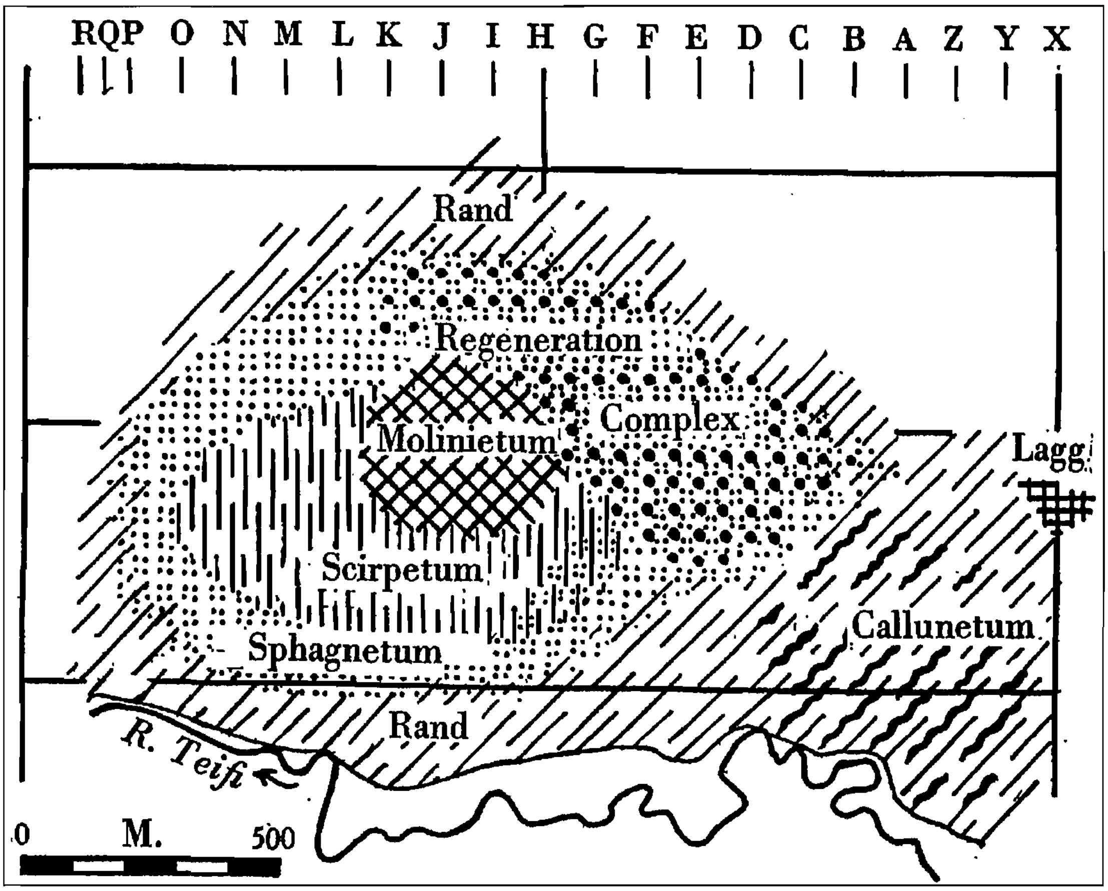


Figure 6.1: Vegetation map of the West Bog established by Godwin and Conway (1939) showing the different plant communities and their distribution.

6.1.1 Comparison of the 1936/37 and 2001/02 transect data

The 1936/37 – 2001/02 vegetation comparison based on the transect data are presented as vegetation maps of the West Bog in the Figures 6.2 to 6.4. Every row of the maps in these figures demonstrates the situation for a particular plant species in 1936/37 (left), 2001/02 (centre) and the changes (right) that occurred over the last 65 years. The left column of each vegetation map shows the distance from the baseline. The top of the maps represents the west side of the West Bog with transect names D-M running north to south as in Godwin and Conway, shown in Figure 6.1. Every cell in the vegetation maps of 2001/2 represents the percentage cover a particular plant species in a quadrat of 3×3 m. The cells in the vegetation maps of 1936/37 represent the same species recorded in 1936/37 along 20 m wide transects in 50 m steps. The comparison is based on the assumption that both, the 3×3 m quadrats recorded in 2002 and the 20×50 m plots recorded by Godwin and Conway are representative. Therefore, there are differences in size and quality of the vegetation records between these two data sets, it has to be acknowledged, that they may not be wholly comparable, even though every effort was made to ensure that the 2002 sampling was of representative units.

From the the Figures 6.2.a and d to 6.4.a and d show the situation in 1936/37 derived from retrieved data of the Figures 4.14 and 4.15 in chapter 4.4 from Godwin and Conway. Depending on the information available from this publication the vegetation cover in these figures is given as percentage cover or frequency. The Figures 6.2.b and e to 6.4.b and e show the situation in 2001/02. Here the vegetation cover is always given as percentage cover. Figures 6.2.c and f to 6.4.c and f demonstrate the changes in the vegetation cover over the last 65 years in percentage cover or in a presence/absence pattern. After constructing the tables it was conspicuous that some of the distribution patterns of the plant species from the survey in 1936/37 appeared more or less 'stripy' (for example see Figure 6.3.a). In contrast, the present vegetation data appear to be 'patchy' (for example see Figure 6.3.b). This may be caused by the different approaches of the past and recent surveys but also, as Godwin and Conway quote, due to differences in knowledge and experience between the different surveyors in 1936/37. Some of the surveyors were students who may not have recognised species or quantified them in the same way.

6.1.1.1 *Sphagnum (excluding S. cuspidatum and S. tenellum)*

The results of the comparison for *Sphagnum* (excluding *S. cuspidatum* and *S. tenellum*) are shown in Figure 6.2. a-c. Godwin and Conway excluded *S. cuspidatum* and *S. tenellum* from their results because they considered these species not to be peat-forming Sphagna. Therefore they were also excluded from the comparison of the *Sphagnum* cover. The species included in this category are, in order of their abundance in 1936/37, *S. papillosum*, *S. pulchrum*, *S. rubellum*, *S. subnitens* and *S. magellanicum*. Figure 6.2.a, containing the data retrieved from Figure 4.14/6 of Godwin and Conway, shows the situation in 1936/37. The numbers represent the percentage cover of *Sphagnum* carpet. The background shading is derived from Figure 4.15/24 and shows the coverage below 10 %, between 10-15 % and over 15 %. The 1936/37 distribution pattern forms a circle with the densest cover in the north-western area of the west bog, in the former Regeneration Complex, but also the southern and eastern periphery exhibit a higher percentage cover. Very low values characterise the southeastern and central area where the *Sphagnum* cover stays below 10 %. The modern data (Figure 6.2.b) show that the area of 10-15 % coverage in *Sphagnum* is almost entirely restricted to the former Regeneration Complex. A comparison of the former and recent data shows a dramatic loss of *Sphagnum* cover over the 65 year period (Figure 6.2.c). The greatest loss occurred in those areas where *Sphagnum* was most abundant in the 1930s; the Regeneration Complex and the southeastern periphery of the West Bog. The average percentage cover of the recorded quadrats diminished from 15 % to 6 %.

6.1.1.2 *Sphagnum pulchrum*

For *S. pulchrum* no specific data are available from 1936/37. Figure 4.15/25 in Godwin and Conway gives an overview of the distribution and main range of the species on the West Bog but no specific percentage cover. The shading in this figure refers to frequencies from 1 to 3. However, there is no comment to which percentage cover these frequencies are equivalent too. Therefore it is only possible to compare loss or gain in area and shifts in the distribution pattern. Godwin and Conway infer that *S. pulchrum* is restricted to the Regeneration Complex in the north-west of the bog with the highest cover in two patches at J-H:850-600 and F-D:650-300 (Figure 6.2.d). The modern distribution of *S. pulchrum* (Figure 6.2.e) is generally still around the same location, but when comparing the distribution pattern (Figure 6.2.f) it appears that it has retreated from the central peat dome while gaining more territory around the bog margin to the south and it has also spread to the east. Altogether there is only a minor loss in its distribution area from 79 to 74 grid points.

6.1.1.3 Calluna vulgaris

An overview of the percentage cover of *C. vulgaris* in 1936/37 and 2001/02 and the changes over the last 65 years is shown in Figure 6.3.a-c. In 1936/37 the main range of high cover values, in excess of 40-50 %, was located in the central western area of the bog and at the eastern margin of the peat dome around the baseline (Figure 6.3.a). The lowest coverage was northwest in the Regeneration Complex and around the southeast. Generally the *C. vulgaris* cover was very high. At the present time the main coverage is located in the northwestern part of the peat dome (Figure 6.3.b). Changes mainly show a retreat in the central and western parts of the bog whereas an increase of *C. vulgaris* occurred in the northwestern area of the former Regeneration Complex (see Figure 3.6.c). Altogether the average percentage cover of *C. vulgaris* decreased from an estimated 22 % to about 13 % within the area of the recorded quadrats at the grid points.

6.1.1.4 Cladonia

The *Cladonia* species monitored in 1936/37 (Figure 6.3.d) was identified as *Cladonia sylvatica*, which is now, renamed *Cladonia arbuscula.* By contrast, the *Cladonia* species that is currently most abundant on the bog is *C. portentosa.* As both species are very similar it is most likely that *C. portentosa* was mistaken for *C. arbuscula.* With this error in mind, it is doubtful that a distinction was made between *C. arbuscula* and *C. ciliata*, which also occurs on the bog. The presence of another lichen species, *Cladonia unicalis* was separately recorded, indicating that the observers tried to identify and to record the different lichen species. However, it is likely that *C. ciliata* was not recognised as a different species and included in the mistaken *C. arbuscula.* The comparison refers therefore to the distribution and percentage cover of the aggregate *C. portentosa* and *C. ciliata.* In 1936/37 the distribution of *C. portentosa* + *C. ciliata* shows a ‘stripy’ pattern which is, the authors assume, a result of recorder error. Figure 4.15/28 in Godwin and Conway, shows only the abundance of *Cladonia* coverage of 15 % and more. A comparison can only be made on the basis of the category of coverage $\geq$ 15 %.

The inconsistency in the Cladonia distribution recorded in 1936/37 is probably due to subjectivity of the observers who, consisting of pre- and postgraduate students, had varying knowledge and experience. These problems of inconsistency were repeatedly addressed by Godwin and Conway. However, the authors conclude that the main range of *C. portentosa* + *C. ciliata* is located around the bog margin and in particular at the northern part of the bog, which is the driest. The survey data from 2001/02 exhibits a more even distribution of *C. portentosa* and *C. ciliata* without a distinctive pattern (Figure 6.3.e). A comparison of the area covered by $\geq$ 15 % of *C. portentosa* + *C. ciliata* (Figure 6.3.f) shows a general and significant decrease

and specifically a retreat on the bog margins. In contrast to this there is an increase of *Cladonia* cover in the bog centre. Altogether the percentage cover of *Cladonia* seems to be very high compared to other bogs, for example Wedholme Flow and Ballynahone Bog (Table 6.1).

Table 6.1: Presence and percentage cover of *Cladonia portentosa* at different lowland raised bogs

Site	Average presence of *Cladonia portentosa* in vegetation records of 3×3 m quadrats in percentage cover	Average percentage of *Cladonia portentosa* in vegetation records of 3×3 m quadrats in percentage cover
Cors Caron West Bog, Ceredigion/West Wales	100	9.26
Ballynahone Bog, Londonderry/Northern Ireland	31.81	0.68
Wedholme Flow, Cumbria/Northern England	0	0

6.1.1.5 Molinia caerulea

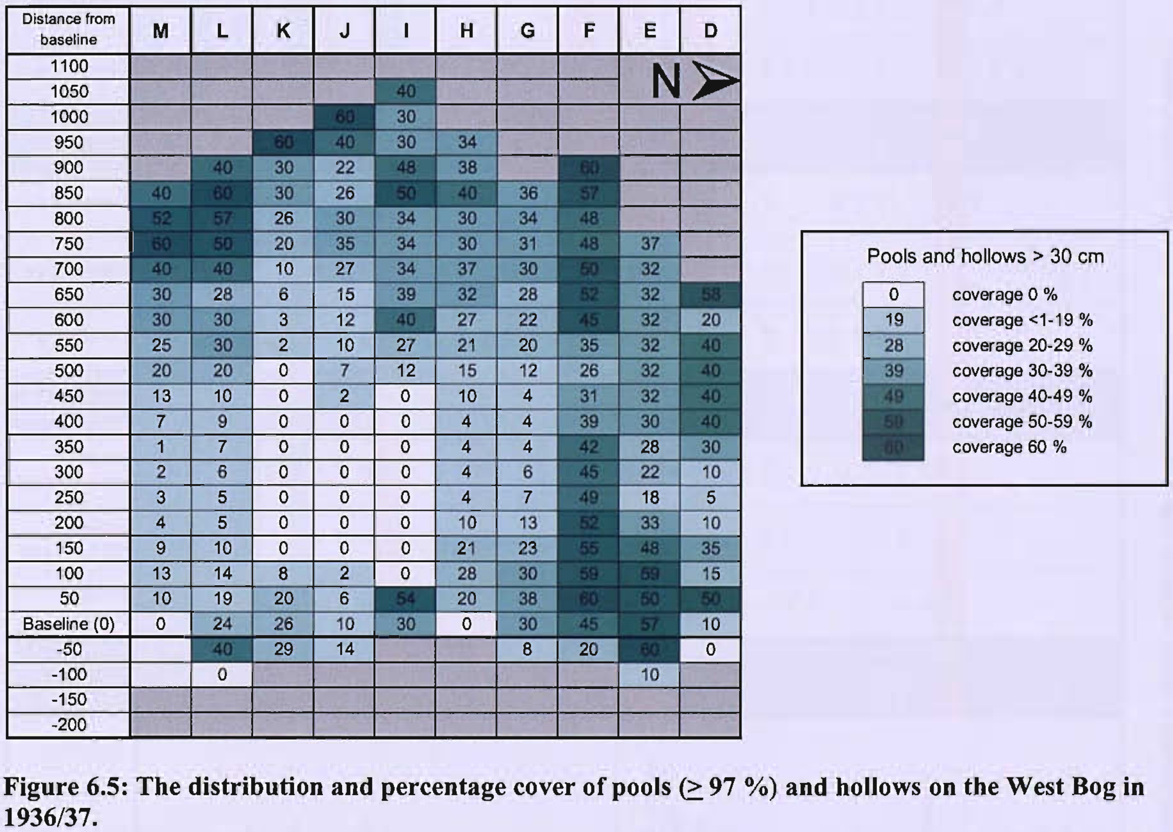
In 1936/37 this species formed a conspicuous area in the central part of the West Bog but, as Godwin and Conway (1939) point out, not at the summit of the peat dome. The other areas of its distribution are the steeper margins around the West Bog. The authors also mention that species like *Potentilla erecta*, which was associated with *M. caerulea* on the bog margins, occur likewise in the Molinietum in the centre. Figure 6.4.c shows that little change in the distribution of *M. caerulea* has occurred. It still forms a noticeably different vegetation community in the centre of the West Bog, but its distribution has partially shifted (Figure 6.4.c). In Godwin and Conway's approach the frequency of *M. caerulea* was only estimated where it formed a continuous area. Single clusters or tufts of *M. caerulea* were disregarded in the description of the distribution. The 2001/02 survey, restricted to 3×3 m quadrats, resulted in a similar outcome. Where *M. caerulea* formed single tussocks or patches outside of a quadrat it was not covered by the record. Therefore the 1936/37 and 2001/02 data of *Molinia* are comparable and should not include major errors.

6.1.1.6 Rhynchospora alba

Tracking the change of *R. alba* is difficult because Figure 6.4.a, derived from Figure 4.15/5 of Godwin and Conway can only give information about the percentage cover of pools with sparse *R. alba*. Godwin and Conway report that these pools were often large and up to 2 m width. Non-pool areas and pools smaller than 30 cm in diameter, bearing dense *R. alba*, where disregarded in the publication of Godwin and Conway. Thus, it is not possible to assess the percentage cover of the species, nor the entire area of its presence. However, Figure 6.4.a allows the conclusion that *R. alba* in 1936/37 was present at most parts of the mire expanse, but very scarce or absent from the south-eastern area of the bog crown, where the scarcity or absence of pools indicates a lower surface wetness. *R. alba* was possibly more abundant in the pool-rich area which formed a ring-like pattern around the crown of the bog. The data from the original quadrats 1, 5 and 9 (see Tables 6.2 and 6.3) suggest a cover of *R. alba* between 1 and 8 %, which is considerably higher than the present values which are now often below 1. At the present time the species is present within the former pool and hollow area (Figure 6.4.e), but has largely retreated from the eastern periphery and the centre of the mire expanse (Figure 6.4.c). Thus it is tentatively concluded that *R. alba* has suffered from a significant loss in area and percentage cover.

6.1.1.7 *Past and present presence of pools*

In the 1930s a complex of pools and hollows was present on the West Bog, which is still visible on the aerial photographs from 1948 (see Figure 7.2). Godwin and Conway did not differentiate between hollows and pools and included in the term 'pool', *Sphagnum* filled hollows as well as open water bodies. Thus, Figure 6.5, derived from Figure 4.14/1 of Godwin and Conway, represents the distribution of open water pools and wet hollows, which are wider than 30 cm. From the diagrams of Godwin and Conway (see Figure 4.14) it could be calculated, that the pools which were smaller than 30 cm in diameter represented not more than 3 % of all pools. This percentage is probably smaller than the scale of error occurring during retrieval of the data. Therefore Figure 6.5 could be considered to represent the distribution and percentage cover of pools and hollows in general at the time of the survey in 1936/37. The main range of the pool and hollow complex was located in a circle around the centre of the bog. The wettest areas are found at the south-western and north-western edge of the West Bog, where the summit of the mire expanse borders the adjacent hill. Another area of greater wetness is located at the north-eastern part of the investigated area. In contrast, in the south-eastern part of the bog centre, pools and hollows are almost absent.



Distance from baseline	M	L	K	J	I	H	G	F	E	D
1100									N ➤	
1050					40					
1000				60	30					
950			60	40	30	34				
900		40	30	22	48	38		60		
850	40	60	30	26	50	40	36	57		
800	52	57	26	30	34	30	34	48		
750	60	50	20	35	34	30	31	48	37	
700	40	40	10	27	34	37	30	50	32	
650	30	28	6	15	39	32	28	52	32	58
600	30	30	3	12	40	27	22	45	32	20
550	25	30	2	10	27	21	20	35	32	40
500	20	20	0	7	12	15	12	26	32	40
450	13	10	0	2	0	10	4	31	32	40
400	7	9	0	0	0	4	4	39	30	40
350	1	7	0	0	0	4	4	42	28	30
300	2	6	0	0	0	4	6	45	22	10
250	3	5	0	0	0	4	7	49	18	5
200	4	5	0	0	0	10	13	52	33	10
150	9	10	0	0	0	21	23	55	48	35
100	13	14	8	2	0	28	30	59	59	15
50	10	19	20	6	54	20	38	60	50	50
Baseline (0)	0	24	26	10	30	0	30	45	57	10
-50		40	29	14			8	20	60	0
-100		0							10	
-150										
-200										

Pools and hollows > 30 cm

0	coverage 0 %
19	coverage <1-19 %
28	coverage 20-29 %
39	coverage 30-39 %
49	coverage 40-49 %
59	coverage 50-59 %
60	coverage 60 %

Figure 6.5: The distribution and percentage cover of pools (≥ 97 %) and hollows on the West Bog in 1936/37.

Aerial photographs from the late 1940s (see Figure 7.2) show that remains of the pool system were still present at this time. By contrast, the aerial photographs from 1998 do not show any evidence for the existence of the former natural pool system. During the 2001/02 survey virtually no pools containing open water were found. However, the pans of former pools within the Regeneration Complex could occasionally be identified. They were often found filled with *Sphagnum pulchrum* and *Narthecium ossifragum* and now

	Original 1 Regeneration Complex	Resurvey 1-1 (Average)	Resurvey 1-15 (Average)	Resurvey 1-21 (Average)	Original 2 Sphagnetum	Average 2-5	Average 2-14	Average 2-24	Original 4 Scirptetum	Average 4-6	Average 4-9	Average 4-25	Original 8 Molinietum	Average 8-4	Average 8-6	Average 8-17	Original 9 upper Rand	Average 9-13	Average 9-15	Average 9-16
Calluna vulgaris	7	14	12	18	4	11	10	5	1	10	14	10	12	11	7	14	6	3	10	4
Erica tetralix	4	9	12	10	2	5	5	5	10	9	7	10	8	6	4	4	2	4	6	5
Empetrum nigrum	·	<1	<1	·		<1	2	<1	·	3	4	5	3	·	<1	·	·	<1	·	<1
Andromeda polyfolia	·	2	3	2	<1	<1	<1	<1	·	2	2	2	4	<1	<1	<1	·	<1	1	1
Vaccinium oxycoccus	·	3	3	4	·	1	<1	1	·	4	3	3	25	2	1	1	·	1	<1	2
Erio. angustifolium	1.5	<1	<1	<1	<1	<1	·	<1	·	<1	<1	<1	1	·	·	·	1	<1	<1	<1
Eriophorum vaginatum	5	6	7	5	2	7	5	8	·	10	12	9	·	11	4	9	<1	4	6	5
Scirpus cespitosus	9	7	7	5	7	3	3	3	>25	3	3	3	7	<1	<1	·	1	<1	1	<1
Rhynchospora alba	5	<1	<1	<1	1	<1	<1	<1	·	·	·	·	·	·	·	·	8	·	<1	<1
Narthecium ossifragum	<1	2	5	2	<1	<1	<1	<1	1	<1	<1	<1	<1	·	·	·	·	·	·	·
Cladonia portentosa	15	7	5	9	15	7	6	8	·	10	10	16	7	20	6	10	16	4	5	10
Molinia caerulea	·	·	·	v	·	·	·	·	1	<1	·	·	35	12	22	27	·	34	25	28
S. subnitens	·	·	·	<1	·	·	·	<1	·	1	<1	<1	1	<1	2	<1	·	·	<1	<1
S. capillifolium	·	<1	<1	<1	·	<1	<1	3	·	·	·	<1	·	<1	1	<1	·	<1	·	<1
S. papillosum	24	1	1	3	·	<1	3	<1	<1	<1	<1	<1	·	·	<1	<1	3	1	2	5
S. magellanicum	·	·	·	·		<1	1	·	·	·	·	·	·	·	·	·	·	·	·	·
S. pulchrum	3	3	7	6	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
S. fallax	·	·	·	·		<1	·	·	·	·	·	·	·	·	·	·	·	·	·	·
S. cuspidatum	11	<1	1	<1	15	3	1	3	12	<1	<1	<1	·	·	·	<1	5	<1	<1	<1
S. tenellum	1	5	<1	·	1	<1	<1	<1	40	<1	<1	<1	<1	·	·	·	<1	·	<1	<1
Total *Sphagnum*	**39**	**9**	**9**	**10**	**39**	**4**	**6**	**7**	**52**	**2**	**2**	**<1**	1	<1	3	<1	**8**	**2**	**3**	**6**
Sphagnum (excl. *S. cuspid. / tenellum*)	27	4	8	9	23	<1	5	3	<1	1	<1	<1	1	<1	3	<1	3	1	2	6
Odontoschisma sphagni	·	8	5	8		8	3	3	·	4	2	4	·	2	1	2		2	3	3
Hypnum cupressiforme	1.5	5	7	4	1	6	4	5	3	10	9	9	6	6	5	4	1	5	5	6
Pleurozium schreberi	·	·	·	·		·	·	·	·	·	·	·	·	<1	1	2	·	<1	·	·
Calypogeia	·	·	·	·		·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Cladonia subfurcata	·	·	<1	<1		<1	<1	<1	·	<1	<1	·	·	·	·	·	·	·	·	·
Cladonia unicalis	<1	<1	1	·		·	·	·	<1	<1	·	·	·	·	·	·	·	·	·	·
Cladonia crispata	·	<1	·	·		<1	·	·	·	·	<1	<1	·	·	·	·	·	·	<1	<1
Campylopus spec	·	·	·	·		<1	<1	<1	·	<1	<1	·	·	<1	<1	·	·	·	·	·
Leucobryum glaucum	·	·	·	·		<1	·	<1	·	·	<1	·	·	·	<1	<1	·	·	·	·
Cladonia fimbriata	·	·	·	·		<1	<1	<1	·	<1	<1	<1	·	<1	<1	<1	·	<1	<1	<1
Drosera rotundifolia	<1	<1	<1	<1	<1	·	<1	·	·	·	·	·	·		<1		·	<1	<1	<1
Racomitrium lanuginosum	3	<1	·	<1		·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
open Waterpools	15	<1	·	<1	6	·	·	<1	11	·	<1	·	·	·	·	·	47	·	·	·
Dicranumscoparium	·	·	<1	<1	·	<1	·	<1	·	<1	<1	<1	·	<1	·	<1	·	<1	<1	<1
Vaccinium myrtillus	·	·	·	·	·	·	·	·	·	<1	<1	<1	1	<1	2	·	·	<1	·	·
Polytrichum strictum	·	·	·	·	·	<1	2	·	·	<1	·	·	·	<1	<1	<1	·	·	·	<1
Polytrichum commune	·	·	·	·	·	·	·	·	·	·	·	·	·	·	<1	·	·	·	·	·
Aulacomnium palustre	·	·	·	·	·	·	<1	·	·	·	·	·	4	·	<1	·	·	·	·	·
Rhytidiadelphus (s)	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
Betula + litter	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	5	·	·

Table 6.2: Percentage cover of species in 1936/37 and 2001/02 of the quadrats 1, 2, 4, 8 and 9, involving the full range of species.

	Original 3 Transition between Sphagnetum and Scirpetum	Average 3-3	Average 3-5	Average 3-11	Original 5 Regeneration Complex	Average 5-3	Average 5-5	Average 5-7	Original 6 edge of Regeneration Complex	Average 6-2	Average 6-5	Average 6-16	Edge of Moliniietum	Average 7-3	Average 7-13	Average 7-18
Calluna vulgaris	3	5	4	9	·	23	<1	19	·	2	<1	0	·	6	13	8
Erica tetralix	7	10	9	10	·	6	4	8	·	6	6	7	·	8	4	7
Empetrum nigrum	·	2	1	2	1	·	·	·	<1	1	<1	<1	4	+	+	<1
Andromeda polyfolia	·	4	3	3	·	·	<1	<1	·	1	2	2	·	1	1	1
Vaccinium oxycoccus	·	7	3	4	·	·	<1	<1	·	2	2	2	·	2	2	<1
Eriophorum angustifolium	·	<1	·	<1	1/<1	·	<1	·	10/3	·	·	·	<1	·	·	·
Eriophorum vaginatum	·	10	7	10	·	3	2	3	·	5	3	3	·	4	5	4
Scirpus cespitosus	·	8	11	5	·	<1	<1	1	·	<1	<1	<1	·	<1	<1	<1
Rhynchospora alba	·	<1	<1	<1	·	·	·	·	·	·	·	·	·	·	·	·
Narthecium ossifragum	·	2	<1	<1	·	<1	<1	<1	·	<1	<1	·	·	<1	<1	·
Cladonia arbuscula	1	8	7	11		<1	<1	<1		7	15	5	·	6	13	10
Molinia caerulea	·	·	·	·	·	30	59	34	·	27	36	29	21	22	11	24
S. subnitens	·	·	·	<1		<1	<1	<1	·	1	<1	4	·	2	<1	2
S. capillifolium	·	·	<1	·		·	·	<1	·	·	<1	1	·	<1	<1	<1
S. papillosum	4	10	4	2	16	<1	<1	2	2	<1	<1	·	2	·	·	<1
S. magellanicum	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
S. pulchrum	·	·	·	·	2	·	·	·	3	·	<1	<1	·	·	·	·
S. fallax	·	·	·	·	·	·	·	·	·	·	·	·	·	·	<1	·
S. cuspidatum	·	4	3	1	1	·	<1	·	4	<1	·	<1	4	<1	<1	·
S. tenellum	12	<1	<1	2	·	<1		<1	·	<1	<1	<1	·	·	·	·
Total *Sphagnum*	**16**	**17**	**7**	**7**	**19**	**1**	**2**	**3**	**9**	**3**	**1**	**5**	·	**2**	**<1**	**2**
Sphagnum (excl. S. cuspid. / tenellum)	12	5	4	4	18	<1	1	3	5	2	<1	5	·	2	<1	2
Odontoschisma sphagni	·	10	8	7	·	4	1	4	·	3	2	3	·	2	2	2
Hypnum cupressiforme	·	4	6	10	·	4	5	3	·	5	3	5	·	4	4	5
Pleurozium schreberi	·	·	·	·	·	<1	·	·	·	<1	<1	·	·	2	1	<1
Calypogeia spec.	·	·	·	·	·	<1	<1	<1	·	·	·	·	·	·	·	·
Cladonia subfurcata	·	<1	<1	<1	·	·	·	·	·	·	·	·	·	·	·	·
Cladonia unicalis	·	·	<1	·	·	·	·	·	·	·	·	·	·	·	·	·
Cladonia crispata	·	·	<1	<1	·	·	·	·	·	·	·	·	·	·	·	·
Leucobryum glaucum	·	<1	<1	<1	·	<1	<1	<1	·	<1	<1	<1	·	<1	5	<1
Cladonia fimbriata	·	<1	<1	<1	·	<1	·	·	·	<1	<1	<1	·	<1	<1	<1
Drosera rotundifolia	·	<1	<1		·	<1	·	<1	·	·	·	<1	·	·	·	·
Racomitrium lanuginosum	·	·	<1	·	·	·	·	·	·	<1	·	<1	·	·	·	·
open Waterpools	29	3	2	<1	14	·	·	·	8	<1	·	·	·	·	·	·
Dicranumscoparium	·	·	·	<1	·	<1	<1	·	·	·	<1	·	·	<1	·	·
Vaccinium myrtillus	·	<1	·	·	·	·	·	·	·	<1	·	·	·	1	1	<1
Polytrichum strictum	·	·	·	<1	·	<1	·	·	·	3	·	1	·	<1	·	<1
Polytrichum commune	·	·	·	<1	·	·	·	·	·	·	·	·	·	·	·	·
Aulacomnium palustre	·	·	·	·	·	<1	·	·	·	<1	·	·	·	·	·	·
Rhytidiadelphus spec.	·	·	<1	·	·	·	·	·	·	·	·	·	·	·	·	·
Betula + litter	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·

Table 6.3: Percentage cover of species in 1936/37 and 2001/02 of the quadrats 3, 5, 6 and 7, involving a selection of species.

represent wet hollows. Figure 5.37, showing the macrofossil diagram of core TWH 2000, in Chapter 5.2 represents the development of such a former pool. The far bigger current marginal pools have been created artificially in cutover parts by the CCW of the bog. They are supposed to inhibit runoff of surface water and to provide breeding habitats for dragonflies. It is concluded that the extended natural pool system, once characterising the Cors Caron West Bog, has disappeared completely. However, the different gradient of surface wetness, indicated by the percentage cover of the pools in 1936/37, is still reflected in the present species distribution and percentage cover (see for example Figure 6.2.e).

6.1.2 The change in the vegetation communities over the last 65 years

The analysis of the changes within the vegetation communities described by Godwin and Conway (1939) orientates on the way the authors introduced the vegetation of the Cors Caron West Bog. However, the changes in the quadrats 1-9, established by the authors to illustrate the vegetation in the different vegetation units of the West Bog, show the dramatic shift in the vegetation composition more clear than the accompanying description. Thus the changes in the vegetation quadrats 1-9 are presented first, followed by a more comprehensive description involving the changes in the quadrats.

6.1.2.1 Comparison of the 1936/37 and 2001/02 data from the quadrats No. 1 to 9 from Godwin and Conway

The results of the chronological comparison of the quadrat data are presented in three different ways:
The percentage cover of the species in 1936/37 and in 2001/02 is shown in Table 6.2 and 6.3.
The most important changes of the Figure 6.2 and 6.3 are summarised in Tables 6.4, 6.5 and 6.6.
Detrended Correspondence Analysis (DCA) of the vegetation data from the original and re-surveyed quadrats was carried out on frequency data (based on the twenty-five 1×1m cells). The DCA diagrams are shown in the Figures 6.6, 6.7 and 6.8.

Table 6.4: Overview of important changes in the quadrats 1,2,4,8 and 9 between 1936/37 and 200/01.

Quadrat	Main changes in the vegetation
1	- More than two-fold increase in *C. vulgaris*, *Erica tetralix*, *Narthecium ossifragum* and *Hypnum cupressiforme*; - Emergence of *Empetrum nigrum*, *Andromeda polifolia*, *Vaccinium oxycoccus*, hummock *Sphagna* - **Approximately 75 % reduction of total *Sphagnum* cover**, mostly affecting *S. papillosum* and *S. cuspidatum*; open water is reduced from 15 % to less than 1 %; *Rhynchospora alba* from 5 % to less than 1 % and *Cladonia portentosa/C. ciliata* values decreased about 30 – 60 %
2	- More than two-fold increase in *C. vulgaris*, *E. tetralix*, *Eriophorum vaginatum* and *H. cupressiforme* - Emergence of *E. nigrum*, *V. oxycoccus*, hummock *Sphagna* - **More than 80 % reduction of total *Sphagnum* cover**, mainly in *S. papillosum* and *S. cuspidatum*; almost total disappearance of open water; *Cladonia portentosa/C. ciliata*

	decreased more than 30 % and *S. caespitosus* values more than 50 %
4	- More than ten-fold increase in *Calluna vulgaris* and three-fold increase in *H. cupressiforme* - Appearance of *E. nigrum*, *A. polifolia*, *V. oxycoccus*, hummock *Sphagna* along with *Eriophorum vaginatum* and *E. angustifolium* and *C. portentosa*/*C. ciliata* - **More than 90 % reduction of total *Sphagnum* cover**, mostly affecting *S. cuspidatum* and *S. tenellum*; open water nearly vanished; substantial decrease in *S. caespitosus* and also *N. ossifragum*
8	- Significant increase in *C. portentosa/C. ciliata* - Emergence of *Pleurozium schreberi*, *E. vaginatum*, *S. capillifolium*, *S. papillosum and S. cuspidatum* - Substantial decrease in *M. caerulea*, *V. oxycoccus* and *Scirpus caespitosus*, *E. nigrum* and *A. polifolia* - Disappearance of *E. angustifolium*, *S. tenellum* and *N. ossifragum*
9	- More than two-fold increase in *E. tetralix; E. vaginatum* values raised from less than 1 % to 4-6 % and *H. cupressiforme* from 1 to 5 % - Appearance of *M. caerulea*, *E. nigrum*, *A. polifolia*, *V. oxycoccus*, hummock *Sphagna*, *Drosera rotundifolia* - Significant decrease in open water, *S. cuspidatum*, *R. alba* and total *Sphagnum* cover along with *C. portentosa/C. ciliata*

Table 6.5: Changes in Quadrat 3.

Quadrat	**Changes**
3	- Significant increase in *C. vulgaris*, *E. tetralix* and *C. portentosa /C. ciliata* - Substantial decrease in open water from 29% to 3% and less; *S. tenellum* values fall from 12 to 2 % and less

Table 6.6: Changes in the quadrats 5, 6 and 7.

Quadrat	**Changes**
5	- Emergence and dominance of *M. caerulea* which covers more than 30 % of the ground - Substantial decrease in total *Sphagnum* cover from 19 % to 3 % and less - Disappearance of open water, *E. nigrum* and *S. pulchrum*
6	- Emergence and dominance of *Molinia caerulea* covering 27-36 % of the ground - Decrease in total *Sphagnum* cover of two thirds affecting *S. papillosum*, *S. pulchrum* and *S. cuspidatum* - Disappearance of *E. angustifolium* and (almost) open water
7	- The *Sphagnum* (*S. papillosum* and *S. cuspidatum*) cover shrinks from 6 % to 2 % and less - *E. angustifolium* disappears

The diagram in the Figure 6.6 shows the results of the DCA of the quadrates 1 (red), 2 (yellow), 4 (blue), 8 (violet) and 9 (green). In all DCA diagrams (also Figures 6.4 and 6.5) the triangles represent the quadrats recorded in 1936/37 and the diamonds the ones re-surveyed in 2001. The distribution of the species along

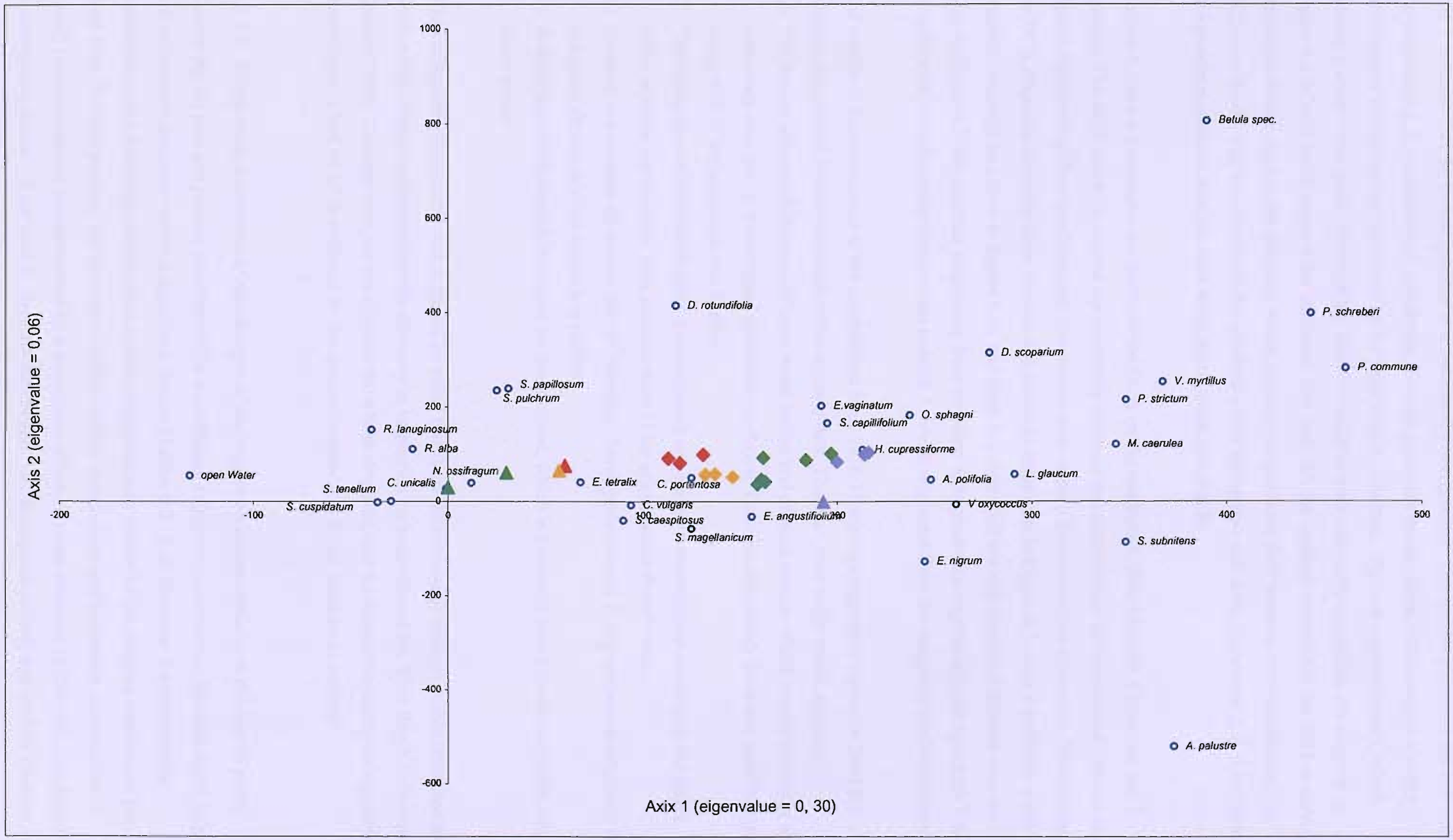


Figure 6.6: DCA of the quadrats 1 (red), 2 (yellow), 4 (blue), 8 (violet) and 9 (green) ; detrended by segments and Downweighting of rare species.

axis 1 indicates that the largest gradient is a wetness-dryness gradient. The species placed on the left side of the diagram (e.g. *S. cuspidatum*, *S. pulchrum*, *N. ossifragum*) are mostly those which require a wetter environment within the bog than those on the right (e.g. *S. subnitens*, *Hypnum cupressiforme*), which tolerate a lower water table. Although the data for the DCA were extremely simplified, the diagram in Figure 6.3 reflects the changes in the quadrates very well. All the quadrats recorded in the 2001 re-survey are placed further right in the diagram, which indicates a significant shift towards dryer conditions. The DCA also shows, that the changes in the quadrats within *Sphagnum*-rich areas (quadrates 1, 2, 4 and 9) are of a greater magnitude than the ones in the Molinietum (quadrat 8).

Figures 6.7 and 6.8 represent the results of the DCA on the quadrats 3, (blue) 5 (red), 6 (yellow) and 7 (green). The DCA had to be carried out separately for these quadrats because in Godwin and Conway the figures representing these quadrats only give information about a limited number of species. Nonetheless, the DCA diagrams show the same features and trends as those seen in Figure 6.3. Axis 1 indicates a wetness gradient (although less clear in Figure 6.4) and there is a clear shift towards increased dryness over time. Also in Figure 6.5, the quadrats originating from the more *Sphagnum*-rich vegetation units (quadrats 5 and 6) underwent a much greater change than quadrat 7, which originates from the margin of the Molinietum.

The results of the comparison of the quadrat data from 1936/37 with the vegetation survey in 2001/02 strongly support the results and trends of the transect data. There are four major trends apparent:

(1) The loss or substantial decrease of open water bodies and of plant species which require a more or less constantly very wet or waterlogged substratum to thrive. This includes mainly lawn and pool *Sphagna* along with *E. angustifolium* and *R. alba.*

(2) The appearance or increase in plant species, which can endure a waterlogged substratum but thrive better at lower water levels. This includes most of the ericaceaeous dwarf shrubs.

(3) Invasion and increase of species like *M. caerulea, Betula pubescens* or *E. nigrum*, which originally do not occur abundantly in a raised bog habitat.

(4) A significant shift towards increased surface dryness, which is a possible major cause for trends 1-3, listed above.

When comparing the quadrat data it should be noted that these data represent changes within restricted areas which where chosen to demonstrate the diversity in vegetation communities on the West Bog (Godwin and Conway 1939). Changes over the last 65 years have been dramatic, and the former variability in vegetation assemblages is lost which is reflected by the species composition in the quadrats at present.

6.1.2.2 Comparing description of the changes in the vegetation communities over the last 65 years

Comparing the past and present situation within the different vegetation communities the data of the original and re-surveyed quadrats express a significant change (Tables 6.2 - 6.6). However the comparative description in the following section gives a more comprehensive picture of the changed situation on the West Bog. For this purpose, the description of the surface morphology and vegetation communities in 1936/37 is rendered and complemented by a description of the situation observed in 2001/02. The data of the re-surveyed quadrats 1-9 are used to illustrate the change. The description follows that used by Godwin and

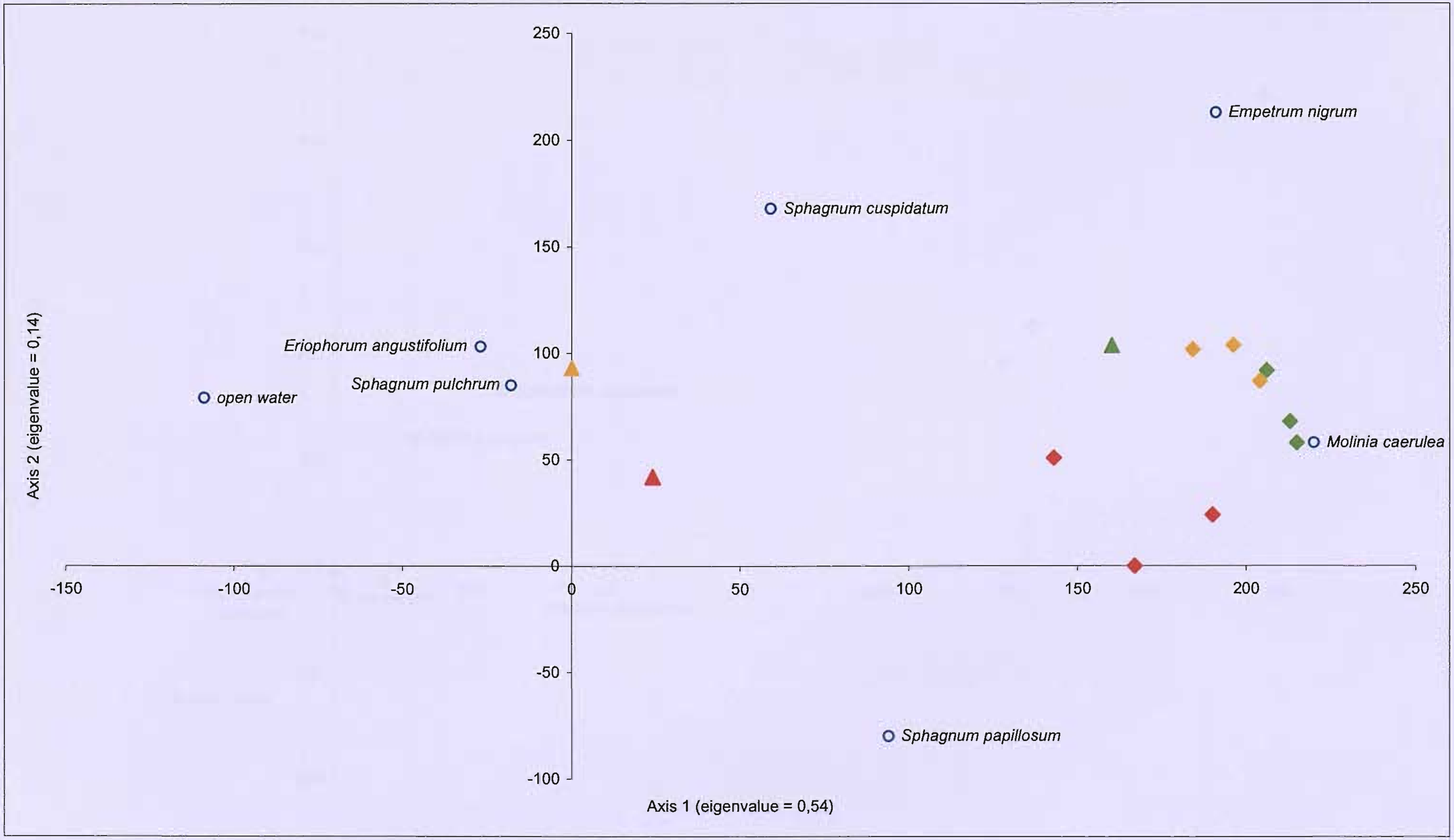


Figure 6.7: DCA of the quadrats 5 (red), 6 (yellow) and 7 (green); detrended by segments and downweighting of rare species.

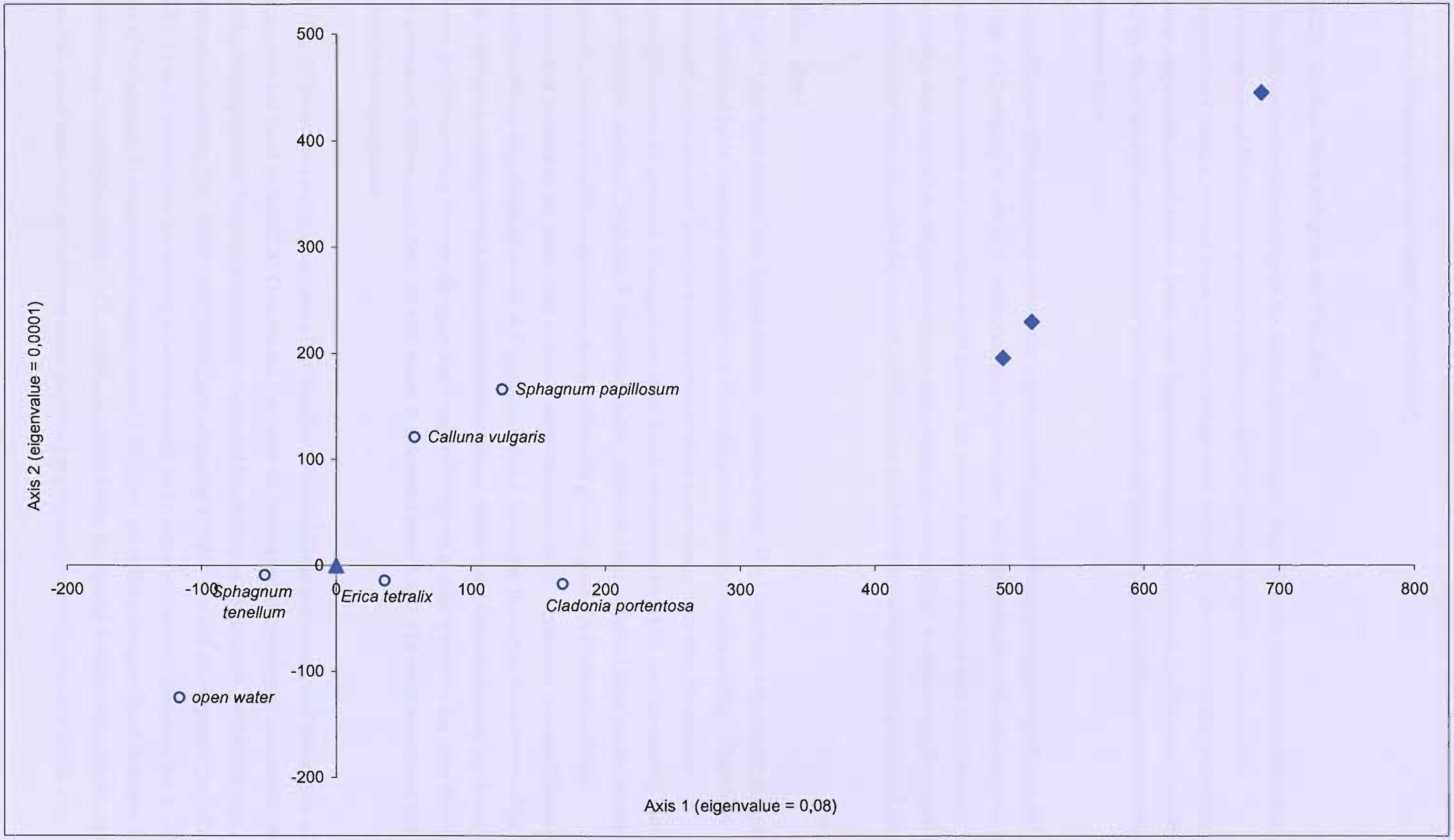


Figure 6.8: DCA of quadrat 3 (detrended by segments and downweighting of rare species).

Conway, dividing the investigated area into the vegetation units Rand, Sphagnetum incl. Regeneration Complex, Scirpetum and Molinietum (see Figure 6.1).

6.1.2.3 Surface- Morphology on the West Bog

In 1936/37 the surface morphology of the West Bog was largely linked with the vegetation communities. The Scirpetum and Molinietum were very uniform, sward-like and without pools. In contrast, the Regeneration Complex, and to a lesser extent the Sphagnetum, were characterised by an alternation of low *Sphagnum* hummocks and shallow pools, with *Sphagna* dominating. Godwin and Conway report, that the species lists in the different communities were very similar but the proportions varied greatly in the different vegetation types.

In 2001/02 most of the vegetation on the mire expanse shows a homogenous character dominated by old bushes of *C. vulgaris* as well as *E. vaginatum* and *C. portentosa.* The differences in surface morphology are much less pronounced and not visible at first glance. The former pools and hollows have dried out and overgrown with vegetation. *Sphagnum* does not form continuous lawns rather, it occurs as patchy single cushions often occupying small depressions, which are not similar to the structure former pools and hollows.

6.1.2.4 Rand

In 1936/37 the Rand covered two distinct different vegetation types. The lower part at the steeper margins was dominated by *M. caerulea* (associated with *Potentilla erecta* and *Vaccinium myrtillus*). There were occasionally wide and deep drainage channels present which were mostly filled with *Eriophorum angustifolium* and *M. caerulea.* The upper part of the Rand was covered by highly variable cover of species from the crown such as *C. vulgaris*, *S. caespitosus* and *C. portentosa* and contained many narrow drainage channels. An example of the vegetation on the upper Rand is given in quadrat 9 (Table 6.5). *Betula pubescens* is frequent on the upper Rand in widely scattered bushes and *E. vaginatum*, *E. angustifolium* and *Erica tetralix* are also abundant as well as *S. papillosum* and *S. subnitens.* In contrast to the crown of the bog, *Narthecium ossifragum* and *Drosera* species were absent. Godwin and Conway mention that it was hard to find the boundary between the upper Rand and the Sphagnetum. Also typical for the upper Rand was the presence of shallow pools, bare but with sparse *R. alba* (see Figure 6.4.d). The pools were linked and formed a drainage system.

In 2001/02 the western and southern part of the Rand are disturbed due to peat cutting and the creation of large pools and dams by the CCW. Over the last two years the eastern and morphological undisturbed part of the Rand along the river Teifi is almost entirely dominated by *Molinia* up to the crown, with hardly any other species present. The 1936/37 and 2001/02 data of quadrat 9 (Table 6.2) and also Figures 6.2.c, 6.3.c and 6.4.c and f demonstrate the increase in *Molinia* density and a retreat of *Calluna*, *Sphagnum* and *R. alba* east of the baseline. The macrofossil diagram of core TWC 2000, taken from the upper Rand illustrates this development, showing the presence of *S. papillosum* shortly below the present *Molinia* cover. Finally, there is a total loss of open water on the upper Rand, no pools have been encountered in this area during the

2001/02 re-survey. The depressions of former pools now seem partly filled with *Sphagnum*. This is underpinned by the loss of all open water in quadrat 9 (Table 6.2).

6.1.2.5 Sphagnetum and Regeneration Complex

In 1936/37 the Sphagnetum, including the Regeneration Complex, formed an encircling zone from the upper Rand to the mire expanse around the bog centre (Figure 6.1). The community was characterised by an abundance of actively growing of *Sphagna,* which constituted the field layer in these communities (represented by the quadrats 1, 2, 5 and 6 in the Tables 6.5. and 6.6.). The most typical facies of the Sphagnetum was the Regeneration Complex. An example of the vegetation in the most typical part of the Regeneration Complex in 1936/37 quadrat 1 (Table 6.5). In the southeastern part of the West Bog the Sphagnetum was most similar to the Regeneration Complex (represented by quadrat 2, Table 6.5). However, the Regeneration Complex differed from the Sphagnetum by the presence of *S. pulchrum*, *R. fusca*, frequent *Drosera intermedia* and *Drosera anglica* and a lesser abundance of *Scirpus caespitosus*. The ground of the Regeneration Complex was much more quaking than the rest of the Sphagnetum. The morphology of the ground was uneven with frequent pools of varying size (50-200 cm). Most of these pools were defined as "soft". In this definition fell all pools where a person, stepping into a pool would sank rapidly below the ankles or further. Godwin and Conway had the impression that most of the peat currently forming in 1936/37 was composed of *S. papillosum*. *S. pulchrum* was abundant and characteristic but was considered not to be the main peat former. The authors also mention the occasional presence of *S. magellanicum* in the Regeneration Complex and the presence of dense vegetated *Eriophorum vaginatum* clusters that they named "*Eriophorum* islands".

In 2001/02 the area of the former Sphagnetum still supports the highest coverage of *Sphagnum* with the Regeneration Complex still forming the wettest part of the West Bog. However, the loss in *Sphagnum* cover is alarming. The retreat in *Sphagnum* is most drastic, where it was most abundant in 1936/37, in the Regeneration Complex and the southeastern part of the Sphagnetum (see Figure 6.2.c). In the quadrats 1, 2, 5 and 6 there is a substantial loss in total *Sphagnum* about 60 to >75 % of the former cover. The species most affected are *S. papillosum* and *S. cuspidatum* (80 and 90 %). By contrast, *Sphagna*, which tolerate more dryness such as *S. subnitens* and *S. rubellum*, emerge in quadrats 1, 2, 5 and 6. *S. subnitens* had been absent in the mentioned quadrats in 1936/37. Altogether species, which require very wet habitats like pools and pool margins became extinct or fell in frequency. This concerns *R. fusca* (extinct) along with *D.* intermedia and *D. anglica* and *S. cuspidatum*. *S. pulchrum* has lost percentage cover and area in the northern and eastern margins of the Regeneration Complex (see quadrats 5 and 6, Table 6.6 and Figure 6.2.f) but has spread further along the south-eastern margin of the crown. Loss and gain in the distribution of *S. pulchrum* seem more or less balanced. Comparing the 1936/37 quadrat data with those of 2001/02, *S. pulchrum* has increased in percentage cover at this place. During the 2001/02 re-survey the species was often found in the depressions, which are probably identical to the former pools. This observation leads to an interesting point regarding the vegetation development within the Sphagnetum and the Regeneration Complex: In 1936/37 there was an abundance of *S. cuspidatum* in the Regeneration Complex, as shown by the data of quadrat 1 and 6. In 2001/02 there is hardly any *S. cuspidatum* present in the former Regeneration Complex but it occurs on the southern and eastern part of the mire expanse. Figure 6.11 shows that *S. cuspidatum* and *S.*

pulchrum are almost entirely separated in their distributions on the West Bog. This gives the impression that *S. pulchrum* retained its area by occupying the dried former pools, at the expense of *S. cuspidatum*. This assumption is supported by Figure 5.37, the macrofossil diagram of core TWH 2002, taken from a former pool. At this core location *S. cuspidatum* is succeeded by *S. pulchrum*. In contrast to the Regeneration Complex, *S. cuspidatum* fills the depressions of the former pools on the upper western Rand and the southern and western part of the former Sphagnetum.

6.1.2.6 Scirpetum

In 1936/37 the Scirpetum was characterised by a similar species assemblage to the Sphagnetum. However, this vegetation type differed from the Sphagnetum in the paucity of most *Sphagna* and the dominance of *Scirpus caespitosus*. Presumably in this vegetation community *Scirpus* covered at least 25 % of the surface. The structure of the vegetation in the Scirpetum was very different from the Sphagnetum. Pools wider than 30 cm were rare, and where they were present they were filled with *S. cuspidatum*, whereas *S. papillosum* occurred only in small amounts. *S. caespitosus* formed up to 60 cm wide and up to 15 cm high tussocks. The tussocks were close to each other and gave the vegetation a sward-like appearance. *C. vulgaris* was present but not abundant. *E. vaginatum* and *E. tetralix* occurred frequently associated with *N. ossifragum*, and *Cladonia portentosa,* which formed only small patches. Godwin and Conway report the high abundance of *Sphagnum tenellum* (see quadrat 4, Table 6.2) as very characteristic for the Scirpetum. It was found throughout the Scirpetum covering the surface between the *S. caespitosus* shoots and was almost constantly accompanied by *S. cuspidatum*, *Diplophyllum albicans* and *Lepidozia setacea*. *S. cuspidatum* covered 12 % of the ground in quadrat 4. The authors report that *Scirpus* was so abundant that it was not mapped within quadrat 4. This caused some difficulties when re-assessing the percentage cover of *S. caespitosus* using the hard copy of the published quadrat from Godwin and Conway in the published quadrat. The authors emphasise that the peat beneath this community is clearly formed by *Sphagnum* and resembles the peat underlying the Sphagnetum.

The transition from the Scirpetum to the Molinietum is sudden but the transition towards the Sphagnetum is more gradual. The vegetation at the transition in 1936/37 is represented by quadrat 3 (Table 6.3). As with the Sphagnetum there were also clusters (so called 'islands') of *E. vaginatum* and *M. caerulea* present in the Scirpetum. The *E. vaginatum* 'islands' resembled those of the Sphagnetum but often showed a centric structure with *E. vaginatum* somewhat raised, in the centre surrounded by a zone of *E. vaginatum* mixed with Ericaceae, *S. caespitosus* and *Pleurozium schreberi*. The *Molinia* patches have no centric structure and were associated with the plants listed in Table 6.7. Most of these associated plants, except *Osmunda regalis* and *Dicranum scoparium*, do not occur on undisturbed ombrotrophic bogs and indicate eutrophication.

Table 6.7: Species associated with *M. caerulea* patches in the Scirpetum.

Potentilla erecta	frequent	*Vaccinium oxycoccus*	all less frequent
Rumex acetosa	occasional	*Andromeda polifolia*	
Juncus effusus	occasional	*E. tetralix*	
Luzula multiflora	occasional	*E. angustifolium*	
Anthoxantum odoratum	occasional	*P. alpestre*	
Deschampsia cespitosa	occasional	*S. papillosum*	
Holcus lanatus	occasional	*S. rubellum*	
Aspidium spinulosum	very frequent		
Polytrichum commune	frequent		

Osmunda regalis	occasional		
Dicranum scoparium	very frequent		

The vegetation re-survey of Cors Caron in 2001/02 shows that within the area of the former Scirpetum the vegetation changed significantly. It is assumed that *S. caespitosus* had its main range in 1936/37 in the Scirpetum. As Figure 6.6.e indicates *S. caespitosus* is at the present time rather evenly distributed over the mire expanse except in the bog centre, where it is absent and in the Regeneration Complex, where it occasionally reaches a higher percentage cover. Although the species is not rare on the West Bog at the present, it suffers from a substantial loss of cover. The present coverage in the area of the former Scirpetum is between <1 and 12 % compared with an estimated >25 % in 1936/37(see quadrat 4 Table 6.2). *Scirpus* associate *S. tenellum* also contracted its range. According to the data of the quadrats 3 and 4 as well as the descriptions of the vegetation communities in Godwin and Conway, this *Sphagnum* species must have had its main range in the Scirpetum. Looking at its modern distribution and percentage cover Figure 6.10.a shows that at the present *S. tenellum* mostly covers less than 1 % of the surface in the former Scirpetum. The data of quadrat 4, in Table 6.5., indicate a loss in percentage cover of more than 99%. However, at the present *S. tenellum* is most abundant around the southwestern area of the mire expanse. Another species, showing a significant decrease is *S. cuspidatum.* Presently it covers less than one percent of the area in the former Scirpetum. A significant rise occurred in species like *Cladonia portentosa* and *Calluna vulgaris* and *E. vaginatum* (see quadrat 4 in Table 6.5.). Further changes in the area of the former Scirpetum include the disappearance of the *Eriophorum-* and *Molinia-*'islands' and most of the plant species associated with them, which are listed in Table 6.7. Whereas most of the listed species are abundant in more eutrophic habitats and do not belong to ombrotrophic bogs, the disappearance of the rare *Osmunda regalis* from the mire expanse is very regretful. On Cors Fochno, this fern species is still present at the centre of the bog and more frequent in the lagg (Peter Moore, personal communication). Altogether the alterations in of the former Scirpetum are so substantial, that it is justified to conclude that this vegetation community does not exist any more in its former distribution area.

6.1.2.7 Molinietum

In 1936/37 the Molinietum was located in the centre of the West Bog (see Figure 6.1) though not at its summit. A typical example of the vegetation assemblage in the Molinietum is shown in Table 6.5 (quadrat 8). The vegetation community is dominated by *Molinia caerulea* associated with frequent *Betula pubescens.* Godwin and Conway mention that some of the trees had trunks up to 15 cm in diameter. Because many of them were relatively young the authors predicted that *B. pubescens* might become more dominant in the future. *Sphagna* were rare and other mosses such as *Aulacomnium palustre* and *Hypnum cupressiforme* seem to have occurred frequently. Other associated species are listed in Table 6.8 below. Worth noting is the presence of *E. angustifolium* in 1936/37 and the absence of *E. vaginatum.*

Table 6.8: Species associated with the Molinietum.

Empetrum nigrum	abundant	*E. angustifolium*	occasional to frequent
Vaccinium myrtillus	occasional to frequent	*S. subnitens*	occasional
Vaccinium oxycoccus	frequent	*S. tenellum*	rare to occasional
Andromeda polifolia	occasional	*Pleurozium schreberi*	occasional
Erica tetralix	frequent	*Potentilla erecta*	unknown
C. vulgaris	abundant		

S. caespitosus	occasional to frequent	

An investigation of the peat below the Molinietum showed that this community too, is underlain by fresh *Sphagnum* peat and its ground is still quaking. Godwin and Conway conclude from their findings that the development of this vegetation type, like that of the other communities, must be a more or less a recent event. The eastern and southern borders of the Molinietum with the Scirpetum are abrupt but on the northwestern side there is a gradual transition into the Regeneration Complex, demonstrated by the quadrats 6 and 7. The very high abundance of *E. angustifolium* was conspicuous in this transition zone.

Considering the degree of vegetation change over the last 65 years up to 2001/02, the Molinietum is the community that is most stable. The retreat of *V. oxycoccus* is worth considering, which once covered, about a quarter of the ground surface (Quadrat 8). The most dramatic change is the loss of almost all open water bodies and the disappearance of *E. angustifolium* from this community. This is reflected in the re-mapped quadrats 6 and 7 (Table 6.3) in the transitional area but also by Figure 6.10.b, showing the present distribution of *E. angustifolium*. Another interesting feature of the vegetation change is that *E. vaginatum*, which was absent from the Molinietum in 1936/37, migrated into the Molinietum and is now present there with a percentage cover of between 3 and 10 %. The cover of *M. caerulea* itself has somewhat decreased. Further changes involve the disappearance of *Potentilla erecta* and the lack of *Betula pubescens*. This is due to restoration work by the CCW, which involves the removing of trees on the West Bog. Despite a general decrease in *Sphagnum* within the Molinietum (see Figure 6.2.c), it is worth noting that at present *Sphagna* of the *Acutifolia* section form impressive hummocks in the Molinietum.

6.1.2.8 Summary of the comparison between 1936/37 and 2000/01 surveys

The change in most considered vegetation communities is dramatic. Over the entire re-surveyed area a significant decrease of the main peat former, *Sphagnum*, occurred. The *Sphagnum* species most affected by this are *S. cuspidatum*, and *S. papillosum*. In the Sphagnetum and Regeneration Complex the total *Sphagnum* cover in quadrats 1 and 2 fell from 39 % to values between 4 % and 10 %. Furthermore there is a dramatic loss in vascular plants requiring a near surface water table, such as, *R. alba*, *E. angustifolium, Drosera intermedia* and *D. anglica*. However, the former Sphagnetum and Regeneration Complex represent the areas in which the current density of *Sphagnum* and hygrophilic vascular plants have their highest densities. The former pool system, consisting partly of pools up to 2 metres width, disappeared completely. During the re-survey in 2001/02 virtually no open water bodies were found. In the Scirpetum, the *Sphagnum* cover fell from 12 % to less than 1% for *S. cuspidatum*, and from 52 % to *ca.* 2% for *S. tenellum*, respectively. The *Scirpus* ground cover fell from 25% to less than 1 %. These losses of hygrophilic plant species indicate, that the bog surface has become significantly dryer over the past 65 years.

By contrast, plant species which are normally not dominant on peat forming vegetation communities, like most of the Ericaceae, *M. caerulea*, and *C. portentosa* have either suffered to a much lesser extent or increased in density. This is reflected in the Molinietum being the most stable vegetation community over the past 65 years. However, some changes in the Molinietum may indicate a slight trend towards an increase in peat-forming vegetation. This involves the appearance of *E. vaginatum* in the Molinietum, and a slight increase in Sphagna such as *S. capilifolium* and *S. subnitens*, which form impressive hummocks in some parts of the Molinietum using the *Molinia* tussocks as support.

It can be concluded that the current peat-forming vegetation on the Cors Caron West Bog is in very poor condition, compared with that of other structurally intact raised bogs. Species, which are of no or less importance as peat formers have suffered less or even increased their ground cover. The results drawn from this chapter the raises the question: Is Cors Canon still forming peat?

6.2 Analysis of the patterns in the modern vegetation distribution at Cors Caron West Bog of the transects D-M

The following section presents the current distribution pattern and percentage cover of each species recorded on the present mire surface. The inclusion of all species (except small liverworts) in the re-survey allows a assessment of the composition and quality of the present bog vegetation. The results are presented as vegetation maps in Figures 6.5.to 6.12. Each figure is analysed in the next section.

6.2.1 The species distribution in 2001/02

Calluna vulgaris

Figure 6.9.a shows the recent distribution and coverage of *C. vulgaris* on the bog. It is present all over the bog apart from the eastern margin where it is excluded by *Molinia caerulea*. *Calluna* is very conspicuous and especially its flowering bushes visibly dominate the West Bog, forming an extra layer above the field layer. The species reaches its highest density in the northwestern part of the bog, in the former Regeneration Complex, but also extends to the southwest and northeast. The lowest percentage cover of *Calluna* is in the centre and southeastern part of the mire expanse, forming a conspicuous brighter patch on the vegetation map. The *Calluna* shrubs are often quite old and there are few younger shoots.

Erica tetralix

Figure 6.9.b shows that *E. tetralix* occurs throughout most of the surveyed area, apart from the steep eastern margin. *E. tetralix* never reaches high densities and always stays below 15 %. The highest percentage cover of this species occurs in the Regeneration Complex and on the southwestern and northwestern parts of the mire expanse. In contrast, the cover is somewhat lower in the centre of the West Bog.

Andromeda polifolia

The distribution pattern of this species is shown in Figure 6.9.c. *A. polifolia* is almost continuously present on the mire expanse at low densities but it is absent from the *Molinia*-dominated eastern margin. Its density rises somewhat to the north and also within the southeastern central part of the bog. In the southeastern part of the central expanse where *C. vulgaris* coverage does not exceed 10 % of cover, *A. polifolia* reaches higher cover densities.

Vaccinium myrtillus

As Figure 6.9.d indicates, this species is rather rare on the West Bog. It occupies high hummocks in the drier central part in the bog in the Molinietum and south of it. In the Molinietum it reaches high densities, up to 10 % of the ground cover, and it is also fructifying. Outside of the Molinietum *V. myrtillus* is often confined to areas of former *Betula* woods. The *Betula* has been mostly killed or removed by management practices, but the species assemblage in areas previously occupied by *Betula* is still different from the surrounding bog vegetation.

Vaccinium oxycoccus

The distribution of *V. oxycoccus* is presented in Figure 6.9.e. Its percentage cover is highest in the former Molinietum and Scirpetum and lowest in the *Sphagnum* dominated areas of the Regeneration Complex and the Sphagnetum. The low *V. oxycoccus* values correlate with high *Sphagnum* percentage cover and where the *Sphagnum* cover is low, this correlates with higher coverage of *V. oxycoccus*. The species is particularly abundant and vigorous within the former *Betula* woods and in the Molinietum. Within these areas *V. oxycoccus* occupies the tops of hummocks and grows as vigorously as in the area of the former Scirpetum.

Empetrum nigrum

E. nigrum is confined to the crown of the West Bog where it forms a circular pattern. Figure 6.9.f shows the distribution of this species. The species is absent from the southern central part of the bog crown and from the margins of the mire expanse. It occurs infrequently, covering between >1 and 6 % of the ground usually on top of extended hummocks.

Rhynchospora alba

The distribution of *R. alba* is illustrated by Figure 6.10.a, which shows that this species forms a ring-like pattern around the centre of the bog crown, correlating with the area of the former Sphagnetum and Regeneration Complex. *R. alba* never reaches high densities in percentage cover, which are generally below 4% and mostly between <1 and 2%. One exception is transect point E-750, were a percentage cover of 20 % was reached.

Eriophorum angustifolium

As shown in Figure 6.10.b, *E. angustifolium* occurs with high consistency over the mire expanse with the exception of the *Molinia*-dominated centre and the eastern margin. A concerning fact is its less consistent presence in the former Regeneration Complex. The cover of *E.* angustifolium at the present time is mostly below 1 % and there are few places where it reaches higher densities. This is the case at the southwestern area of the West Bog where the Sphagnetum was most similar to the Regeneration Complex in 1936/37.

Eriophorum vaginatum

This species is present over the whole mire expanse but is absent from the lower eastern bog margin. As demonstrated in Figure 6.10.c, an area of higher density forms a circular pattern around the bog centre, mostly covering between 10 and 20 % of the surface. However, in the southern and northeastern part of the 'circle', *E. vaginatum* often reaches more than 20 % of the ground cover. The low percentage cover of *E. vaginatum* occurs in the bog centre and the outer margins of the mire expanse, where the coverage is often

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below 10 %. In the centre and along the eastern margin the area covering less than 10 % of the ground is almost congruent with the area of high *Molinia* cover. On the western margin the lower densities correlate with higher coverage of species indicating greater surface wetness, such as *R. alba* along with *Sphagna* of the section *Cuspidata* and *S. tenellum.*

Narthecium ossifragum

Figure 6.10.d illustrates the distribution pattern of *N. ossifragum*. This species of the Liliaceae family, although abundant, is much less consistent in its presence than the *Eriophorum* species. In common with *E. angustifolium* it has a low cover of 1% or below. In contrast to the latter it often forms little clusters, which become very conspicuous in autumn, when the leaves turn into a pale yellowish colour. The distribution pattern of *N. ossifragum* also, forms a ring pattern on the mire expanse. The species is absent from the centre and also the northeastern part of the crown. The Regeneration Complex is the only area where the gound cover of *N. ossifragum* is higher than 2 %, where it covers up to 6 % of the mire surface. The species often forms loose patches occupying depressions together with *S. pulchrum* or *S. cuspidatum*. Its distribution area is also similar to that of *Sphagna* of the section *Cuspidata*, which includes *S. pulchrum* and *S. cuspidatum* (see Figure 6.11.b and c).

Scirpus caespitosus

S. caespitosus occurs over most parts of the mire expanse (Figure 6.10.e). The only area of the West Bog where this species is absent is the central part and the eastern margin. In common with *E. vaginatum*, *S. caespitosus* forms a ring figure around the centre of the mire expanse where it reaches higher densities of between 2 and 4 % of ground cover. In contrast to *E. vaginatum S. caespitosus* has a higher percentage cover in the Regeneration Complex and to a lesser extent in the former Scirpetum, where it reaches up to 12% of ground cover.

Molinia caerulea

Figure 6.11.f shows the distribution of *M. caerulea*. It is the only Poaceae among the Monocotyledons occurring on the ombrotrophic bog. All other Monocotyledons are members of the Cyperaceae. The distribution of *M. caerulea* contrasts with all other Monocotyledons, concentrated in the centre of the mire expanse and along the slopes of the south- and north-eastern margin. *M. caerulea* also occurs at the western margin of the bog, but here its occurrence was probably induced by human impact, since peat cutting and dam building occurred there. In the bog centre the cover of *M. caerulea* is mostly between 15 and 30 % whereas on the eastern bog margin the density of the cover is much higher, between 65 and 80 %.

Total *Sphagnum*

The cover of all *Sphagnum* species together is shown in Figure 6.12.a. Compared with the *Sphagnum* cover of other lowland raised bogs, which have suffered greater disturbance to the main peat body, the *Sphagnum* cover of Cors Caron West Bog is very low. There are very few areas where the total *Sphagnum* coverage exceeds 20 % and on more than half of the surveyed area the percentage cover is below 10 %. The density of *Sphagnum* is highest in the Regeneration Complex with cover percentages mostly between 8 and 25 %. In contrast, the *Sphagnum* cover is very low in the area of the southeastern centre, where it stays below 6 %.

Table 6.9 represents data of the *Sphagnum* cover from Ballynahone Bog, Northern Ireland and Wedholme Flow, Cumbria compared with those of Cors Caron.

Table 6.9: *Sphagnum* cover from Ballynahone Bog, Northern Ireland and Wedholme Flow, Cumbria and Cors Caron, West Wales.

Sites	Average *Sphagnum* cover from primary areas
Wedholme Flow (based on six 3×3 m quadrats)	56
Ballynahone (based on twelve 3×3 m quadrats)	24
Cors Caron West Bog (based on 195 3×3 m quadrats)	9

Sphagnum section *Cuspidata*

As demonstrated in Figure 6.11.b, the distribution of this *Sphagnum* section is concentrated in the former Regeneration Complex and Sphagnetum. The highest values in percentage cover are in the range of 10 % to 29 % in the Regeneration Complex. In most other parts of its distribution the cover of the *Sphagnum* section is generally very low and below 6 %.

Sphagnum section *Acutifolia*

This *Sphagnum* section has its main range in the central part of the West Bog, as illustrated by Figure 6.11.c. The species included are *S. rubellum* and *S. subnitens*. The section is less frequent in the upper parts of the Regeneration Complex and outer parts of the former Sphagnetum. The highest cover values occur in the central part of the bog.

Sphagnum papillosum

S. papillosum is the most abundant *Sphagnum* species on the West Bog (see Figure 6.11.a). It occurs over most of the mire expanse but is partially absent from the central part and the eastern margin of the crown. Its main range lies within the Regeneration Complex and Sphagnetum. However, even there it usually covers less than 10% of the ground surface. Outside the Regeneration Complex area its cover is rather low, often forming less than 1 % of the vegetation cover.

Sphagnum pulchrum

This species is confined to the Regeneration Complex (see Figure 6.11.b) on the wettest and highest part of the West Bog. Within this area its density lies between 1 % and 20 % cover. Especially close to the western margin of the mire expanse its coverage reaches higher values. It is worth noting that *S. pulchrum* and the related *S. cuspidatum* almost exclude each other in their distribution on the bog surface. This feature was also captured by the statistical analysis (TWINSPAN). Both species belong to the same *Sphagnum* section (*Cuspidata*) and occupy a similar microhabitat (wet hollows) in bogs.

Sphagnum cuspidatum

As illustrated by Figure 6.11.c, *S. cuspidatum* has its main range in the eastern and southern parts of the mire expanse in the Sphagnetum. However, generally its cover is very low and lies mostly between <1 and 2 %. It is very rare in the Regeneration Complex and mostly fills small depressions. Close to the western margin of

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the bog, some pools have been created artificially by the CCW to provide suitable breeding habitats for dragon flies. In these pools *S. cuspidatum* forms floating mats.

Sphagnum tenellum

The distribution pattern of this *Sphagnum* species is demonstrated in Figure 6.11.f. In contrast to most other *Sphagna* it is rather widespread on the West Bog and forms a ring pattern on the crown, but is absent from the bog centre. The percentage cover of *S. tenellum* is low, being found at less than 3 % cover over more than half of its range. Higher densities were recorded on the south-western area of the crown, where it reaches cover percentages of between 3 and 22 %. It is interesting that *S. tenellum* as a species preferring rather wet conditions, has its highest density in a different area to both, *S. pulchrum* and *S. cuspidatum.*

Sphagnum rubellum

As presented in Figure 6.11.d, *S. rubellum* has its main range scattered over the western centre of the bog crown and along the western bog margin. This area is mostly within the Regeneration Complex. Another cluster occurs on the eastern margin of the crown. Its percentage cover lies between <1 % and 14 %, the highest densities occur on the eastern central crown, partly within the Molinietum. In the Molinietum *S. rubellum* occurs on high hummocks between the *Molinia* tussocks. In the Regeneration Complex and Sphagnetum this species forms small hummocks. Like *S.* pulchrum and *S. cuspidatum,* the species has a markedly different distribution on the West Bog from a closed relative, S. *subnitens. S. rubellum* and *S.* subnitens too, are members of the same section and occupy the same habitat (hummocks) in bogs.

Sphagnum subnitens

The distribution area of *S. subnitens* is given in Figure 6.11.e. The species is quite abundant and fills the expanse in the bog centre, where the other *Sphagnum* species are rare or absent. Its main range, located in the more eastern half of the West Bog, covers a different area compared with the main range of its closest relative on Cors, Caron, *S. rubellum.* The percentage cover of *S. subnitens* ranges from <1 % up to 12 % and it reaches the highest densities in the eastern part of the bog crown. Where *S. subnitens* thrives it forms small hummocks, often using weak or dying *Calluna* bushes as racks to climb on. In the Molinietum *S. subnitens* is, like *S. rubellum,* present on high hummocks using the *Molinia* tufts as support.

Sphagnum magellanicum

In contrast to other lowland raised bogs such as Ballynahone Bog in Northern Ireland and many Cumbrian raised bogs (Wedholme Flow, Walton Moss, Felicia Moss) *S. magellanicum* has no importance on Cors Caron (and neither on Cors Fochno). On the Cors Caron West Bog it occurs only in very few locations (see Figure 6.12.d), in the north on transect D and in the south on transect M, L and K (quadrats 2-5 and 2-14). Where *S. magellanicum* occurs, it forms hummocks or it is present on the tops of hummocks.

S. angustifolium

This Species is present in three quadrats on transect K, shown in Figure 6.12.d. Outside the West Bog it is very abundant in former peat cuttings on the south-western edge of the North-east Bog crown, where it forms dense carpets, associated with *E. vaginatum.* The community appears on the aerial photograph as a brighter patch, bordering the uncut part of the crown (Figure 3.2). As *S. angustifolium* prefers slightly minerotrophic conditions, it normally does not occur in ombrotrophic habitats. It is worth noting that in the areas, where *S. angustifolium* occurs, the ombrotrophic species of the same section, *S. pulchrum* and *S. cuspidatum*, are absent.

Sphagnum recurvum

S. recurvum is also confined to more mesotrophic habitats. It has been found at the foot of the rand slope (see Figure 6.12.d) of the raised bog on transect I. It is more abundant on the floodplain.

Sphagnum fimbriatum

This species has been found in one quadrat on transect H, as illustrated by figure 6.12.d. This area seems to be formerly covered by some *Betula*. *S. fimbriatum* too, is not a *Sphagnum* species occurring in open, ombrotrophic conditions. It is widespread within the floodplain along the Teifi, where it is associated with *Juncus effusus* and *Phragmites australis*.

Drosera rotundifolia

D. rotundifolia is by far the most abundant *Drosera* species on the West Bog. As demonstrated in Figure 6.12.e, *D. rotundifolia* is present mostly throughout the Regeneration Complex and parts of the Sphagnetum, where the *Sphagnum* cover is highest in the southwest and southeast sections around the bog centre and it is mostly associated with *Sphagnum* or *Leucobryum glaucum* hummocks.

Drosera intermedia and *Drosera anglica*

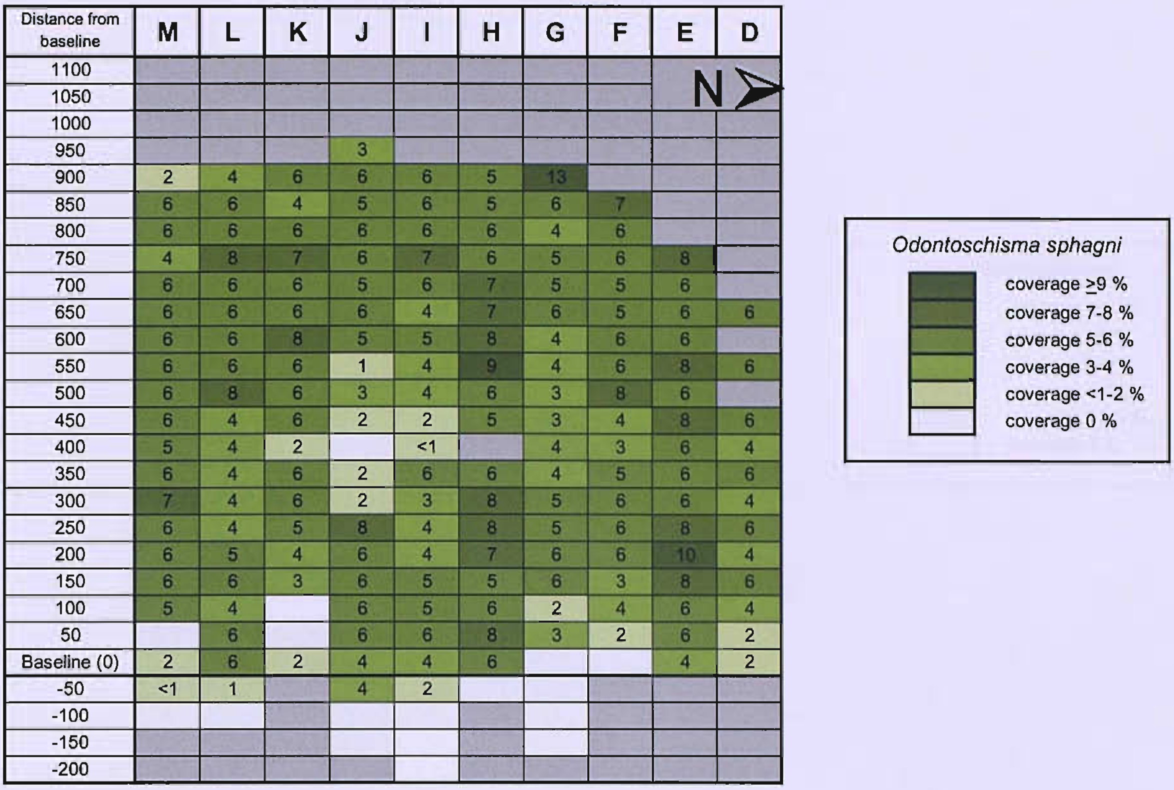
These two *Drosera* species are very rare on the West Bog. *D. intermedia* has been found only in quadrat F-200 (see Figure 6.12.f) and close to quadrat 5 in the Regeneration Complex. It is more abundant on the cutover parts of the South-east Bog. *D. anglica* is the rarest *Drosera* species on the West Bog and it has been only encountered once in the Regeneration Complex, between the transects I and H about 50 m west of the Molinietum.

Odontoshisma sphagni

O. sphagni is by far the most abundant liverwort on the West Bog (see Figure 6.13.). It occurs with percentage cover values ranging between 1 % to 10 % over the entire mire expanse. It is associated with *Sphagnum*, usually *S. papillosum*, but forms small patches on bare peat as well. *O. sphagni* is only rare or absent in the bog centre and along the eastern margin of the West Bog. An area of continuously higher density of 6 % and more forms a ring-like pattern around the centre of the crown.

Hypnum cupressiforme

As shown in Figure 6.14, *H. cupressiforme* is found almost everywhere on the West Bog and it mostly covers more than 6 % and occasionally up to 12 % of the surface. An area of higher density is located on the southern half of the mire expanse. *H. cupressiforme* mostly covers the ground under dense bushes of *C. vulgaris* and occurs often dispersed amongst the tufts of *M. caerulea* or *E. vaginatum*.



Distance from baseline	M	L	K	J	I	H	G	F	E	D
1100										
1050										
1000										
950				3						
900	2	4	6	6	6	5	13			
850	6	6	4	5	6	5	6	7		
800	6	6	6	6	6	6	4	6		
750	4	8	7	6	7	6	5	6	8	
700	6	6	6	5	6	7	5	5	6	
650	6	6	6	6	4	7	6	5	6	6
600	6	6	8	5	5	8	4	6	6	
550	6	6	6	1	4	9	4	6	8	6
500	6	8	6	3	4	6	3	8	6	
450	6	4	6	2	2	5	3	4	8	6
400	5	4	2		<1		4	3	6	4
350	6	4	6	2	6	6	4	5	6	6
300	7	4	6	2	3	8	5	6	6	4
250	6	4	5	8	4	8	5	6	8	6
200	6	5	4	6	4	7	6	6	10	4
150	6	6	3	6	5	5	6	3	8	6
100	5	4		6	5	6	2	4	6	4
50		6		6	6	8	3	2	6	2
Baseline (0)	2	6	2	4	4	6			4	2
-50	<1	1		4	2					
-100										
-150										
-200										

Figure 6.13: The distribution of *Odontoschisma sphagni* on the Cors Caron West Bog.

Leucobryum glaucum

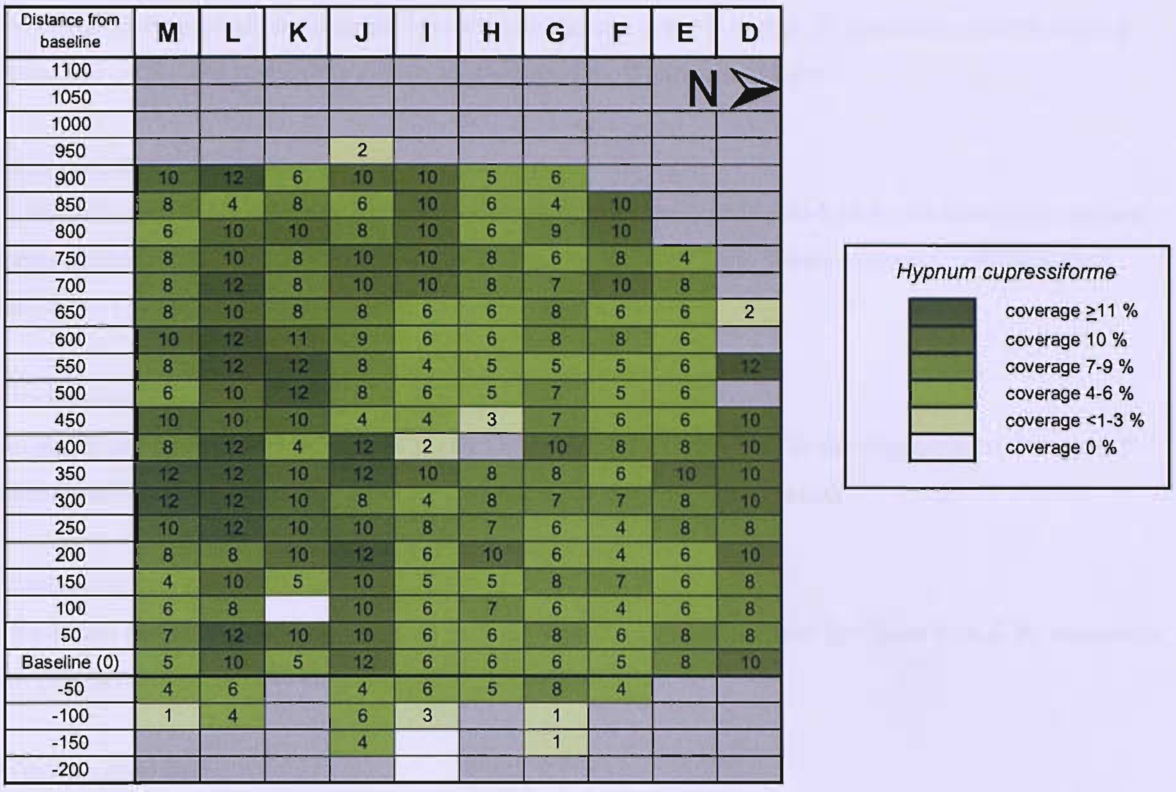
L. glaucum occurs scattered over the mire expanse covering between <1 to 4 % of the ground (see Figure 6.11.a). Towards the western bog margin its distribution area becomes somewhat more continuous, but on the easten edge of the bog it is absent. Where it occurs it forms compact hummocks of varying size, which are often inhabited by *D. rotundifolia* and *V. oxycoccus*.

Polytrichum alpestre

As demonstrated in Figure 6.15.b, *P. alpestre* is almost restricted to the central area of the peat dome. It has percentage covers ranging from <1 % to 18 %. In the Molinietum this species is associated with *Sphagna* of the section *Acutifolia* on high hummocks. Outside the Molinietum *P. alpestre* is present in places where *Betula* woods formerly existed.

Racomitrium lanuginosum

This species is now very rare on the Cors Caron West Bog, as illustrated by Figure 6.15.c. It has been found only at a few quadrat sites in the central part of the West Bog and in quadrat 1 outside the area surveyed along the transects. It inhabits the top of high hummocks, where it mostly covers less than 1% of the bog surface.



Distance from baseline	M	L	K	J	I	H	G	F	E	D
1100										
1050										
1000										
950				2						
900	10	12	6	10	10	5	6			
850	8	4	8	6	10	6	4	10		
800	6	10	10	8	10	6	9	10		
750	8	10	8	10	10	8	6	8	4	
700	8	12	8	10	10	8	7	10	8	
650	8	10	8	8	6	6	8	6	6	2
600	10	12	11	9	6	6	8	8	6	
550	8	12	12	8	4	5	5	5	6	12
500	6	10	12	8	6	5	7	5	6	
450	10	10	10	4	4	3	7	6	6	10
400	8	12	4	12	2		10	8	8	10
350	12	12	10	12	10	8	8	6	10	10
300	12	12	10	8	4	8	7	7	8	10
250	10	12	10	10	8	7	6	4	8	8
200	8	8	10	12	6	10	6	4	6	10
150	4	10	5	10	5	5	8	7	6	8
100	6	8		10	6	7	6	4	6	8
50	7	12	10	10	6	6	8	6	8	8
Baseline (0)	5	10	5	12	6	6	6	5	8	10
-50	4	6		4	6	5	8	4		
-100	1	4		6	3		1			
-150				4			1			
-200										

Hypnum cupressiforme

coverage ≥11 %
coverage 10 %
coverage 7-9 %
coverage 4-6 %
coverage <1-3 %
coverage 0 %

Figure 6.14: Distribution of *Hypnum cupressiforme* on the Cors Caron West Bog.

Aulacomnium palustre

Like *Racomitrium lanuginosum*, *A. palustre* is very rare on the West Bog (see Figure 6.15.d). Its presence is confined to the centre where it is associated with *Sphagnum* sect. *Acutifolia* on hummocks. It does not form continuous patches and stays mostly below 1 % of ground cover. *A. palustre* reaches its highest density in quadrat I-500 where *S. rubellum* and *S. subnitens* also have a higher coverage.

Dicranum scoparium

D. scoparium is sparsely spread over the entire mire expanse, as shown in Figure 6.151.e. The spatial distribution of this species seems not to follow any pattern. *D. scoparium* occurs mostly on hummocks, where it is either dispersed between other mosses or forms small patches.

Pleurozium schreberi

P. schreberi is restricted to the centre of the West Bog. This area is covered by the Molinietum where this cosmopolitan species grows on top of very high hummocks (see Figure 6.15.f)

Cladonia portentosa

C. portentosa is the most abundant Lichen on the West Bog and the only one which affects the overall appearance of the vegetation visibly. As presented in Figure 6.16.a, this species covers from 2 % up to 28 % of the ground. Compared with other raised bogs (see Table 6.1) the lichen cover is very high on Cors Caron. *C. portentosa* is only absent from the slope of the eastern bog margin, where *M. caerulea* covers more than 65 % of the ground. The *C. portentosa* cover is most dense in a ring surrounding the inner centre of the bog. The species is less abundant on the central dome and around the non-central parts of the mire expanse

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including the Regeneration Complex, where the *Sphagnum* cover is higher. *C. portentosa* mostly forms a dense and continuous mat on the ground in open areas most exposed to light.

Cladonia ciliata

C. ciliata is rather rare on the western peat dome of Cors Caron (see Figure 6.16.b). Its distribution pattern forms a discontinuous pattern around the central part of the West Bog. Where present, *C. ciliata* covers between <1 % and 10 % of the ground.

Cladonia unicalis

As shown in Figure 6.16.c, this lichen species is restricted in its presence to the Regeneration Complex. It forms small continuous patches covering between <1% and 3 % of the ground.

Cladonia cf. cenotea

This lichen has a very sparse distribution over the West bog, as is illustrated by Figure 6.16.d. Its percentage cover ranges between <1 % and 1 %.

Cladonia fimbriata

C. fimbriata is the second most widely distributed lichen on the West Bog (see Figure 6.16.e). It always occurs as a few individuals on bare peat or less vigorous *E. vaginatum* hummocks. *C. fimbriata* is distributed over most of the mire expanse but is somewhat less continuously present in the Regeneration Complex and has a more continuous cover in the south-eastern part of the crown.

Cladonia crispata

C. crispata is the rarest lichen species on the West Bog. It has been found only in three quadrates (see Figure 6.16.f), where it covers between <1 and 1 % of the ground surface.

6.2.1.1 Results of the statistical analysis

The modern quadrat data was analysed using DCA and TWINSPAN. An introduction to both statistical analyses is given in chapter 4 (section 4.6). The DCA of the transect data did not yield useful results. The two-way ordered table of TWINSPAN shows differentiations and is presented as Table 6.10. Since the recorded data all derive from the same vegetation community (M18 of the NVC), there is expectantly a limited variability within the table. The names of the species are listed on the left side of the table and the numbers of the records at the top.

A dual code of zeros and ones on the left side of the two-way ordered table in Table 6.10 shows the division of the species groups. The order of the species is related to their presence that defines their importance as differential species. The species present in most quadrats (species group H) are placed at the top of the table and have the least importance in the differentiation of the quadrat-groups A-D. The species, which act as

differential species (species-groups E, F and G) for the separation of the quadrat-groups are placed in the middle and bottom part of the table.

The dual code at the base of the table indicates the divisions of the quadrats made by the program. There are six grades of separation. The spatial distribution of the quadrats according to the main divisions of TWINSPAN are geographically presented in Figure 6.17. The first separation by the program is indicated by the top row of the dual code. It divides the quadrats, which are totally dominated by *Molinia* Group A (with very few other species present) from the rest of the records (Groups B,C and D). The quadrats of group A (yellow), are all located on the eastern slope of the West Bog, where the *Molinia* cover is most dense. An exception is quadrat I-200, which belongs to the floodplain vegetation. The second division, indicated by the second row of numbers, differentiates between the quadrats with *Molinia* (light yellow, group B) and the quadrats without it (groups C and D). The quadrats of group B, with abundant *Molinia*, usually contain less *Sphagnum* than the groups C and D. The third division differentiates between the area of the Regeneration Complex, with *S. pulchrum* presence (group D, orange) and the rest of the Sphagnetum (group C, green). In the quadrats of group C, *S. cuspidatum* and *S. subnitens* are generally more frequent than in the area where it is present. In the quadrats of group D, *Cladonia unicalis* and *Drosera rotundifolia* are more frequent than in the other groups. *S. rubellum* is more frequent in group B and D than in group C. The program divides the main groups still further but any further division does not yield useful information. When comparing the distribution of groups in Figures 6.10 and 6.11, it becomes apparent, that the groups reflect very well the species distribution of *Molinia* and *S. pulchrum*. The divisions of the two-way ordered table also underpin

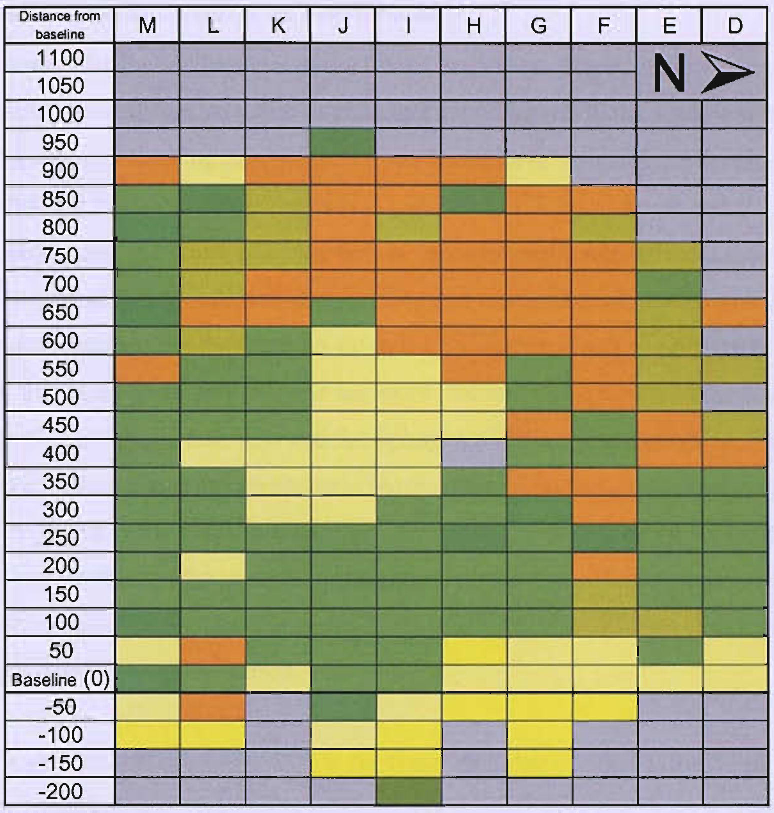

Figure 6.17: Spatial distribution of the quadrats according to the divisions made by TWINSPAN (up to the forth degree).

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what is apparent from the species distribution maps: That *S. pulchrum* and *S. cuspidatum* almost exclude each other in their distribution on the West Bog which is also the case with *S. rubellum* and *S. subnitens*. Both pairs of Sphagna belong to the same section, respectively, and occupy the same microforms in bog habitats. This raises the question, as to whether these spatial exclusions of closely related Sphagna are the result of inter-species competition or not.

6.2.2 Summary of the modern vegetation distribution

In this section the current distribution patterns of the Cors Caron West Bog vegetation have been analysed. The distribution patterns of most species reflect, dependant upon bog relief, the surface wetness of the bog. It is very obvious that species requiring near-surface water levels have their highest densities in the former Regeneration Complex and the Sphagnetum, such as *S. pulchrum* or *S. cuspidatum* and *R. alba*. However, compared to other raised bogs, the cover of *Sphagnum* is very low (see Table 6.9) and species indicating high surface moisture such as *Drosera intermedia* and *Drosera anglica* are almost absent. *Sphagnum* often forms small patches and cushions but there are no extended *Sphagnum* lawns or *Sphagnum* filled hollows. Species favouring or tolerating lower water levels are more frequent in the centre of the bog expanse. Representatives of this group are *M. caerulea* and the Sphagna of the section *Acutifolia*. The distribution pattern of the vegetation also reflects the asymmetric shape of the West Bog, with its highest area on the northwestern border adjacent to the neighbouring hills. Although the species composition of the West Bog is typical for a raised bog community, the percentage cover and distribution of the species is different from other raised bog communities in a near natural stage. The most important differences compared supporting other raised bogs with peat forming vegetation are:

- The overall *Sphagnum* cover averaging 9 % is far lower than that of other raised bogs.
- The lichen cover, predominantly consisting of *Cladonia portentosa* is very high (threat and competition to Spahgnum?).
- *Calluna vulgaris* has not only a high percentage cover; its individuals are also mature and tall, often shading the *Sphagna.*
- *Molinia caerulea,* which is normally not an element of ombrotrophic bog communities, occurs in high densities in the central part of the peat dome.
- *Hypnum cupressiforme* has a high percentage cover, compared with other raised bogs.

These vegetation patterns indicate clearly, that the current bog vegetation on the West Bog has suffering greatly from drying out. Possible causes for these adverse conditions at the present time are discussed in chapter 7.

7 Discussion

Raised bog ecosystems have been heavily exploited by extracting peat for fuel and horticultural growing media. As a result, in Britain only 4000 ha of primary raised bog remain from an original total of 67 000 ha (Plantlife 1992). Cors Caron and Cors Fochno together represent 17% of the near natural lowland raised bogs in England and Wales (P. Jones, pers. communication), which underpins their importance, nationally and internationally, as conservation areas. From earlier research (Godwin and Conway 1939, Slater 1972) it has become evident that the vegetation of Cors Caronshows signs of disturbance, especially on the West Bog. This is surprising since Cors Caron West Bog is structurally much more intact than other raised bogs, for example Cors Fochno (Figure 3.5) , Raheenmore and Wedholme Flow (Figure 7.1), where substantial parts of the margins and centre have been removed by peat cutting.

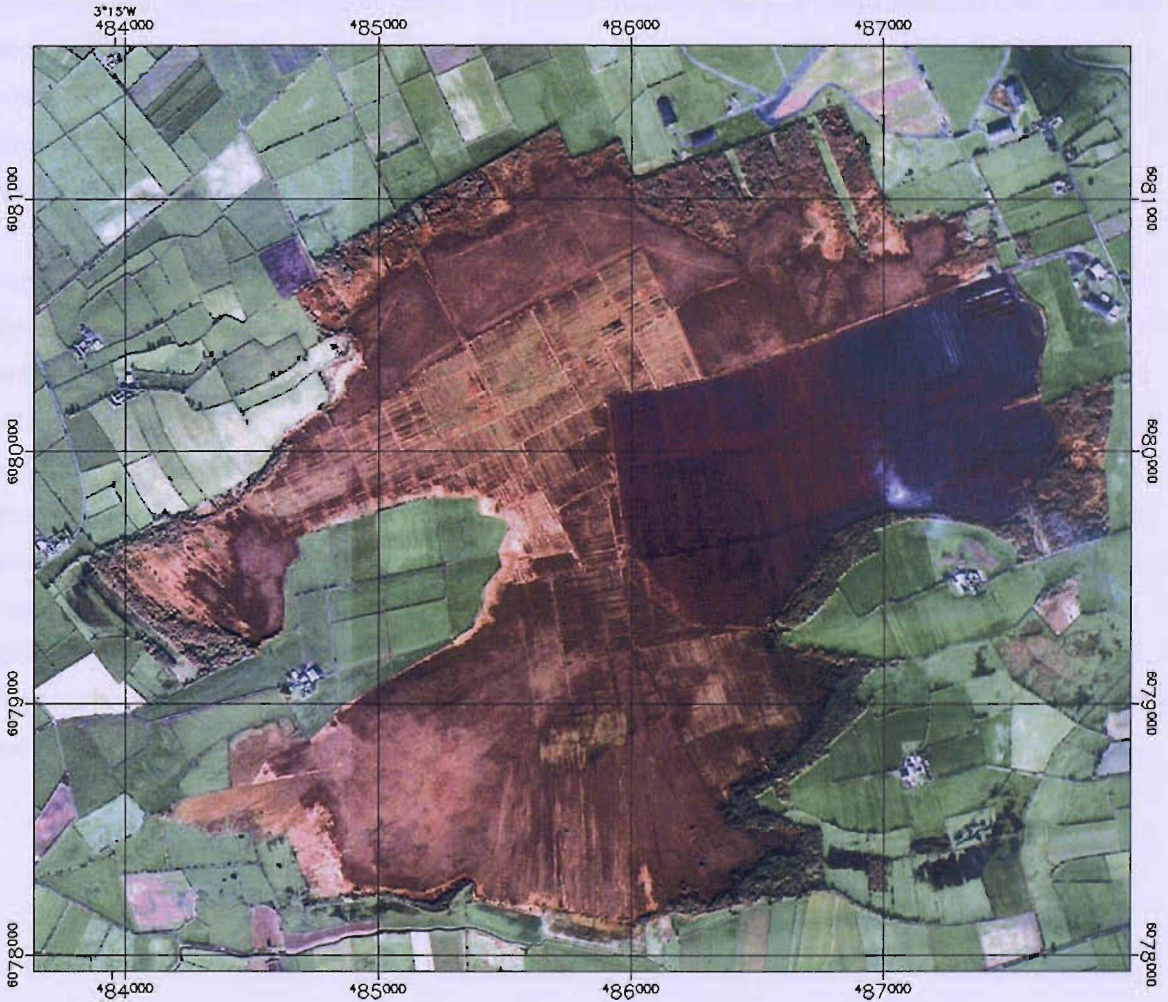

Figure 7.1: Aerial photograph of Wedholme Flow, Cumbria.
The photograph shows that major parts of the bog centre have been cut over with some primary surface left in the north and southwest. The vegetation in the uncut surface is still in much better condition than that of the Cors Caron West Bog.

Cors Caron is only marginally cut, which can be seen from the aerial photographs in the Figures 3.2 and 4.2. The results of this project (see Figures 6.2 to 6.12, Tables 6.2 and 6.3, Figures 6.6-6.8) confirm, that the vegetation of Cors Caron (West Bog) is in a much poorer state than that of structurally more heavily damaged raised bogs. This is illustrated by a comparison of vegetation records at Cors Caron with similar data from Wedholme Flow and Ballynahone Bog (Table 7.1). For example in the most *Sphagnum*-rich areas of the Cors Caron West Bog the total *Sphagnum* cover in quadrats ranged between 2 and 25%. By comparison equivalent figures for Wedholme Flow range between 28 –70% cover and for Ballynahone 1 – 61% cover. This raises questions regarding the causes behind the poor vegetation condition of the Cors Caron West Bog, which are discussed in section 7.1. To identify these causes it is necessary to focus not only on the vegetation succession over the last 65 years but also to examine the vegetation development prior to the 20th century in multiple cores. This involves the histories of the major peat forming vegetation units and species, which have recently become problematic in the mire vegetation such as *Molinia caerulea*, *Betula* and *Myrica gale* (section 7.2). The palaeoecological results presented in chapter 5 clearly show that the development of all three Cors Caron peat domes have followed an unusual path of peat formation, which is not seen elsewhere in the region. Godwin and Mitchell (1938) first noticed the existence of highly humified peat layers in the three bogs (the Retardation Layer), which have been more widely traced and confirmed here. The possible factors behind the peculiar features in the peat accumulation of Cors Caron are discussed in section 7.3. These are influential in the long-term peat accumulation and also determine the conditions for the more recent vegetation development. Potential causes for the slow down in peat accumulation on Cors Caron include factors such as peat cutting, changes in the river channel, burning, climate change and autogenic processes.

Another feature of the younger peat formation, focused upon in section 7.3.3, is the development of the former pool system which is much younger than the pool systems of other raised bogs in Britain. In order to understand whether the pattern of peat accumulation at Cors Caron is controlled by local or regional factors the history of its peat formation is compared against Cors Fochno and Raheenmore in section 7.3.4. In addition to the causal factors behind peat formation, the macrofossil assemblages also provide information about the pathways and rates of change in the vegetation succession over the last two millennia. These data provide a means of studying whether the recent succession at Cors Caron is unusual in a late-Holocene context (section 7.4). The final part of the discussion also examines the presence and loss of species within the macrofossil record as well as the history of *S. austinii* on the investigated sites. The species is the focus of particular attention because it was once one of the main peat formers but now it is absent from Cors Caron and rare at Cors Fochno.

7.1 The vegetation development since 1936/37 and the current status of the vegetation

The results of the re-survey on the Cors Caron West Bog are outlined in chapter 6. They show very clearly that:

a) Since 1936/37 there has been a dramatic change in the vegetation towards drier surface conditions, which is most clearly visible in the DCA diagrams of the re-surveyed 5×5 m quadrats 1-9, shown in the Figures 6.6-6.8.

b) The current vegetation of the West Bog is in a very poor stage compared to other near natural raised bog vegetation (see Table 7.1).

In 1936/37 most of the West Bog (Sphagnetum and Regeneration Complex, upper Rand and Callunetum) belonged to the vegetation community *Erica tetralix – Sphagnum papillosum* raised and blanket mire (M18 of the NVC, Rodwell 1991). The situation in the Scirpetum is less clear. Godwin and Conway (1939) pointed out that in the Scirpetum the same species are present as in the Sphagnetum (= equivalent to the M18) but its structure was much different. The TWINSPAN table (Table 6.10) includes all vegetation records from 2001/02 of the 3×3 m quadrats along the transects. There are only a few divisions in the table, indicating that most of the current vegetation over the West Bog is fairly uniform and contains a species assemblage typical for the M18. Some quadrats from the West Bog centre and margin are dominated by *Molinia caerulea* and could be classified as a transitional stage from M18 towards the community *Molinia caerulea-Potentilla erecta* mire (M25 of the NVC). A clear classification of these records is difficult because *Potentilla erecta*, which should be a constant species in M25, is only present in one of these records. Additionally, most of the *Molinia*-dominated quadrats contain species, which are rather typical for the M18 community. The finer divisions of the two-way ordered table (Table 6.10) also underpin what is apparent from the species distribution maps: that *S. pulchrum* and *S. cuspidatum* almost exclude each other in their distribution on the West Bog similar to *S. rubellum* and *S. subnitens*. Both pairs of Sphagna belong to the same section, respectively and occupy the same microforms in bog habitats. This raises the question, as to whether these spatial exclusions of closely related Sphagna could be the result of inter-species competition or not. To clarify this, further research is needed (see chapter 8).

From the previous section it appears, that by comparing solely the type of vegetation community, the changes since 1936/37 are less important. However, the comparison of particular quadrats (Tables 6.2 and 6.3, Figures 6.6-6.8) and taxa (Figures 6.2-6.4) and surface features (Figure 6.5) from the 1936/37 vegetation survey by Godwin and Conway and the re-survey in 2001/02, in chapter 6, has shown that there were significant changes in the vegetation of the West Bog occurring in the past 65 years. The most important changes are:

(1) The loss or substantial decrease of open water bodies (see Figure 6.5) and of plant species which require a more or less constantly very wet or waterlogged substratum to thrive, including lawn and pool *Sphagna* as well as *Eriophorum angustifolium* and *Rhynchospora alba* (Figure 6.2 and 6.4; Tables 6.2 and 6.3).

	Ballynahone Bog													Wedholme Flow					Cors Caron								
	BYH-3	BYH-4	BYH-5	BYH-6	BYH-7	BYH-8	BYH-9	BYH-10	BYH-11	BYH-13	BYH-17	BYH-18	BYH-19	WHF-1	WHF-2	WHF-3	WHF-19	WHF-20	I15	I16	I17	I18	I19	I20	I21	I22	I23
Betula pubescens, field layer					<1									+									1				
Myrica gale						10	<1	<1																			
Calluna vulgaris	45	12	70	45	75	65	40	40	30	10	50	35	50	20	4	1	30	28	2	1	18	10	20	20	30	25	30
Erica tetralix	10	10	10	10	4		8	8	8	6	6	8	8	25	30	5	7	4	10	8	6	4	10	7	6	8	8
Andromeda polyfolia														2	2	3	3	2	4	4	2	2	2	3	2	3	4
Vaccinium oxycoccos						4	4	4	1								5	4	10	6	3	5	10	8	6	3	4
Vaccinium myrtillus																			<1								
Empetrum nigrum																			<1		2	2	2	4	3	3	
Drosera anglica							r																				
Drosera rotundifolia		<1		<1					<1		<1		<1	2	1	<1	1	1	1			<1	1	<1	<1	<1	<1
Eriophorum angustifolium	<1	<1	3	<1	<1		<1	<1	1	<1	<1	<1	<1	2	2	<1	10	<1		<1	<1	<1	1	<1	<1	<1	<1
Eriophorum vaginatum	5	30		5		8	12	10	3	5	3	2	<1	4	3	25	10	20	3	3	18	12	18	20	8	10	10
Narthecium ossifragum		1		1		1		<1	<1		1	<1							2	4	1	1	<1		<1	<1	<1
Rhynchospora alba				3					<1	3	2	<1	1	2	25	5					<1	<1	1	<1	<1	1	2
Scirpus cespitosus	1	3	<1	3	1			2	2	10	<1	1	1							2	2	2	1	2	4	3	5
Total *Sphagnum*	**8**	**14**	**6**	**20**	**<1**	**34**	**41**	**61**	**40**	**36**	**22**	**30**	**31**	**65**	**28**	**30**	**50**	**70**	**21**	**2**	**14**	**15**	**25**	**10**	**14**	**9**	**19**
Sphagnum rubellum	1	4		6		30	20	40	10	15	2	8	8		3	9	25	30	11		8	4	<1				3
Sphagnum fimbriatum																											
Sphagnum subnitens	4	2		1		1			2	3	3	8	5	43		2			6	<1							<1
Sphagnum magellanicum	<1	<1	1	4		2	1	1	10	2	1		1	10	<1	1	20	20									
Sphagnum papillosum	<1	2	1	4		1			10	10	11	8	10	5	6	5		7	2	1	2	1	16	6	3	6	10
Sphagnum angustifolium						<1																					
Sphagnum cuspidatum											1					2				<1			4			1	<1
Sphagnum pulchrum													5						2	1	1	6	3	2	6	1	2
Sphagnum tenellum	3	6	4	5	<1		20	20	8	6	4	6	2	8	20	15	5	15			3	4	2	2	5	1	4
Aulacomnium palustre							<1												1								
Campylopus flexuosus							<1					<1															
Dicranum scoparium										<1	5									<1	<1	<1		<1		<1	
Hypnum cupressiforme	4		4	2	6	3	4	6	2	4	<1	2	1						6	4	6	6	10	10	10	10	10
Odontoschisma sphagni		10	15	10			6	6	10	12	1	2	5	10	12	10	15	15	4	4	5	4	6	7	6	6	6
Polytrichum alpestre			<1			<1																					
Cladonia cenotea										<1		1															
Cladonia fimbriata				<1																	<1		<1	<1	<1		
Cladonia portentosa	6	<1				<1	2					2	5						5	8	6	9	6	12	10	10	2
Zygogonium ericetorum	<1	<1	<1	<1	<1					1																	

Table 7.1: A Comparison of vegetation records from Ballynahone Bog, Wedhole Flow and Cors Caron West Bog (Transect I).

(2) The appearance and increase in plant species, which endure a waterlogged substratum but thrive better at lower water levels including most Ericaceaeous dwarf shrubs (see Figure 6.3 Tables 6.2 and 6.3).

(3) Invasion and increase of species like *Molinia caerulea* (Tables 6.2 and 6.3) and *Betula pubescens*, which originally did not occur abundantly on raised bogs.

Although the species composition of the vegetation on the West Bog is typical for the raised bog community M18, their percentage cover and distribution differs from that of other raised bogs in a near natural stage. According to Rodwell (1991) Sphagna should be dominant in the M18 community. However, the average *Sphagnum* cover in all recorded 3×3 m quadrats of the Cors Caron West Bog is only 9 % which is far lower than seen in other raised bogs. Table 7.1 shows that the percentage cover of *Sphagnum* on the West Bog is far lower than that of Wedholme Flow and Ballynahone Bog, which are affected by drainage too. In the Table 7.1 a part of transect I was included which is in the more *Sphagnum*-rich area of the Regeneration Complex. If quadrats from the central part of the West Bog are considered (see appendix), the contrast becomes even greater.

A very conspicuous feature on the West Bog is that *Calluna vulgaris* has not only a high percentage cover, but its individuals are also mature and tall, often shading the Sphagna. In natural raised bogs *Calluna* has strong competition and only its upper shoots are visible above the vegetation of hummocks. The high lichen cover on the West Bog, mostly consisting of *Cladonia portentosa*, is also a peculiarity of the site (see Table 6.2). *Cladonia* species are part of natural raised bog vegetation. However, it is not clear if this is a result of the low *Sphagnum* cover or if the lichens are a potential competitor to *Sphagnum*. *Molinia caerulea* is normally not a component of ombrotrophic bog communities, but it occurs in high densities in the central part of the West Bog's peat dome. The species could probably colonise the mire expanse due to fluctuating water levels and increased atmospheric nitrogen deposition (Chambers *et al.* 1999, Tomassen *et al.* 2000). The history of *Molinia caerulea* on the investigated sites is discussed in section 7.2.1. Other species, which occur in raised bog communities without gaining dominance, are *Hypnum cupressiforme* and *Empetrum nigrum*. Although *H. cupressiforme* occurs in the M18 community (Rodwell 1991), it is rather a cosmopolitan species, which also occurs in other communities and indicates rather dry conditions (Ellenberg 1992). This species has a high percentage cover of up to 12 % on the West Bog, compared to other raised bogs (Table 7.1). *Empetrum nigrum* occurs on hummocks in raised bogs but with increasing percentage cover it is considered as an indicator for degeneration (Irmler *et al.* 1998). This development suggests strongly, that the major cause for the loss in peat forming vegetation on the Cors Caron West Bog is increased surface dryness. A reason for the dryness over large parts of the mire expanse could be the fact that there is no acrotelm developed beneath these dry vegetation units. This is also reflected in the macrofossil record of the profiles TWC 2000 (Figure 5.32), TWD 2000 (Figure 5.33), TWE 2002 (Figure 5.34), TWF 2002 (Figure 5.35) and TWG 2002 (Figure 5.36). For example, TWF 2002 shows this in zone TWF-III, which is dominated by UOM at more than 60 % indicating dry, humified peat. In dry seasons the water level fluctuations in this parts of the bog become more extreme because the storage capacity of highly humified peat is smaller than that of the peat beneath the Regeneration Complex, where a larger pore size of the less humified peat provides a greater storage capacity for water. This is also shown in Figure 7.2 deriving from Godwin and Conway (1939).

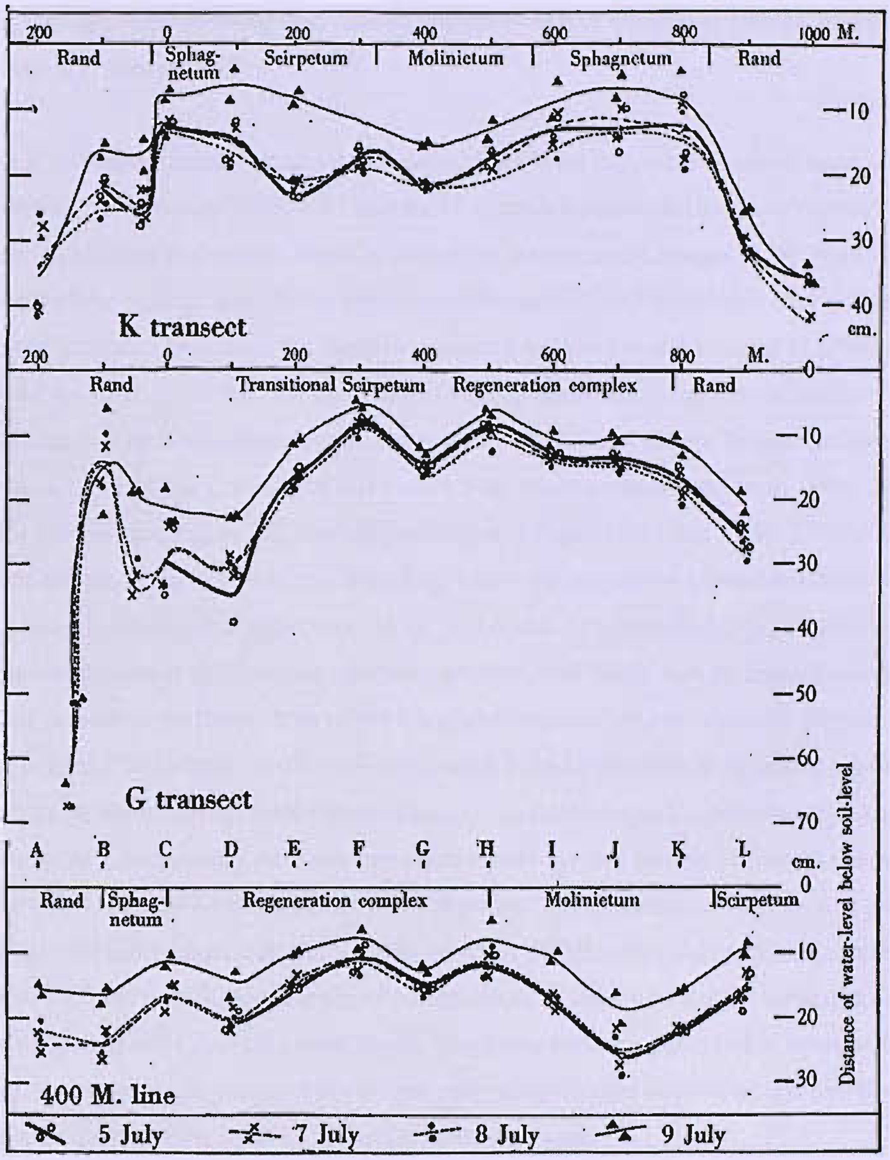

Figure 7.2: Water levels beneath the different vegetation communities in 1937 along transect K (source: Godwin and Conway 1939).

7.2 History of invasive species (*Molinia caerulea*, *Betula pubescens* and *Myrica gale*)

On the Welsh study sites there are several species, which are a matter of concern with respect to the restoration of ombrotrophic peat-forming vegetation. These are *Molinia caerulea*, *Myrica gale* and *Betula pubescens*. The following sections examine the history of these species at Cors Caron and Cors Fochno.

7.2.1 *Molinia caerulea*

The spread of *M. caerulea* in environmentally sensitive areas has become a major problem for nature conservation in recent decades (Chambers *et al.* 1999, Tomassen *et al.* 2000, Tomassen *et al.* 2004). The areas affected by the invasion of *M. caerulea* include heath- and moorland as well as mires. The species has invaded the ombrotrophic vegetation communities of Cors Caron and Cors Fochno where it would not occur under naturally nitrogen-limited conditions. The ecological problems associated with *M. caerulea* are also reviewed in chapter 2, section 2.6.2.

At Cors Caron *M. caerulea* already occupied the centre of the West bog, when Godwin and Conway conducted their vegetation survey in 1936/37 and the *M. caerulea*-dominated area was named by the authors the Molinietum. In addition to the mire centre, it covers the eastern uncut margin of the West Bog and is dominant in most of the cutover areas in the three raised domes of Cors Caron. An investigation of the peat underneath the *M. caerulea* lawn from the West Bog summit by Godwin and Conway (1939) showed that just below the *M. caerulea* cover the peat consisted of slightly humified *Sphagnum imbricatum* (*austinii*) peat. This indicated that the Molinietum must have been of rather recent origin. In order to investigate the history of *Molinia,* two cores at Cors Caron were taken from *Molinia*-dominated areas, TWC 2000 and TWG 2002 (for location see Figure 3.2, macrofossil diagrams Figures 5.32 and 5.36). TWC 2000 originates from the eastern margin of the crown of the West Bog, where the vegetation community M18 (NVC) borders the *M. caerulea*-dominated upper rand of the peat dome. The macrofossil record shows no evidence that the species was present at this location until very recently, indicating, that *M. caerulea*, which was probably always present at the lower slope of the margin has encroached onto the mire expanse. The same result is found in core TWG where the *M. caerulea* tussock is underlain with *Eriophorum vaginatum* remains, which lie on top of *Sphagnum* dominated peat (*S.* s. *Acutifolia* and *S. papillosum*). One could argue that the remains of *M. caerulea* may not have preserved within the peat profile. However, the macrofossil diagrams in the publication by Chambers *et al.* 1999 show that the epidermis of *Molinia* was associated with high levels of unidentifiable organic matter (UOM), which is evidence that the epidermis of the species remains preserved in peat with higher degrees of humification. In none of the other cores of Cors Caron have any macrofossil remains of *M. caerulea* been found. This gives further support to the assumption that *Molinia caerulea* was not a component of the former ombrotrophic mire vegetation and that it was not present on the mire expanse over most of the investigated time span.

On Cors Caron the history of *Molinia* over the last 65 years in the 20th century can be followed from the comparison of the vegetation survey by Godwin and Conway (1939) and the re-survey in 2001/02, carried out as part of this project (see Figure 6.4 a-c) These vegetation maps, as well as a comparison of the aerial photographs from 1948 and 1998 (Figure 7.3) indicate that the area covered by *Molinia caerulea* has increased, especially along the margins of the West Bog and in the peat cuttings in the Northeast and Southeast Bogs. In addition the changes in the quadrats 5, 6 and 9 (see Tables 6.2 and 6.3) indicate that a significant spreading of the species has taken place. This is particularly concerning because these quadrats were in 1936/37 relatively *Sphagnum*-rich areas, where the peat-forming vegetation had been replaced by *M. caerulea*. However, there are reports that cutting the *Molinia* leads to the restoration of moss growth (Bobbink *et al.* 1998) and it may be worth applying this within the management of the sites, especially where *Sphagnum* remains within the *Molinia* dominated areas. The *Molinia*-cover in the cut areas of the bog complex, especially on the Northeast and Southeast Bogs has dramatically increased and it is currently so dense that hardly any other species occur there. This makes the re-establishment of peat-forming vegetation extremely difficult. Examples for such areas are the vegetation records in Table 7.2, originating in the 3×3 m quadrats recorded along the transects in 2002.

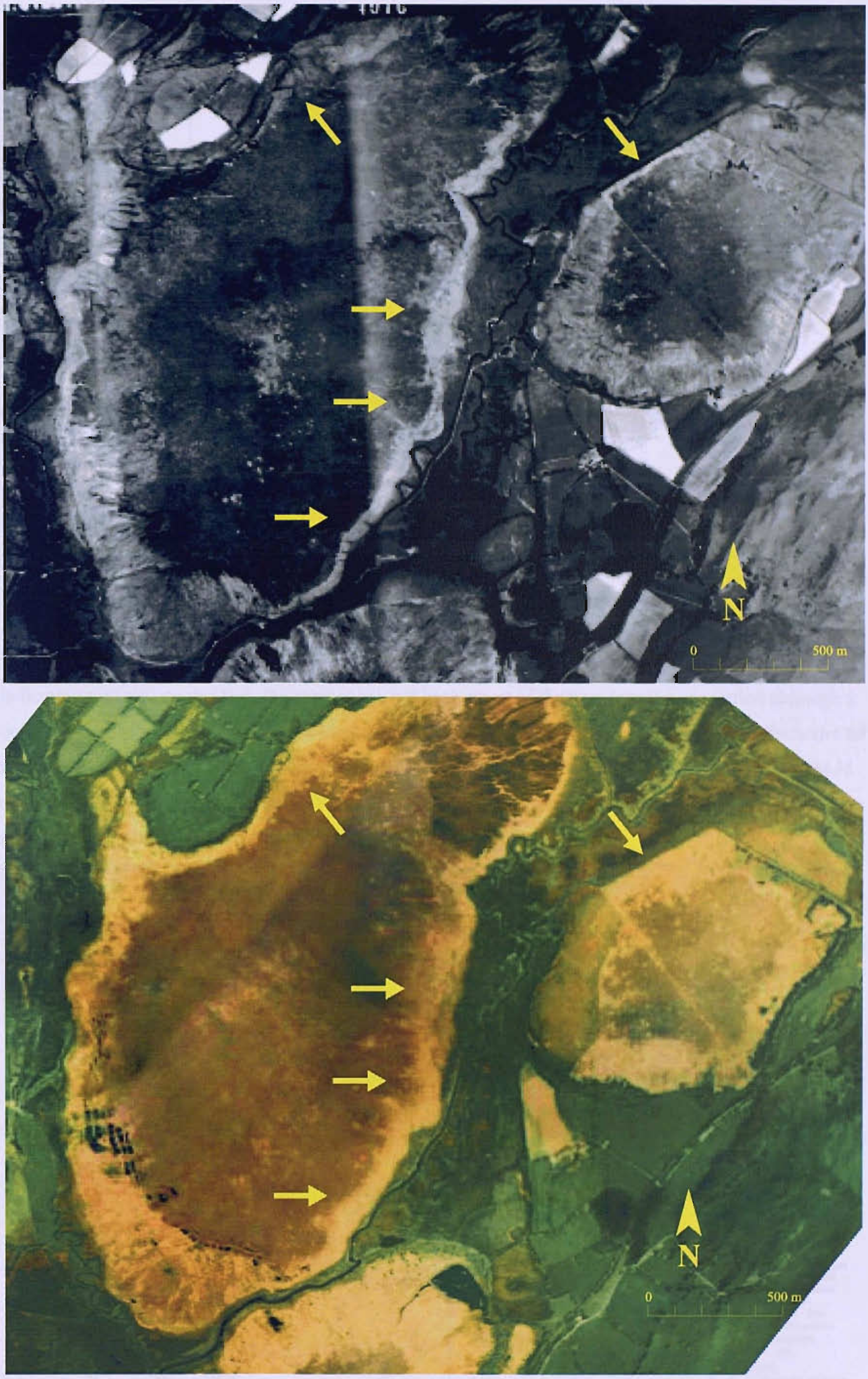

Figure 7.3 : These aerial photographs show Cors Caron in 1948 (top) and 1998 (bottom) in May. The litter of *Molinia caerulea* is visible in the 1998 photograph as bright yellowish bands around the margins of the peat domes and also within the mire expanse.

Table 7.2: Vegetation records from the dense *Molinia* cover of the margins of the West Bog.

	G-150	G-100	H-50	G-50	I-100	J-150	L-100	M-100	F -50	I-150	M50	I-50	F 0
Calluna vulgaris												4	
Erica tetralix			3	8				2			1	5	1
Andromeda polyfolia				4							1	3	2
Erio. angustifolium								+			+		
Eriophorum vaginatum			4	2				<1			2	4	2
Scirpus cespitosus			<1									<1	2
Narthecium ossifragum												<1	
Cladonia portentosa											7	6	4
Molinia caerulea	80	80	80	75	75	75	75	75	75	70	70	65	50
S. capillifolium/ rubellum												2	
S. papillosum												1	
S. fallax										1			
Total Sphagnum										1		3	
Odontoschisma sphagni												2	
Hypnum cupressiforme	1	1	5	8	3	4	4	1	4		7	6	5
Pleurozium schreberi							<1						
Leucobryum glaucum												2	
Vaccinium myrtillus							<1						

Within the four cores taken from Cors Fochno, *M. caerulea* does not appear in the macrofossil record, indicating that also on this bog, the species has not been a part of the peat forming vegetation although it occurs currently scattered over the mire expanse and on the marginal areas of the bog, where the water tables are more affected by drainage. However, a vegetation map in a report by Taylor (1974) indicates that *M. caerulea* was much more widespread on the bog in the 1970's. Then it dominated the southern part of the mire expanse, which has been cut (see Figure 7.4).

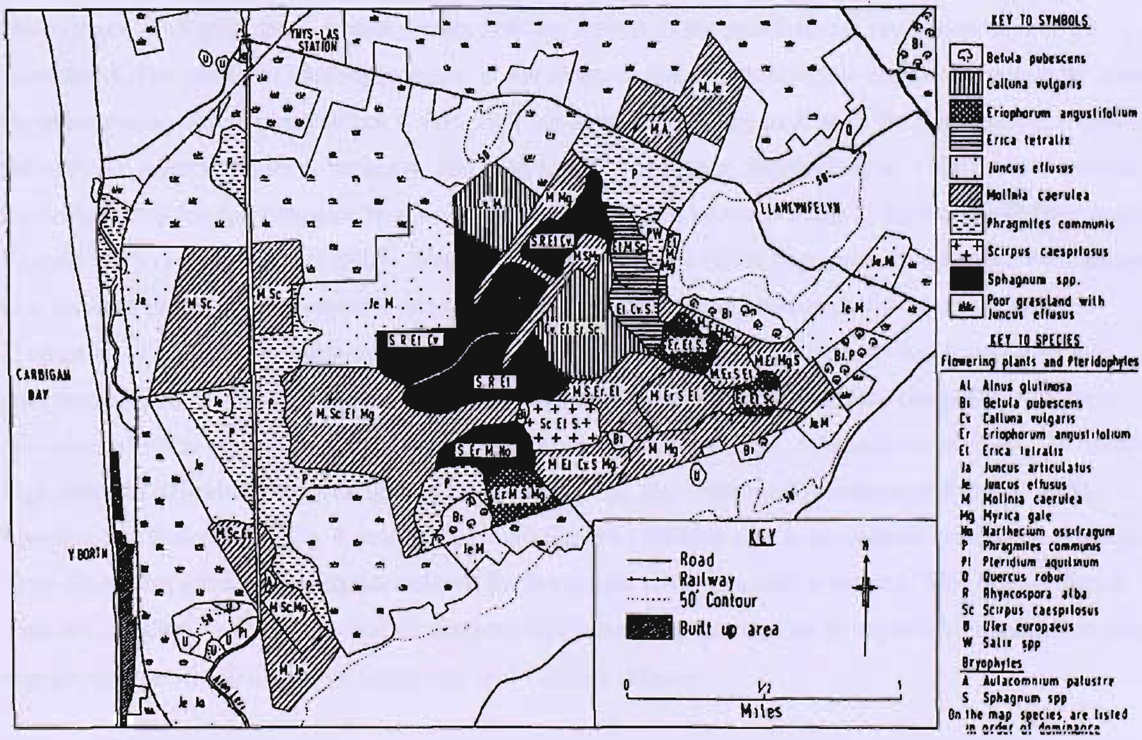

Figure 7.4: Vegetation map of Cors Fochno from the 1970's (source: Taylor 1974).

This is also visible in Figure 7.5, showing a photograph of the southern part of the mire expanse with the former peat cuttings in 1979. The bright leaf litter of *M. caerulea* is seen in great contrast to the other, dark coloured vegetation. In many of these areas, peat-forming vegetation has re-established and the former cut areas are now dominated by very wet *Sphagnum* lawns as a result of water level management practices (observations during field work).

Figure 7.5: View from the south onto the southern peat cuttings of Cors Fochno. Photograph by K.E. Barber in April 1979.

With respect to the fact that *M. caerulea* is currently present at the investigated sites and may be on the increase at Cors Caron, the potential threats deriving from it to the peat forming vegetation have to be considered. The spread of *Molinia caerulea* is a problem in many ombrotrophic bog areas, especially where the atmospheric nitrogen deposition is very high (up to 60 kg/ha/year) such as in the Netherlands. Although the nitrogen input in Wales is far below this level (20-25 kg/ha/year, Reynolds *et al.* 1999), it still exceeds the critical load for ombrotrophic bog environments, which lies between 5 and 10 kg/ha/year (Bobbink and Roelofs 1995, Tomassen *et al.* 2003). If the *Sphagnum* layer in a raised bog becomes saturated with nitrogen as a result of prolonged atmospheric deposition, the nitrogen becomes available for vascular plants (Tomassen *et al.* 2000). Additionally, a high nitrogen load can change nitrogen-limited ecosystems into phosphorus-limited ones (Kirkham 2001). This stimulates the growth of the highly competitive *Molinia caerulea,* which is well adapted to phosphorus limitation (Kirkham 2001, Tomassen *et al.* 2004). In addition, high nitrogen deposition reduces *Sphagnum* growth in bog communities (Gunnarson and Rydin 2000, Limpens and Berendse 2003). A study of Lee and Caporn (1998) is also in accordance with these findings. They found that nitrogen treatments reduced the bryophyte cover in acidic grassland. This implies that at least at Cors Caron a further decline of characteristic raised bog species can be expected including not only bryophytes but also *Eriophorum vaginatum* and *Calluna vulgaris.*

It can be concluded that although the atmospheric nitrogen deposition in Wales is moderate, it is still above the critical load for ombrotrophic environments. Therefore the presence of *Molinia caerulea* in the study areas in association with higher atmospheric nitrogen deposition and fluctuating water tables remains a potential threat to restoration success. In order to secure the latter, further research into the conditions for restoration is needed (see chapter 8.2). Additionally the control of the use of fertilisers on the land bordering the bog complex could improve restoration success.

7.2.2 *Betula pubescens*

Like *Molinia caerulea*, *Betula pubescens* is a species, causing concern in bog environments. On Cors Caron, the species had already encroached onto the summit of the West Bog by 1936/37 (Godwin and Conway 1939). During the fieldwork on the site for this study, many saplings of *Betula* spp. were observed. However, management activities carried out by CCW contract workers include the removal of birch from the bog. The spots on which *Betula* has grown in the recent past are still different with respect to the bog vegetation. Often *Vaccinium oxycoccus* has higher densities in these areas and *Sphagnum* species such as *S. fimbriatum* and *S. angustifolium* are found, which normally do not occur in ombrotrophic vegetation communities.

In the macrofossil record of Cors Caron and Cors Fochno only few seeds of *Betula* were present (for example TRWA 2000, TWD 2000, CFA 2000 and CFC 2001; see Figures 5.31, 5.33, 5.38 and 5.40), indicating that the species was present in the wider environment. No other parts like leaves or wood have been found so that it is assumed that *Betula* did not grow on the peat domes in the past. Although *Betula pubescens* is a component of minerotrophic *Sphagnum*-rich communities, it is usually not part of ombrotrophic vegetation associations in Britain. However, in common with *Molinia caerulea*, *Betula pubescens* has been able to spread in recent decades onto raised bogs, which are exposed to high atmospheric nitrogen deposition (Harding 1993, Tomassen *et al.* 2000). Since nitrogen inputs earlier in the 20th century were below the critical load for raised bogs, the spread of *Betula* on Cors Caron in the first decades of the 20th century may have had a different cause. However, recently the high nitrogen load would favour the spread of *Betula* across the bog surface. This is probably promoted by the relatively dry mire surface on the summit of Cors Caron West Bog. Water table measurements by Godwin and Conway (1939) show, that in the central part of the West Bog in the Molinietum the water levels fall much lower than in other parts of the bog (Figure 7.2). Prolonged drought reduces the growth rate of *Sphagnum* and enhances that of vascular plants (Malmer *et al.* 1994). On the other hand, Tomassen *et al.* (2004) found that in the Irish midlands no invasion of *Molinia* and *Betula* has yet occurred, even on seriously desiccated areas. A similar pattern is seen in the results of the macrofossil analysis on Cors Caron, where no *Betula* or *Molinia* is recorded in dryer phases of bog development (see Figures 5.29 zone TRE-IIIa, 5.30 zone TNEA-IIIa, Figure 5.32 TWC-V, and Figure 5.33 zone TWD-IV). Tomassen *et al.* (2004) conclude from this that desiccation alone can not be the reason for the spread of *Molinia* and *Betula*. In addition, unlike *Molinia*, *Betula* is not able to expand solely as a result of an increase in nitrogen supply and it is assumed that in ombrotrophic areas where the species is spreading, more phosphorus is available (Tomassen *et al.* 2004). However, it could be that the retardation layer, present in all three bogs of the Cors Caron mire complex, contains somewhat more nitrogen and phosphorus than other raised bogs because of its higher degree of humification and exposure to oxygen when the water levels are low. This supports further decay in the oxygenated peat strata, releasing nutrients, which would be available to vascular plants, since there is no vigorous *Sphagnum* layer to absorb the nutrients. Under normal conditions *Sphagnum* is in strong competition with vascular plants, but the remaining *Sphagnum* in the Molinietum, under desiccation stress, would not be able to overgrow *Betula* seedlings leading to the establishment of the trees.

7.2.3 *Myrica gale*

Myrica gale is one of the three nitrogen-fixing woody angiosperms in the British Isles (Sprent *et al.* 1978). It is part of the vegetation community M18 (Rodwell 1991) in many raised bogs (e.g. Cors Fochno, Ballynahone Bog) where it usually remains at the size of a dwarf shrub. The species was originally not present at Cors Caron but a single bush of the species is now growing in the northwestern part of the former Regeneration Complex, where it was probably introduced by visitors (Paul Culyer, personal communication). This former non-presence of *Myrica* on Cors Caron lead to the peculiarity that the caterpillars of the local rosy marsh moth (*Coenophila subrosea*) population feed on *Empetrum nigrum* instead of their usual food source *Myrica.*

At Cors Fochno *Myrica* is very abundant. Depending upon the water table level it grows either to a shrub of considerable size at the marginal areas of the bog, or remains a dwarf shrub of the size of *Calluna vulgaris* in the ombrotrophic areas of the mire expanse. The southern part of the mire expanse has been burnt and as a consequence the *Myrica* cover is much scarcer in this part of the bog (Mike Bailey, pers. communication). On the mire expanse *Myrica* occupies higher hummocks preferentially, becoming a potential threat to remaining *S. austinii* and *S. fuscum* hummocks. This is underpinned by core CFD 2001 (see Figure 5.41), where *Myrica* replaces *S. austinii* at the top of the profile indicating that the change is very recent. However, the macrofossil record shows that *Myrica gale* was present at Cors Fochno over the investigated time span of about 1500 years (core CFC 2001, Figure 5.40). In the other cores at Cors Fochno *Myrica* occurs as well, appearing in about the medieval period (CFA 2000, CFD 2001, Figures 5.38 and 5.41) and within profile CFB 2001 (Figure 5.37) *Myrica* appears within modern times. It can be assumed that *Myrica gale* was a regular component of the peat forming vegetation on Cors Fochno. According to Rodwell (1991), the species occurs naturally in several *Sphagnum*-rich bog communities of which some are ombrotrophic. It seems that the species only became a threat to *Sphagnum* when the water tables fell and began fluctuating as a result of drainage and peat excavation. In common with Ericaceaeous dwarf shrubs, *Myrica gale* may gain competitive advantage over Sphagna due to its developed root system (Malmer *et al.* 2004). Additionally, it shades the *Sphagnum,* which leads to a further disadvantage to the latter (Clymo and Hayward 1982).

In sections 7.1 and 7.2 it has been suggested that the poor condition of the current vegetation on the Cors Caron is linked to the absence of a properly functioning acrotelm underneath extended parts of the West Bog. The pattern of deterioration appears to have been rapid during the 20th century but began several centuries earlier. The process of drying out was probably reinforced by human impact such as peat cutting, which in turn enabled the spread of species which normally do not occur in raised bog communities, such as *Molinia caerulea* and *Betula pubescens*.

7.3 The history of peat accumulation of the investigated sites

7.3.1 The unusual features of peat accumulation on Cors Caron and its potential causes

The first part of the discussion focused on the vegetation of the Cors Caron West Bog and its unusually dry state in comparison with other disturbed raised bogs. As outlined above, the immediate reason for this poor condition is likely to be that there is no functioning acrotelm over large parts of the West bog. This raises the question: Why has Cors Caron been apparently more sensitive to peripheral damage and loss of the acrotelm than other raised bogs? The factors driving the unusual pattern of peat accumulation could be important in this context. That Cors Caron exhibits a phase of slow peat accumulation in its upper peat layers has been pointed out in earlier work (Godwin and Mitchell 1938, Godwin and Conway 1939, Turner 1964, Barber 1981, Morriss 2001, Hughes *et al.* 2001). Very recently, the work of Morriss (2001) confirmed that the Retardation Layer is identical with a phase of significant slow down in peat accumulation at Cors Caron. The results reported here show that this feature is present in all three summit profiles at Cors Caron (see Figures 5.3, 5.5 and 5.7). Possible causes for the development of the Retardation Layer have been discussed by Godwin and Conway (1939), Barber (1981), Morriss (2001) and Hughes *et al.* (2001). For the macrofossil analysis for this PhD project on the cores TRE'98 and TRWA 2000 the same peat profiles that Morriss worked on were used. Thus, the chronology, established by Morriss (2001), published in Hughes *et al.* (2001), could be used and complemented with additional radiocarbon dates. The additional dates add detail to the chronology of both profiles, but do not significant alter the course of peat accumulation (Figures 5.3 and 5.7). The potential reasons for the deceleration in peat accumulation pointed out in the previous literature will be discussed here and complemented with new evidence and information resulting from the current project. They include:

- peat cutting
- changes in the river channel
- burning
- climate change
- autogenic factors

Each of these potential causal factors will be explored and the likelihood of its influence assessed in the following sections.

(1) Peat cutting: Morriss (2001) reports that there is no evidence for uniform peat cutting over the entire bog surface. There are no references mentioning large-scale peat cutting and there is no sharp change in the pollen record, which would suggest such a large impact. Additionally the aerial photographs from 1948 (Figure 7.3) and 1998 (Figure 3.2) indicate undisturbed mire expanses for all three central peat domes. This is supported by the findings of this project. The SCP- (spheroidal carbonaceous particles) record as well as the macrofossil record show no evidence for disruption. Morriss (2001) considers that marginal peat cutting, especially on the Southeast-Bog where much of the upper peat layers have been removed, could have affected the shape of the ground water mound (GWM) of the peat bodies significantly, especially if the peat cutting took place in the *ca.* 5th and 6th centuries AD. In contrast to the chronology established by Morriss (2001), the refined chronology produced for this study shows that the deceleration in peat accumulation on the Southeast Bog started significantly earlier, between *ca.* cal 80 BC and 200 AD. However, Hughes *et al.* (2001) point out that the Ordinance Survey maps from 1906 do not indicate any large peat cutting at the three remaining peat domes. The 1948 aerial photographs show that the peat cuttings around the bog centres are rather recent at this time (peat cutting in this area was undertaken, when Godwin and Conway conducted their field work in 1936/37). Although this intervention has certainly had a negative impact on the bog hydrology, it could not be the reason for slow peat accumulation starting before 2000 BP. Godwin and Conway (1939) point out that marginal drainage would not have the effect seen on the West Bog, with a drier centre and wetter margins. Additionally it can be argued that the other two study sites Cors Fochno and also Raheenmore Bog both suffer from marginal peat cutting at a similar or even greater scale without showing the same signs of slowing peat accumulation.

(2) Changes in the river channel. The fact that Cors Caron is situated in a floodplain of the upper course of the river Teifi distinguishes this raised bog Complex from many other investigated sites such as Cors Fochno and Raheenmore Bog, but also many raised Bogs in Cumbria like Wedholme Flow, Bolton Fell Moss or Walton Moss. Therefore it is assumed that the spatial restriction of the bogs by the valley sides and the Teifi running trough between the different peat domes must have had an influence on the process of peat formation. Furthermore the presence of the river at Cors Caron could potentially provide an explanation for the pattern of Retardation Layers present in all three Cors Caron domes, which is apparently not repeated elsewhere in the region.

Morriss (2001) suggests that it could be possible that a drop in water level of the river might have affected the hydrological system of the bogs as a result of dam building or river straightening. In contradiction to this suggestion there is evidence from maps that the damming and straightening of the river channel must have occurred between the late 1800's and 1906. The maps of the late 1800's shows the old natural river channel, which is dammed and straightened on an Ordnance Survey map of 1906. Thus, these impacts are of recent origin and could not have an influence on the start of the slow down in peat accumulation well before 0 AD. Hughes *et al.* (2001) considers changes in the river channel rather unlikely because the low hydraulic conductivity of catotelmic raised bog peat would tend to insulate the mire surface particularly on the centre of a large raised bog.

Godwin and Mitchell (1938) suggest that incision in the river channel could have influenced the peat formation. As shown by Brown (1997), river floodplains develop in a very complex way with frequent alterations in the river channel. All aerial photographs of Cors Caron show old, meanwhile overgrown parts of the river channel, indicating that the Teifi changed its course frequently adjacent to the raised bog margins. It is therefore possible that the river could have partly eroded sideways into the peat domes or deepened the river channel by incision. The pollen analytical results of both Morriss (2001), and also of

Buckley and Walker (2001) show that there was a reduction in tree pollen and an increase in grass pollen before c. 100 BC, pointing towards clearing in the catchment area of the Teifi. Clearance of woodland would prevent the buffer of interception provided by trees after rainfall and increase the rate of the water discharge into the river system. Increased discharge would increase the potential energy and velocity of the stream resulting in more frequent changes in the river channel and/or its incision. Lateral erosion into the peat domes and/or incision of the Teifi may have caused a similar effect as marginal peat cutting on raised bogs, reported by van der Schaaf (1999, 2000): Drainage can lead to subsidence and subsequent steepening of the bog margins. This in turn causes a faster run-off and result in higher water level fluctuations, unfavourable conditions for the growth of *Sphagnum* but more conclusive for Ericaceae and Monocotyledons which tolerate slightly drier conditions. The way river dynamics could alter the shape of the ground water mound is shown in Figure 7.6. This model would also explain why the slow down in peat accumulation affected first the margins of the bogs and later the summits. If incision of the river channel in connection with a fall of the water level alters the shape of the GWM of the adjacent peat domes this contradicts the concept of raised bogs as hydrologically independent systems. Raised bogs are supposed to have their water level, which is elevated above that of the surrounding mineral water tables solely maintained by precipitation. However, recently (Siegel *et al.* 1995, Glaser *et al.* 1997, Sirin 1998) it was shown at least for continental raised bogs that this is not necessarily the case.

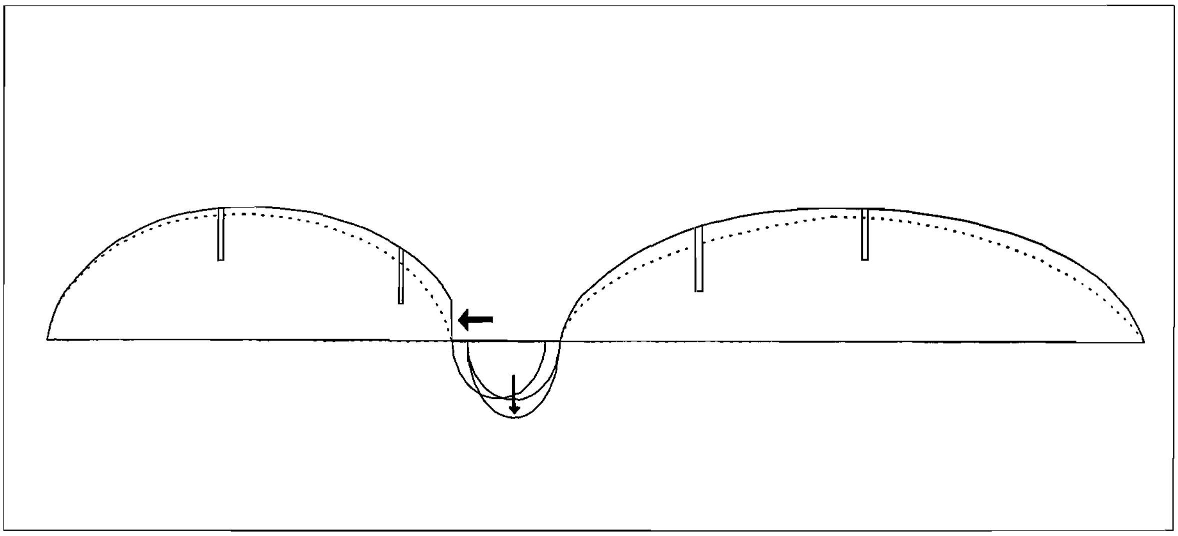

Figure 7.6: Possible influence of lateral erosion (left) and incision of the river channel (right) on the shape of the GWM in the adjacent peat domes.

(3) Burning. Godwin and Conway (1939) mention burning as a potential factor for the formation of the Retardation Layer but do not, as Barber (1981) points out, further discuss the possible influence of fires. Barber (1981) refers to the black, amorphous peat layer in the regeneration complex in Figure 34 in Godwin and Conway (1939, p.357, re-produced in Figure 7.7) and proposes, " *the immediately sub-surface stratigraphy is strongly suggestive of burning*". The author comments further on Figure 13 in Godwin and Conway (1939, p. 336, re-produced in Figure 7.8): " *'mats' of Aulacomnium palustre and Hypnum schreberi are shown overlying a series of 'stumps' of Eriophorum vaginatum and Scirpus (Trichophorum) caespitosus. It is difficult to see how such tussock stumps' could arise by drying out or any other agency apart from a fairly intense fire.*" The first figure Barber refers to (Figure 7.7) shows the stratigraphy in the Regeneration Complex. The same sequence in the left part of Figure 7.7a is reflected by the macrofossil diagram of TRWA 2000 (Figure 5.29), but here the upper layer of the *S.* cf. *austinii* peat itself represents the phase of deceleration in peat accumulation. The macrofossil record of TWH 2002, likewise from the former

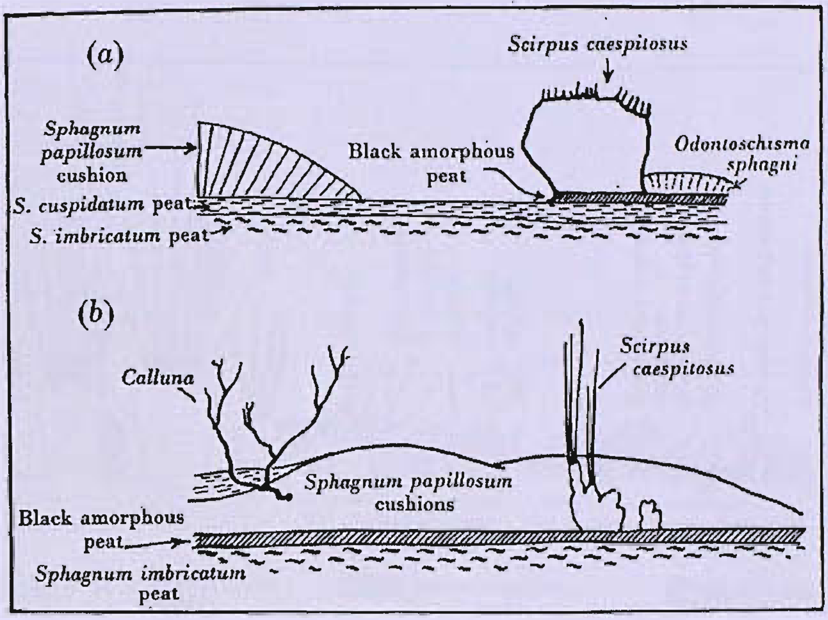

Figure 7.7: The black amorphous peat layer in the regeneration complex (source: Godwin and Conway 1939).

Regeneration Complex shows also no sign of a black amorphous peat layer. The right part of the same sketch in Figure 7.7.a showing the black amorphous peat layer is not reflected in any of the macrofossil diagrams. From TRWA 2000 it can be assumed that the *S. cuspidatum* layer and therefore also the layer of black amorphous peat in Figure 7.7.a (right) are of recent origin and not linked with the phase of slow peat growth. It is likely that fire had an influence on the origin of the black amorphous peat layer despite the fact that Regeneration Complex is the wettest part of the West Bog. The situation in Figure 7.7.b, too is not reflected in any of the cores taken from the West Bog, although it has to be regarded that the cores cover only a tiny fraction of the peat dome. In Figure 7.7.b where the black amorphous peat layer marks the extinction of *S. imbricatum* (cf. *austinii*) it could be caused by fire, supported by a drier bog surface at this time. However, without particular knowledge of the constituents of this black amorphous peat layer the cause of its origin remains speculation. From the evidence of the macrofossil diagrams originating from the former Regeneration Complex it is unlikely that this black amorphous peat layer and the phase of slow peat accumulation are identical because this layer does not occur in both profiles. The other Figure (see Figure 7.8), commented on by Barber (1981) shows a situation across a *Molinia* 'island'. Here moss layers overlay stumps of *Molinia caerulea* and *Eriophorum vaginatum*. The occurrence of *Molinia caerulea* is of very recent origin, as indicated by Godwin and Conway's (1939) findings and the macrofossil record of TWG 2002 (see Figure 5.34). If there was any severe burning after the establishment of *Molinia*, it also would not be linked with the onset of the slow down in peat accumulation, which started in the Regeneration Complex in about the 11th century. The macrofossil record of Cors Caron does not support the possibility of burning as a causal factor for the deceleration in peat accumulation. There are only traces of charcoal present in the macrofossil diagrams of Cors Caron (see Figures 5.29-5.33). However, since the same is valid for the macrofossil record of Cors Fochno, although there several fires occurred in the 20th century. This raises questions regarding how much charred material remains in the macrofossil record after the occurrence of fires. Morriss (2001) discusses a possible explanation for burning caused by the railway but she argues that this would probably not affect the West Bog because the fire could not cross the river Teifi. Additionally, the railway is also too recent to have caused an event that started many centuries before it was built.

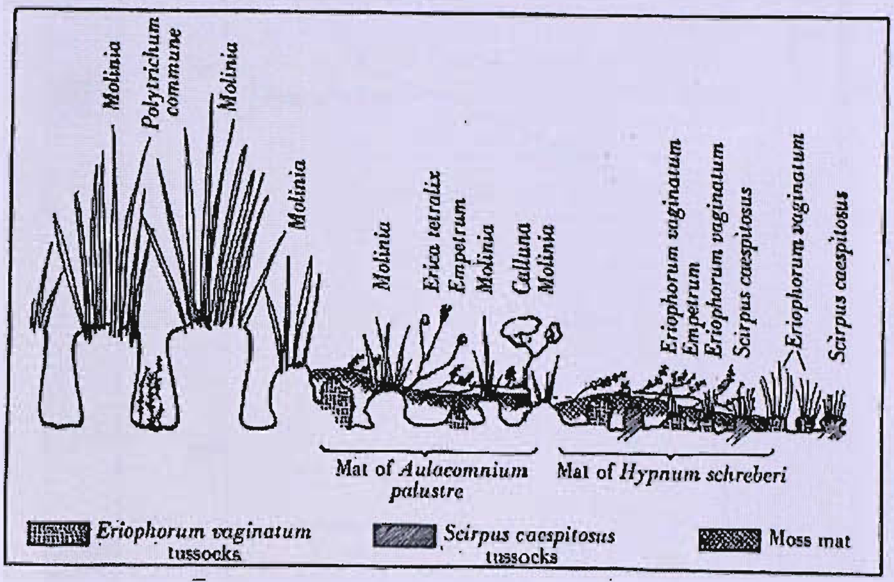

Figure 7.8: Cross section of a *Molinia* 'island' (source: Godwin and Conway 1939).

(4) Climate change: Godwin and Conway (1939) saw climate change as the most plausible explanation for the formation of the Retardation Layer, which they considered to have developed in a drier phase of bog development. Morriss (2001) and Hughes *et al.* (2001) suggest the phase of decelerated peat accumulation could represent a Stillstand Complex (*sensu* Oswald), where peat accumulation stopped for some time, or a phase of continuous but very slow peat accumulation. The evidence provided in this study supports this explanation. The radiocarbon dates in the macrofossil diagrams suggest very slow peat accumulation, which became even slower or stopped towards the top of the Retardation Layer (see Figures 5.29 - zone TRE-III, Figure 5.30 -zone TNEA-III and 5.31 – zone TRWA IV). Morriss (2001) and Hughes (2001) discusses as a possible explanation that this dry phase could have been caused by lower effective precipitation in the Medieval Warm Period (MWP). Hughes *et al.* (2001) point out that the peat record from core TRWA 2000 appears to be climatically sensitive. Phases of higher water levels in the upper part of zone TRWA I and TRWA III represent 'wetshifts' at about *c.* cal. 215 AD and *c.* cal. 525 AD, which are known from other bogs in northern England and Scotland. However this explanation can only serve on the West Bog and the Northeast Bog. On the Southeast Bog the deceleration of peat growth started much earlier, at about 404 BC on the margin of the mire expanse (Turner 1964, Clymo 1965) which is shown in Figure 7.9 and at about cal. BC 60 at the centre of the Southeast Bog (see Figure 5.3). Thus, the Medieval Warm Period cannot account for the beginning of the phase in slow peat accumulation there. However, the slow down may be equivalent to Walton Moss (Hughes *et al.* 2000). There is a dry phase at about 200 AD. Similar dry phases are reported by Barber *et al.* 2003 and Barber *et al.* 2004 from raised bogs in Cumbria, Ireland and Danmark.

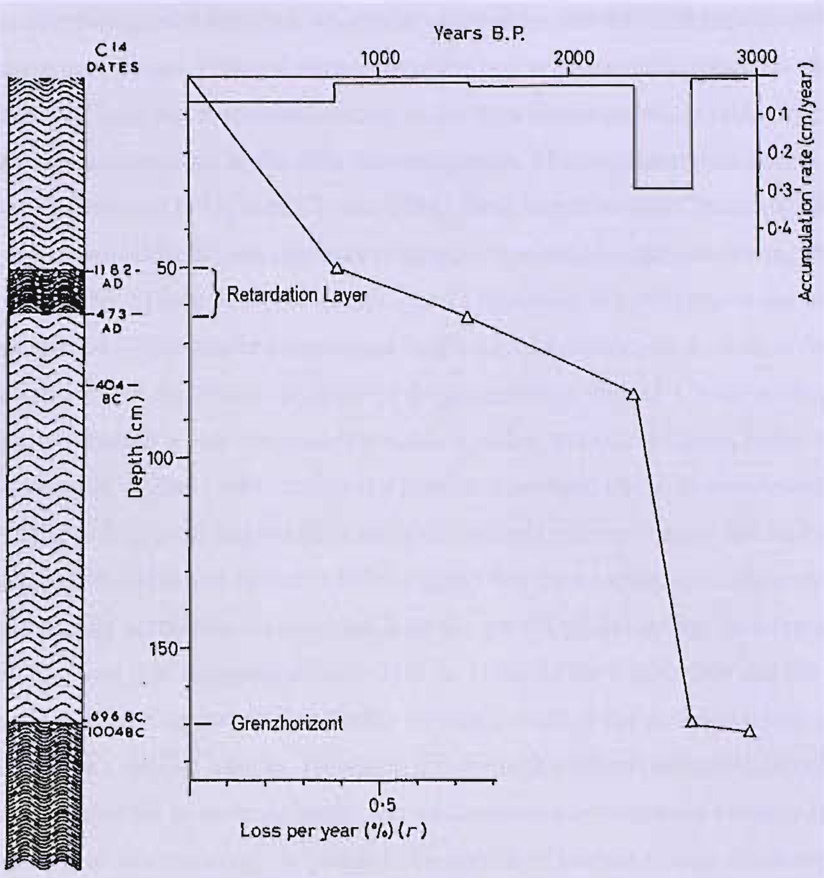

Figure 7.9: Combination of peat profile (source: Turner 1964) and age-depth model (established by Clymo 1965) of the profile from the Southeast Bog, taken by Turner (1964) from an open peat bank on the Southeast Bog.

Morriss (2001) points out, that the Cors Caron peat domes show no reaction to the early part of the LIA, suggesting that in recent times they have not been climatically sensitive. Another fact contrasting with the climate change explanation is, that the onset of the slow down in peat accumulation starts not only at different times in the three raised bogs but also at different times within the Southeast and West Bog. This makes a single climatic dry shift unlikely to be the cause for the slow down in peat growth.

(5) Autogenic factors: It has been shown that the climate is a driving factor in the development of Atlantic raised bogs (Aaby 1976, Barber 1994, Mauquoy and Barber 1999a). Other authors (Foster and Wright 1990, Almqist-Jacobson and Foster 1995, Ilomets 2000) suggest that autogenic factors may also play a role in raised bog development, at least in raised bogs in continental areas. The presence of the Retardation Layer (equivalent to Recurrence Surfaces; Godwin 1954) is a feature Cors Caron has in common with these more continental raised bogs, which can have several Recurrence Surfaces (Granlund 1932). The results of the history in peat accumulation of Cors Caron show, that the bog development is clearly different from that of most other raised bogs in Britain in that it contains layers of very highly humified peat where accumulation seems to have slowed dramatically or stopped. Most undisturbed Atlantic bogs in Britain appear to have continued accumulating peat in *Eriophorum / Calluna* communities through phases of lower effective precipitation. Apart from other local factors like the presence of the Teifi there is also the possibility that autogenic factors may have had an influence on the path of peat accumulation. These factors could be determined by the morphological restriction, which the valley sides and the Teifi impose on the lateral expansion of all three peat domes. If lateral expansion of the bog is prevented by physical barriers, further vertical peat growth may lead to a steep cross-section to the bogs where the water table depth is too deep to support *Sphagnum*-rich communities in the drier climatic phases. This explanation is similar to the height limiting hypothesis of Granlund (1932) and Clymo (1984). Both Granlund and Clymo suggest that bogs may develop through an autogenically-driven sequence of changes that tend towards increasing dryness, thus explaining the development of recurrence surfaces. Clymo's hypothsis suggests that under constant climatic conditions the bog dome will increase to a maximum height beyond which peat formation cannot occur because there is a limit on the maximum curvature of the groundwater mound. Clymo envisaged that this process would be augmented if a bog was resticted within a valley, as at Cors Caron, rather than occupying a flat interfluve. Walker and Walker (1961) invoke the processes outlined above to explain shifts in the peat stratigraphy of Fallahogy Bog from 'rejuvenated surfaces' towards a more 'mature and uniform vegetation'. Similarly, Damman (1979, 1986) and Ilomets (2000) suggest that the continuous increase in the height of the bog surface will eventually accelerate drainage and limit the growth of *Sphagnum*. In summary the height limiting hypotheis proposes that autogenic changes lead to drying of the bog surface and the production of a recurrence surface (retardation layer) and that further upward growth of the peat dome only occurs when there is a change towards a moister climate. However, this concept has been criticised, initially by Godwin (1954) who pointed out that the hypothesis would rely on continuously increasing oceanity during the Holocene to maintain peat accumulation. In practice this pattern of climate change is not supported by palaeoclimatic records, instead there is a pattern of cyclic change in Holocene climate variability (Aaby 1976, Barber 1981, Barber et. al. 1994, Hughes et al. 2002, Langdon and Barber 2001, Barber et al., 2003 and 2004). Godwin (1954) has also suggested that peat accumulation in the order of 50 – 60 cm across the main retardations layers at Cors Caron could not be held responsible for the entire difference between continued peat growth and total cessation on a site that is several kilometres in length.

In this section several potential factors were examined, which could potentially have driven the peat accumulation on the three bogs of the Cors Caron mire complex. It can be concluded that it is likely that there is no single factor which can account for the slow peat accumulation but a combination of changes in the river channel (2), spatial restriction (autogenic factor) (5) and also climatic influence (3) have driven the path of bog development on Cors Caron. The possibility that early marginal peat cutting (1) and burning contributed to the formation of the Retardation Layer can not be excluded but is considered to be minor since the scale of marginal damage is, at least on the West Bog, very small and there is no evidence for extensive burning (like high amounts of charcoal) in the macrofossil record.

7.3.2 Remarks on the morphology of the West Bog

The locations of TWC 2000 and TWD 2000, on the edges of the mire expanse seem to have been exposed to fluctuating water tables since 300 BC. Also the short cores TWE 2002, TWF 2002 and TWG 2002 (Figures 5.34-5.36), of the West Bog show that the Retardation Layer in more central parts was formed by plants, which tolerate lower water tables and contain almost no *Sphagnum* remains. In contrast, the western part of the West Bog remained wetter throughout the phase of decelerated peat accumulation. Even during the phase of slow peat accumulation the *Sphagnum* content (*S.* cf. *austinii*) in these profiles remains relatively high (TRWA 2000, TWH 2002, Figure 6.5). Also the fact that within the Regeneration Complex *S. papillosum* is associated with *S. austinii* points towards higher wetness in this area. This implies that the hydrology and therefore peat accumulation was not affected in the same way all over the West Bog. The comparison of the retardation layer in the different profiles from Cors Caron shows, that the Regeneration Complex on the West Bog remained much wetter than the other parts of mire complex. A possible explanation could lie in the morphology of the West bog. The Regeneration Complex occupies the highest part in the north-western part of the West Bog, which grades into the adjacent hillside of the Ynys-Y-Berfedd farm (Figure 3.3 reproduced from Godwin and Mitchell 1938). Therefore the water accumulating on the mire expanse cannot drain in this direction resulting in impeded and delayed drainage. Additionally part of the run-off water from the hills could have drained into the lagg (before the establishment of the drainage channel along the hillside) and could well have seeped further into the area of the Regeneration complex. This would provide an additional water supply of catchment water at this part of the West Bog it would also imply that this part of the bog is not entirely ombrotrophic.

7.3.3 The history of the former pool system on Cors Caron West Bog

Godwin and Conway (1939) report the presence of an extended pool and hollow system on the Cors Caron West Bog. The pools were shallow and up to 2 metres wide. The results of the re-survey show that this pool system disappeared entirely. During the field work in 2001/02 no open water pools or mud buttoms were encountered (see chapter 6, section 6.1.1.7). On the aerial photographs from 1948 an accumulation of black spots is visible if the photograph is enlarged especially in the area of the former regeneration complex (see Figure 7.10). It is very likely that these black spots represent open water bodies, the larger pools. Also other open water such as the Teifi are black on the aerial photograph. It is possible but rather unlikely that the black spots represent bushes or small individuals of *Betula*. Godwin and Conway did not mention such an abundance of *Betula* in the Regeneration Complex and neither the macrofossil record nor the present vegetation composition indicate the presence of *Betula* (in the areas where *Betula* was formerly present, the vegetation composition is usually different from the surroundings). From the macrofossil record it appears that the formation of the pool system is rather recent. There is no evidence in the macrofossil record that supports the presence of pools before the onset of modern times such as *S.* s. *Cuspidata* peat layers (see Figure 5.31–5.35). However, all three summit cores and also TWC 2000 and TWH 2002 show in modern times a shift in the macrofossils towards a *S.* s. *Cuspidata* layer succeeding the Retardation Layer, indicated by the macrofossils (in the Figures 5.29, 5.30, 5.31, 5.33 and 5.36). Core TWH 2002 was taken from a wet hollow, which was assumed to be one of the former pools with the aim of investigating the history of the pool system. The macrofossil record shows that the bottom zone of this profile was formed by *S. austinii* peat. This peat was succeeded by *S. papillosum* remains, followed by *S. cuspidatum*. Both layers, the *S. papillosum* as well as the *S. cuspidatum* layer were associated with high numbers of chironomid head capsules and Cladocera ephippia, indicating that the moss layer in which they lived must have been saturated

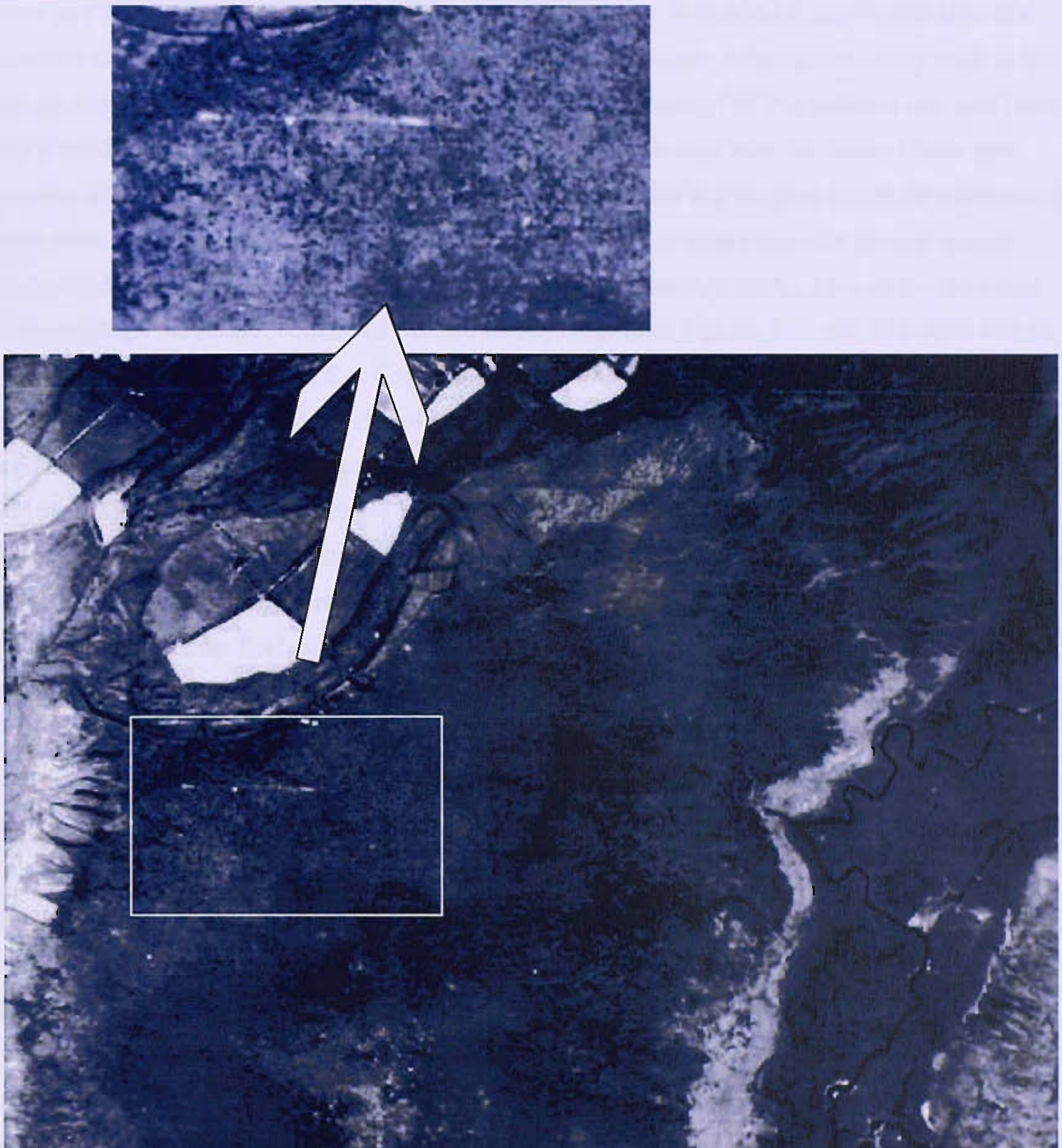

Figure 7.10: Aerial photograph of the Cors Caron West Bog from May 1948. The enlarged section shows a pattern of dark spots which are very likely to represent part of the pool system.

with water and thus represent a wet lawn or *Sphagnum* filled hollow. Within the *S. papillosum*-layer the SCP-numbers start to rise and increase sharply in the *S. cuspidatum* layer. Although the earlier peak in SCPs may also be partly caused by a slow peat accumulation, the high amount of SCP's indicates that both layers probably formed in modern times (after 1800). This occurs simultaneously with the onset of faster peat accumulation in the summit profiles. The chronology supports the idea that the pool system developed at the same time when faster peat accumulation started again around 1800. It seems then that surface wetness increased considerably, possibly within the last phases of the Little Ice Age (LIA). Also on the Northeast and Southeast Bogs, the surface conditions became wetter at this time. Figures 5.29 and 5.30 show that the top layers of both profiles consist of *S.* s. *Cuspidata* and *S. papillosum*. As the macrofossil record suggests that the pool system on Cors Caron developed in the last phase of the LIA this implies that the former pool system of the West Bog is much younger than that of other raised bogs, where pool formation started several thousand years ago (Moore 1977, Karofeld 1998). However, it is not clear, if there were also pool systems developed on the Northeast and Southeast Bog. The peat layers that would give evidence of the presence of open water pools have been largely removed by extensive peat cutting of the marginal mire expanse (see Figure 3.2 and 4.2). At Cors Fochno is only one profile, which indicates higher surface wetness at the same time (CFA 2000, see Figures 7.11and 5.38 – zones CFA-IV and CFA-V). Most of the other profiles in this study show relatively dry conditions (Figure 7.11) in the time after 1800). In contrast Bolton Fell Moss, Walton Moss and many other bogs do show an equivalent phase of pool formation at this time (Barber *et al.* 1994, Hughes *et al.* 2000).

During the slow down in peat accumulation the macrofossil record supports the assumption that Ericaceous shrubs and Cyperaceae were prevalent. The vegetation of the bog surface could be imagined to have resembled that of a wet heath. It is unlikely that under such conditions an extended pool system could have occurred. The macrofossil record also supports the assumption, that there was no functioning acrotelm over wide parts of the bog complex by the end of the phase of slow peat accumulation and thus there was no reservoir to store the surplus water. This would also explain why the bog reacted so late to the LIA. The pool-and channel system probably evolved on the mire surface when the conditions became wetter. This is supported by Karofeld (1998), pointing out that the formation of pools is often related to wet or/and cool climatic conditions but also referring to Hulme (1986), who argued that there is an interplay between climate and the developmental stage of the bog, which delay the hollow formation. One could speculate that without human intervention on the bog, it would have returned to a steady peat accumulation since a wet surface supports the conditions for *Sphagnum*. However, with continuous peat excavation the bog complex became further exposed to prolonged desiccation, which impeded the recovery of the *Sphagnum*-layer. Additionally, a series of dry summers in the early 1970's certainly contributed to, if not triggered the disappearance of the pool system on the Cors Caron West Bog as it did on Raheenmore Bog (Jim Ryan, DUCAS, personal communication).

7.3.4 The peat accumulation on Cors Caron in comparison to other sites (Cors Fochno, Raheenmore Bog)

7.3.4.1 The history of peat accumulation at Cors Fochno

The history of peat accumulation on Cors Fochno is represented in the macrofossil diagrams in chapter 5 (see Figures 5.38-5.40) and also in the age-depth models (see Figures 5.17, 5.19, 5.21 and 5.24). When comparing the age-depth models of Cors Fochno, it appears that the peat accumulation rate is very similar in the profiles CFB 2001 and CFC 2001 between *c.* cal. AD 1100 and *c.* cal. AD 1750/1800. In profile CFA 2000 and CFD 2001 the accumulation is slightly faster rate between *c.* cal. AD 1100 and *c.* 1800. However, the calculation of the accumulation rate in years/cm is not necessarily reliable since the peat layers could have been subject to subsidence and compaction if the bog has been affected by drainage.

Figure 7.11 shows that at *c.* cal. AD 1100 changes in the macrofossil assemblage occur simultaneously in CFA 2000, CFB 2001, CFC 2001 and with a delay of about 250 years also in profile CFD 2001. The vegetation changes in the cores CFB 2001, CFC 2001 and CFD 2001 show a tendency towards drier surface conditions as shown by the presence of higher UOM values Ericaceae and Monocotyledons, whereas in contrast to this in core CFA 2000 there is a shift towards a much wetter environment indicated by the dominance of *S. papillosum* and Monocotyledons which include *Rhynchospora alba* and *Menyanthes trifoliata*. These tendencies are also clearly visible in the DCA diagrams of all cores from Cors Fochno (see Figures 5.62, 5.64, 5.66 and 5.68).

In the profiles CFB 2001, CFC 2001 and CFD 2001 the change after 1100 is from the dominance of *S. papillosum* and Monocotyledons towards the prevalence of UOM, Ericaceae and Monocotyledons. This change could be interpreted as a result of the medieval warm period (MWP). However since no analysis of multi proxy records was applied, further evidence to support this assumption from other proxies such as testate amoebae analysis or humification analysis is not available. The further vegetation succession in those three profiles is remarkably similar but there seems to be no clear reaction to the little ice age (LIA). It may be that due to human impact that the vegetation did not react to the climatic change with an increase in lawn and pool Sphagna, but shows rather signs of slightly drier conditions. This is indicated in Figure 7.11 by the dominance of Sphagna which tolerate lower water tables and in the following vegetation change points also rather towards 'drier' vegetation indicated by the dominance of UOM and Ericaceae in the macrofossil assemblage. As reported by Colyer (1977), drainage ditches were present before the start of more extensive drainage on Cors Fochno.

It is possible that the lack of a reaction to the LIA enabled *S. austinii* to survive on Cors Fochno, since Stoneman *et al.* 1993 as well as Mauquoy and Barber (1999) have argued that LIA pool formation displaced *S. imbricatum* (*austinii*) on bogs in Cumbria. The only case where *S. austinii* is replaced by *S. papillosum* is in profile CFA 2000, which seems to be generally much wetter than the other three profiles.

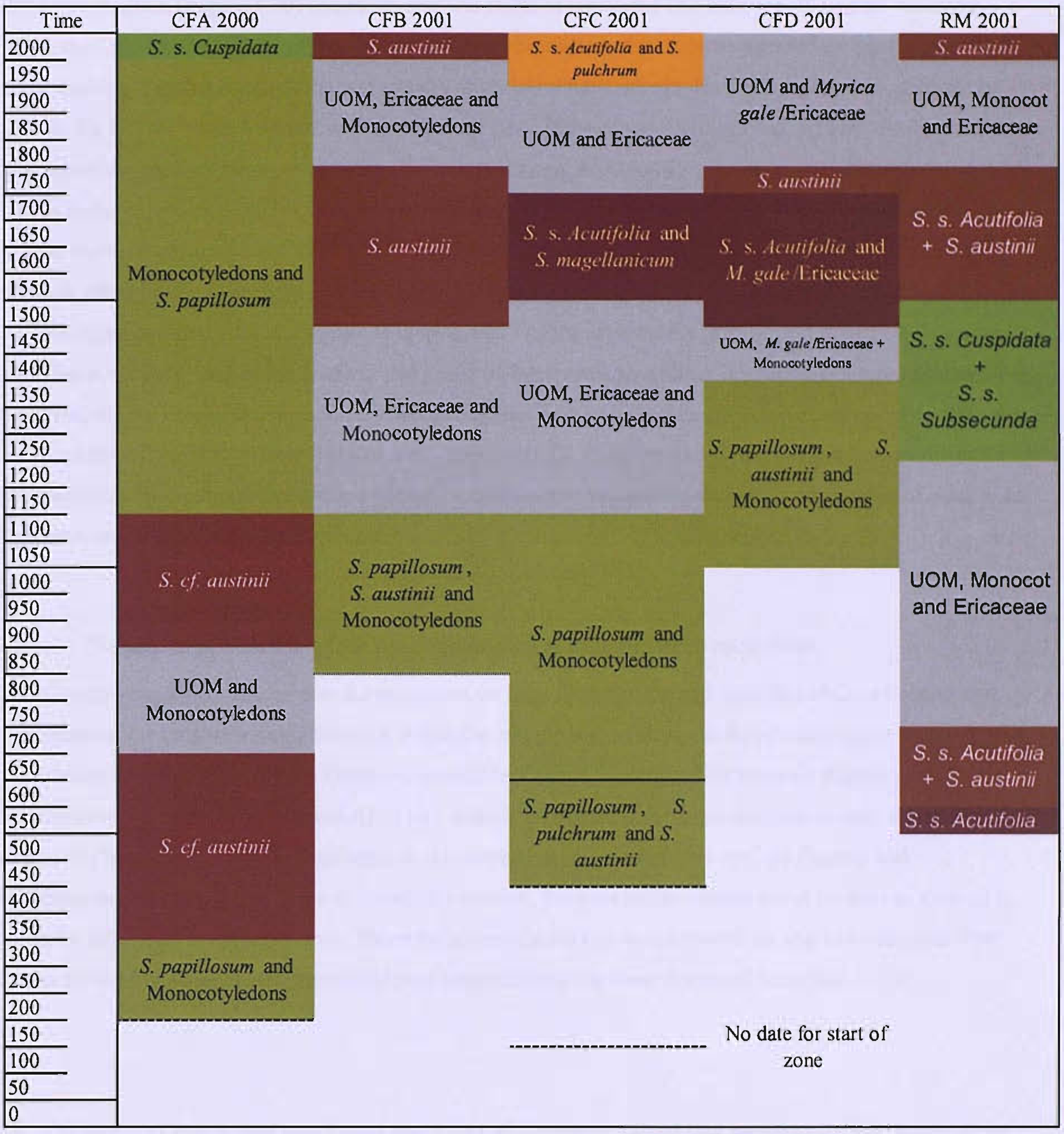

Figure 7.11: Time-vegetation model showing the succession of vegetation units on Cors Fochno (the line above each century marks its end).

7.3.4.2 The history of peat accumulation at Raheenmore Bog

The history of peat accumulation and vegetation succession on Raheenmore Bog is presented in the Figures 5.26 and 5.42 in chapter 5. In contrast to the Welsh study sites, *S. austinii* is not associated or alternating with *S. papillosum* on Raheenmore Bog nor does it alterate with *S. papillosum*. In fact, *S. papillosum* does not appear at all within the macrofossil record. *S. austinii* occurs regularly together with *S.* s. *Acutifolia* in the zones RM-I, RM-II, RM-IV and RM-VI (see Figure 5.42). However, it could be that the potential phase, where *S. austinii* is associated with lawn and pool *Sphagna* is situated in the deeper peat layers, which are not covered by the core.

The DCA diagram (Figure 5.70) shows several wet shifts of which the one between 70 and 80 cm could reflect the LIA. Unfortunately, it is not clear which of the two top radiocarbon dates of the profile are out of range, making it difficult to link the wet and dry shifts to climate change. However, if the date at 80 cm is correct, the wet shift above 90 cm should reflect the LIA. If the other date is correct, it is not easily possible to interpret the gradient changes in terms of climatic change. Additionally, the most recent dry shift could be similar to the record on Cors Fochno, reflecting human interference. Raheenmore has been marginally cut and the work of van der Schaaf (1999, 2000) gives evidence that marginal drainage has had a substantial negative effect on the hydrology of Raheenmore Bog. A comment needs to be made on the degree of wetness expressed in the DCA diagram (Figure 5.70). The top layer of the profile, dominated by *S. austinii* is placed at the dryer end of the gradient that could be interpreted as a rather dry hummock environment. However, the core originates from a very wet *Sphagnum* lawn, which appears to be in contradiction with the results of the DCA. This implies that dry and wet shifts in DCA diagrams are relative within the core and 'wet' and 'dry' between different cores should be cautiously compared as well as interpretation of what is a hummock and what a hollow environment.

7.3.4.3 The peat accumulation of the investigated sites in comparison to each other

When comparing the history of peat accumulation on Cors Caron compared with that of Cors Fochno and Raheenmore, the most obvious difference is that the two latter sites show no feature equivalent to the Retardation Layer on Cors Caron. Despite a general tendency in most profiles towards slightly drier environmental conditions after about AD 1100, there is no evidence for a deceleration in peat accumulation similar to Cors Caron. There is a variation in the average accumulation rates at Cors Fochno and Raheenmore Bog, ranging between c. 7 and 29 years/cm, but peat accumulation never became as slow as in the Retardation Layer of Cors Caron. There the accumulation rate was between 30 and 124 years/cm. The reason for the big difference in the rate of peat accumulation has been discussed in section 7.3.1.

7.4 Pathways of vegetation succession and rates of change in raised bog community development on Cors Caron compared to Cors Fochno and Raheenmore Bog

In this section the pathways and succession rate over the last two millennia as well as the most recent vegetation development in the 20th century will be discussed. At this stage the palaeoecological approach applied in this project can be linked with modern vegetation mapping. The pioneering work of Godwin and Conway (1939) enables a study of the vegetation development at the Cors Caron West Bog over the past sixty-five years. Few studies have attempted to study the difference between sub-fossil mire assemblages and their equivalent modern communities. However, the vegetation survey by Godwin and Conway (1939) as well as the re-survey in 2001/02 involved a much larger area than the nine cores representing the vegetation development in the past 2000 years. The number of species enclosed in a core of a few cm^2 is not adequate to compared with that of the 5×5 or 3×3 m quadrats used in both vegetation surveys on the West Bog. Additionally, the process of preservation and peat formation is selective, depending on the plant material itself and the environmental conditions (a comprehensive overview of peat formation and interpretation of the macrofossil record is given in chapter 2, section 2.3). Consequently the macrofossil diagrams may not reliably reflect the full rage of species present in the original vegetation community. Thus, it is very difficult to reconstruct the former vegetation communities and to assess reliably the spatial change in vegetation and biodiversity over such a large area over a long time span. Whilst acknowledging these problems, an attempt is made to draw the major trends in the vegetation succession over the last two millennia and to link it with the most recent vegetation development.

In the last two millennia covered by the macrofossil record, the most important change throughout Cors Caron is the alteration from *Sphagnum austinii* dominated vegetation to 'drier' communities, dominated by vascular plants and the simultaneous disappearance of *S. austinii*. Additionally, this peat layer is highly humified. Highly humified peat layers are linked to a decreased surface wetness. Such changes are often used to reconstruct palaeo-climatic conditions (Blackford and Chambers 1993). The 'dry' horizon is spatially the most extensive one, occurring in all three peat domes of Cors Caron. The extension of this change was already noticed by Godwin and Conway (1939; the Retardation Layer). This process of slow peat accumulation combined with a change in vegetation starts on the three bogs at different times and affects the eastern and northern margins of the West Bog earlier than the centre and western parts (the Regeneration Complex). In Figure 7.12 the dominating macrofossils of the longer profiles are plotted against a time scale in order to show, which vegetation units occurred simultaneously on the different parts of the bog complex.. From Figure 7.12 it becomes obvious that the change towards 'drier' vegetation communities of the Retardation Layer occurred much earlier in TWC 2000 and TWD 2000 when compared to TRWA 2000. In the profiles TWC 2000 and TWD 2000, the shift occurs at about the second century cal. BC. In profile TRWA 2000, in the Regeneration Complex, the change in the macrofossil assemblage towards a highly humified peat layer with more vascular plant remains starts in medieval times.

Figure 7.12 also indicates that throughout the past two millennia different vegetation units occurred at the same time on the different parts of Cors Caron. For example, at *c.* 800 AD in TWC 2000 Ericaceae and Monocotyledons were dominant whereas in TRWA 2000 *S. austinii* and *S. papillosum* dominated. In Figure 7.13 the short cores are shown, which were not radiocarbon dated and it is therefore not possible to plot them against the same time scale. However, they underpin the existence of a diversity of vegetation units throughout time. Since the number of cores is very small it can be assumed that more cores in different parts of the bog would probably diversify the picture even more.

As pointed out before, the eastern and western margins, and later the centre of the west bog were occupied by communities dominated by vascular plants (Ericaceae and Cyperaceae). This and the high UOM content in these peat layers, associated with somewhat higher numbers of *Cenococcum* fruit bodies point towards a drier bog surface and more fluctuating water tables. With peat cutting becoming more intensive at the beginning of the 20th century, the ongoing process of drying out was probably reinforced and the water tables fluctuating ever more, especially on the margins and the centre of the West Bog. Godwin and Conway (1939) found that the water table in summer was much lower in the Molinietum than in the other communities (see Figure 7.5). Gore and Urquhard (1966) found that *Molinia* becomes more competitive against *Eriophorum vaginatum* in habitats where the water tables are fluctuating, whereas *E. vaginatum* gains advantage in habitats with a high and stagnant water table. Together with higher inputs of atmospheric nitrogen from the beginning of the 20th century this could have enabled *Molinia* to colonise the mire expanse and to replace the former wet heath vegetation in the same way as it did in many upland heaths during the past couple of decades (Chambers *et al.* 1999).

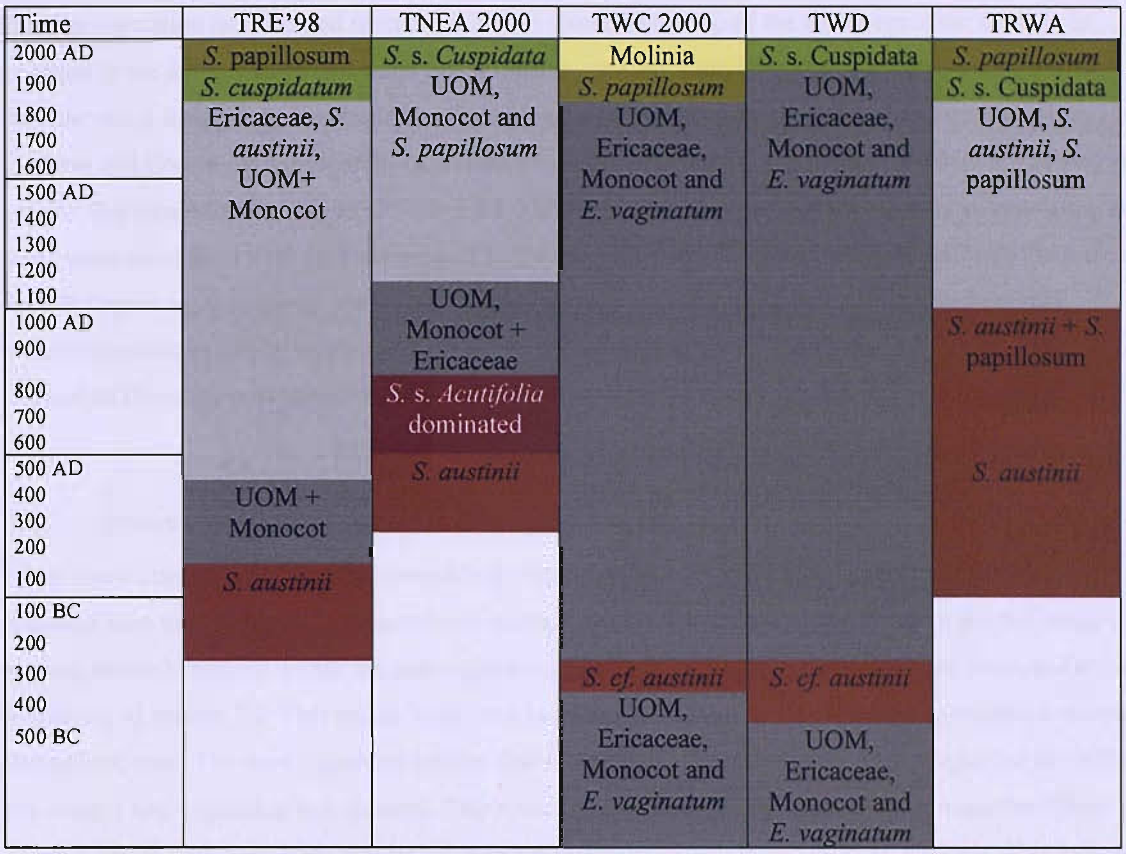

Figure 7.12: The succession of vegetation units on the long cores of Cors Caron.

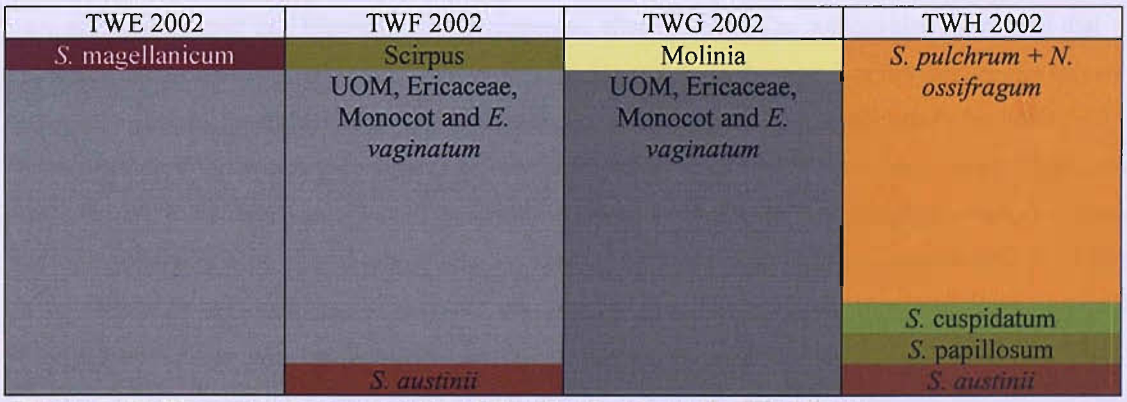

Figure 7.13: The vegetation succession of the short cores on the West Bog.

7.4.1 Scale and rate in vegetation change over time

In order to facilitate the comparison of the vegetation succession with respect to time, time-vegetation models of Cors Caron and Cors Fochno were established (Figures 7.11 and 7.12), showing the major changes in the macrofossil assemblages of all radiocarbon dated profiles from the sites. The comparison of the time-vegetation models shows, that on Cors Caron the rate of changes over the late Holocene was significantly slower than on the two other sites Cors Fochno and Raheenmore Bog. The time- vegetation models show much more clearly than the macrofossil diagrams that the Retardation Layer was formed over a time span of 1000 to 2000 years (Figure 7.12). In contrast to this the vegetation units on Cors Fochno and Raheenmore bog changed frequently after a few centuries. A similar development on all investigated sites is, that the vegetation has changed recently, which is shown in the top of the time-vegetation models. In contrast to the development of the last two millennia, on Cors Caron the rate of vegetation change has become much faster. From the macrofossil diagrams of Cors Caron compared to the vegetation survey by Godwin and Conway (1939) it appears that the vegetation communities present in 1936/37 are of very recent origin. The comparison of the 1936/37 and 2001/02 vegetation surveys indicates that these vegetation units were more short lived than the ones present in the last 2000 years. This can be explained with the increased human impact on Cors Caron within the 20th century and with this impact continuing further rapid vegetation changes can be expected in the future. However, the kind and direction of these changes will depend on the success of restoration management.

7.4.2 Presence and loss of species in the macrofossil record

Most species occurring within the current bog vegetation have been found as macrofossils. However, although they may preserve, the macrofossil assemblage in each sample may not reflect the full range of species formerly present within the past vegetation communities for reasons which were discussed at the beginning of section 7.2. This makes it difficult to assess the loss of species from the macrofossil record throughout time. The most important species that is present in the macrofossil assemblages but not within the current bog vegetation is *S. austinii.* This species often dominates peat layers over centuries. Other species, which may have been present but rare are difficult to track by macrofossil analysis. This includes *Osmunda regalis* and *Rhynchospora fusca* which were present in the past bog vegetation but do not appear within the macrofossil record. From the publication of Godwin and Conway (1939) it is apparent that they were part of the raised bog vegetation but disappeared after 1936/37. The authors also mentioned that *Potentilla erecta* was present within *Molinia* dominated patches on the west bog but this species can be difficult to track by macrofossil analysis (although the seeds preserve quite well even in fen peat). *Narthecium ossifragum* is still common on Cors Caron but no macrofossils have been found, which may be due to the fact that the species, like *O. regalis* and *R. fusca* was not dominant, which decreases the chance of finding it within the macrofossil assemblage. *N. ossifragum* peat is known from Scandinavia and northwest German raised bogs (Overbeck 1975) which indicates that the species may be preserved depending on its importance within the bog vegetation and the preservation conditions. Another species which is present on Cors Caron (see Figure 6.9.f) but did not appear in the macrofossil record is *Empetrum nigrum.* Furthermore Morriss (2001) found small amounts of *Empetrum* pollen throughout profile TRE'98, indicating that the species was present on Cors Caron in the last two millennia. The absence of *Empetrum* from the macrofossil record can by explained with the same reasons as for the previous species. *Empetrum nigrum* too was not abundant enough to be tracked by a 4cm diameter for macrofossil core. Additionally, the species preferably occupies the tops of high hummocks where the conditions for preservation are not optimal. Coulson and Butterfield (1978) found that ericaceous remains were preferentially eaten by soil animals decreasing the chance of the species' preservation.

7.4.3 History of *Sphagnum austinii*

Sphagnum austinii was the main peat former in many Atlantic raised bogs over the mid-to late Holocene (Barber 1993), but has vanished from most raised bogs (Godwin and Conway 1939, Green 1968). Its decline started before the medieval age and continues to the present day. Many reasons for its decline have been discussed but it seems that each possible reason accounts only partly for the retreat of the species. The current situation of *S. austinii* is different on Cors Caron, Cors Fochno and Raheenmoor, which may provide further information to add to the debate about its decline. An overview of the literature dealing with this issue is given in chapter 2, section 2.6.1.

There is still confusion regarding the species/subspecies of the *S. imbricatum* complex which formed the bulk of peat in the mid- and late Holocene. There are hardly any studies which have tried to determine the subfossil *S. imbricatum* down to *S. austinii* or *S. affine*, which adds to the confusion since it is not known to what extent both species contributed to peat formation. Stoneman *et al.* (1993) propose that the bulk of the peat was formed by the wet ecad of *S. imbricatum* ssp. *austinii*, which changed its ecology from a lawn inhabitant to a hummock forming *Sphagnum* for yet unknown reasons. Thingsgaard (2002) doubts the suggestions by Stoneman *et al.* (1993) and suggests that the subfossil *S. imbricatum*, associated with more hydrophilous *Sphagnum* species such as *S. auriculatum*, could be *S. affine*. However, the findings within this project do not support Thingsgaards assumption, but back Stoneman's proposal. The core of Raheenmore Bog was taken from a wet lawn consisting of *S. austinii*. In all cases where the determination was made, the subfossil material was identified as *S. austinii* (for details of determination see section 4.4.3.3).

The history of *S. austinii* is different in all investigated sites of this project. At Cors Caron the species disappeared after cal. AD 1444-1635. Godwin and Conway (1939) report that despite a prolonged search, no living *S. imbricatum* (*austinii*) was found during their fieldwork in 1936 and 1937. As *S. austinii* is the dominant *Sphagnum* species over most of the investigated time-span in all long cores (this conclusion can be made because it was identified down to species level in this PhD project). The macrofossil diagrams established by Hughes (1997) and Haslam (1988) suggest that it was the main peat former on Cors Caron throughout the entire mid- to late Holocene. The species abundance declined sharply at the beginning of the slow down in peat accumulation, which starts at all three raised bogs of the mire complex at different times. The start of *S. austinii*'s decline is not synchron with a single event. However the decline of the species seems linked with increasing dryness, indicated by higher amounts of Ericaceae remains, *Cenococcum* fruit bodies as well as Monocot.–, *E. vaginatum* rootlets and UOM (see Figures 5.29: zone TRE III, 5.30: zone TNEA III and 5.31: zone TRWA IV). *S. austinii* persists in traces in all cores sampled on the crown of the bogs and TWD 2000 throughout the period of slow peat accumulation. This implies that, the falling water tables must have had an adverse effect on *S. austinii*. Even if the species was able to withstand more extreme dryness than other Sphagna (Green 1968), and did persist throughout the dry phase in its compact ecad, the dryness would have had adverse effects on the species. Dry periods give a competitive advantage to vascular plants such as Ericaceaeous shrubs because of their water conducting system is more developed than that of Sphagna (Malmer *et al.* 1994). Thus it may be that vascular plants represented serious competition to *S. austinii*, especially since most Ericaceae as well as *E. vaginatum* endure high water levels but also thrive better under slightly drier conditions (Gimingham 1960, Bannister 1966, Wein 1973). Additionally, the shading of dwarf shrubs has a negative affect on *Sphagnum* growth (Hayward and Clymo 1983). This is supported by the profile CFD 2001, at Cors Fochno, where *Myrica gale* grows on top of a former *S. austinii* spot, displacing not only the *S. austinii* but also the associated *S.* s. *Acutifolia.* On the Cors Caron summits the start of the decline of *S. austinii* occurs at different times, whereas its disappearance occurred within a narrower time span (TRE'98 – after *c.* AD 1200, TNEA – *c.* AD 1100, TRWA2000 – *c.* AD 1500) . The species disappeared towards the end of a dry phase in most cores before the onset of the 1800's. A possible factor for its final disappearance could be a climatically induced increase in surface wetness at the end of the Little Ice Age (LIA) as pointed out by Mauquoy and Barber (1999a). At all three summit cores as well as core TWH 2002 the species is replaced by either *S. cuspidatum* or *S. papillosum,* which both thrive in very wet habitats. If the surviving patches of *S. austinii* had a depleted genetic diversity, as found by Thingsgaard (2002) this may have enforced the extinction on Cors Caron, with the remaining *S. austinii* not flexible enough to react to a changing environment and new competitors. At Cors Caron, dryness possibly contributed to the decline of the species, which could also have been a factor promoting burning. As Barber (1981) pointed out, the black amorphous peat layer suggests the presence of fire. Repeated burning additionally has an adverse effect on *S. austinii* as known from Cors Fochno in recent time (Slater 1972). The factor finally enforcing the disappearance of the species is likely to be climatically induced wetness as it was the case in Cumbrian raised bogs, described by Mauquoy and Barber (1999a), Blundell in press, Hughes *et al.* (2000).

At Cors Fochno *Sphagnum austinii* is still present but confined to a number of high hummocks. These hummocks have been monitored over the 1960's by Johnston (1970) and the 1970's by Slater and Slater (1978). The results of both studies showed that the *S. austinii* hummocks were adversely affected by burning and that the species is in decline on Cors Fochno. However, Slater and Slater (1978) point out that the decline is due to external factors such as fire and water table changes, which can be considered as anthropogenic. The authors consider further that *S. austinii*, if left undisturbed, still has the potential to recover. A more recent survey conducted by Hale in 1992/93 resulted in the discovery of only two *S. austinii* hummocks (Hale 1993). Later, more systematic continuous surveys (Newton 2000) lead to the detection of six *S. austinii* hummocks and the most recent number of known *S. austinii* spots is 19 (Mike Bailey, personal communication). This latest higher count of *S. austinii* hummocks is probably a result of higher quality survey than a spread of the species.

In contrast to Cors Caron, *S. austinii* shares the position as major peat former with *S. papillosum* on Cors Fochno throughout the investigated time period. It is dominant throughout core CFA 2000 (Figure 5.36) but occurs very little in CFC 2001(Figure 5.38). In CFB 2001 (Figure 5.37) *S. austinii* is dominant on the top of the profile but in the course of the core it occurs in alternation with *S. papillosum*. In core CFD 2001 it is associated with *S. papillosum* and becomes dominant in the uppermost (Figure 5.39). In all cores from Cors Fochno, the species is associated with *S. papillosum* and *S.* s. *Cuspidata* (especially in the lower zones of the profile). By contrast, towards the top of the profiles, *S. austinii* is either associated or alternates with *S.* s. *Acutifolia*. This is in accordance with the findings and suggestions of Stoneman *et al.* (1993). The authors likewise found that in the past *S. imbricatum* (cf. *austinii*) was associated with *S.* s. *Cuspidata* in wet lawn environments on Cumbrian raised bogs. By contrast, today the species mostly occupies the tops of high hummocks. Stoneman *et al.* (1993) concluded that the species disappeared earlier from lawn environments and persisted longer on hummocks, which was also found by Barber (1981). This could indicate that at Cors Fochno the dry ecad of *S. austinii* was able to deal with lower water tables since it competes in the upper parts of the profiles with *S.* s. *Acutifolia* (which are more tolerant to lower water tables than *S.* s. *Cuspidata* or *S. papillosum*). It may also be possible that the increased presence of *S.* s. *Acutifolia* indicates early attempts at drainage, at least around the bog. Although serious drainage attempts on Cors Fochno were not made before 1813, a publication by Colyer (1977) mentions the existence of older drainage ditches around the bog margins. It is very likely that the local population used peat from the margins as a fuel throughout the time span covered by the cores. However, to associate *S. austinii* co-existing with *S.* s. *Acutifolia* species automatically with a hummock environment has to be treated with caution. *Sphagnum* s. *Acutifolia* has been found growing in mixed *Sphagnum* lawns together with more hygrophilous Sphagna, indicating that it also thrives in lawn conditions (for example see Figure 5.40, zone CFC Vb). Field observations by the author found different *Sphagnum* species of the section *Acutifolia* (*S. rubellum*, *S. fuscum* and *S. subnitens*) associated with wet lawn conditions in various raised bogs across Europe.

The lower water tables resulting from drainage, peat excavation and burning had a negative effect on the peat forming vegetation of Cors Fochno as reported by Evans (1950). Also in the report by Taylor (1974) a vegetation map indicates that over large areas of the bog *Molinia caerulea* and Ericaceaeous shrubs had a higher ground cover. A further matter of concern was the fact that *Myrica gale* covers many hummocks and was seen as a potential threat to the remaining *S. austinii* hummocks. On Cors Fochno both species seem to occupy the same ecological niche, reflected in the Figures 5.39 zone CFB-V which is on of the remaining *S.austinii* hummocks and Figure 5.42 zone CFD-V representing a hummock too. The DCA of the macrofossils in Figures 5.62 and 5.64 shows that both species occur toghether at the dry end of the gradient. That these concerns are justified is supported by the macrofossil diagram of core CFD 2001. In zone CFD IV *S. austinii* is dominant but in the following zone (the top zone) it becomes overgrown by *Myrica gale*.

On Raheenmore Bog *S. austinii* is reported to occupy hummocks (National Parks and Wildlife Service 1997[14]). However, at the coring location the species formed a very wet lawn. The macrofossil diagram (Figure 5.42) shows that at this site *S. austinii* is associated with *S.* s. *Acutifolia* (mostly *S. rubellum*) throughout most of the core. In the lower zones of RM 2001 the species less well represented as a peat former, with *S.* s. *Acutifolia* being the main peat former. By contrast, the top 40 cm of the core are absolutely dominated by *S. austinii*, with *S.* s. *Acutifolia* retreating. These observations raise additional questions because the species reacts rather differently than on most other sites. Instead of declining it seems to expand despite the presence of *S. magellanicum* on the site. The results from Raheenmore Bog could support the assumption by Green (1986) that the wet ecad of *S. austinii* may be often overlooked. One reason for this is that in a lawn environment *S. austinii* looks very much like *S. papillosum* in the field. When choosing the core location it was assumed to be a *S. papillosum* lawn and the identification of *S. austinii* in the laboratory came as a big surprise. However, if the species occurs still in its wet ecad, this means that, at least on Raheenmore, *S. austinii* has not changed its ecology as suggested by Stoneman *et al.* (1993).

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[14] http://www.duchas.ie/ie/LSCannaLCSannaLONanna/LSCLCSEolas/UibhShaile/d5864.ie.v1.0.t4.html

After looking at the site-specific history of *S. austinii* on the investigated raised bogs it is also worth considering the history of its main competitors, *S. magellanicum* and *S. papillosum*. On many raised bogs in Cumbria, Scotland and Northern Ireland *S. austinii* was outcompeted by *S. magellanicum* and also *S. papillosum.* (Mauquoy and Barber, 1999a,b, Langdon 1999, Hughes *et al.* 2000, McMullen *et al.* 2004). Table 7.3 gives an overview of the *Sphagnum* species replacing *S. imbricatum (austinii)*. Mauquoy and Barber (1999a) point out that there are no records on British raised bog peat of high *S. magellanicum* quantities before the decline of *S. imbricatum (austinii*). By contrast, in West German raised bogs *S. magellanicum* was an abundant peat former throughout the mid- and late Holocene (Overbeck 1975). In all three study areas the role of *S. magellanicum* is very different from that in many other parts of the British Isles. *S. magellanicum* appears on all the study sites in the macrofossil record in the younger peat but never became important as a peat former. It is interesting that *S. magellanicum* behaves at Cors Caron like *S. austinii* at Cors Fochno: it is confined to high hummocks of rather young age and seems not to expand. Its minor presence at Cors Caron was also mentioned by Godwin and Conway (1939, p. 328): "*Important also is the presence of S. medium, since this species is the main peat builder in many other raised bogs. That it does not play this part at Tregaron is evidently due to local conditions and not to the chance absence of parent plants.*" The authors do not explain further which local conditions they refer to but their observations of the ecology of *S. magellanicum* are congruent with those made during the re-survey Godwin and Conway (1939, p. 358) state that: "*It is here limited as an active tussock-former to certain parts of the Regeneration Complex.*" The presence of *S. magellanicum* does not necessarily imply the spread of the species. Hill *et al.* (1992) points out that *S. magellanicum* produces capsules rather rarely, on bogs where the species is abundant. This must have been different in the past. Looking at the pattern of its occurrence in Britain there seems to have been a widespread invasion by *S. magellanicum* in parts of Western Europe and the British Isles which can only be explained by intensive spore production. McQueen (1987) found that *S. magellanicum* protonemata grew faster than those of other species in a trial, which could explain why it spread rapidly in many bogs. However, at present *Sphagnum magellanicum* protonemata have been rarely observed in the field and phosphorus concentrations are considered insufficient for spore establishment (Sundberg and Rydin 2002). This implies that in the past conditions must have been favourable for the establishment of *S. magellanicum* via sporulation. Among the substrates enhancing spore germination the authors used were animal dung and *Sphagnum* ash. This could imply that grazing and burning of raised bogs, factors, which negatively affect *S. austinii*, may have had an influence in the establishment of *S. magellanicum*. It is worth noting that *S. austinii* does not occur in association with *S. magellanicum* in the British Islands, whereas it did in Northwest Germany over longer time periods (Overbeck 1975). By contrast, *S. papillosum* often grew together with *S. austinii* on Cors Caron and Cors Fochno. Both species co-existed (at TRWA 2000 four about thousand years, CFA 2000 ca. 600 years) or alternated over longer time-scales, with *S. papillosum* finally displacing *S. austinii*. This could be explained by the fact that, although *S. papillosum* also grows faster than the wet ecad of *S. austinii*, it was the slowest growing of the other species in Green's experiment (Green 1968).

It can be concluded that the history of *S. imbricatum* (*austinii*) is very different on the investigated raised bogs, which all are affected by hydrological disturbance. Its history is also different from many other raised bogs in Britain and parts of Ireland where the species was replaced by *S. magellanicum* or *S. papillosum*. Part of the answer could be that the different *S. austinii* populations on the present study sites may have a different range of genetic diversity, enabling the surviving populations to react to changing environmental conditions. The extinction process might be enforced by a depleted genetic diversity within the species.

Table 7.3: *Sphagnum* species which were associated with *S. austinii* at the same time.

Core/site	Accompanying *Sphagnum* species	Decline date and dismissing factor	Disappearance date + dismissing species
TRE'98	in phases with few UOM with somewhat *S. cuspidatum*, with more UOM *S.* s. *Acutifolia*	At ca. BC 170 – AD 60 due to rise in UOM, Monocot. rootlets	At about 1800 by *S. cuspidatum*
TNEA 2000	*S.* s. *Acutifolia*	Ca. AD 690-893 by high UOM and Monocot. radicell amounts	At modern times by *S. papillosum*
TRWA 2000	Somewhat *S. Acutifolia* and *S. papillosum* +*S. cuspidatum*, partly all three species together	Ca. 1000 by high UOM and Monocot. rootlet amounts	At ca. 1800 by *S.* s. *Cuspidata* (*cuspidatum*)
TWC 2000	None	Ca. BC 383-171 by high amounts of UOM, Monocot. rootlets and *E.* vaginatum rootlets	Ca. BC 383-171 by high amounts of UOM, Monocot. rootlets and *E.* vaginatum rootlets
TWD 2000	None	Ca. BC 379-119 by high amounts of UOM, Monocotyledon rootlets and *E.* vaginatum rootlets	At modern times *S.* s. *Cuspidata* (*cuspidatum*)
TWF 2002	*S.*s. *Acutifolia*, *S. papillosum*	Medieval (?)by high amounts of UOM, Monocotyledon rootlets and probably Ericaceae (high numbers of *E. tetralix* seeds)	Modern (SCP) by *Scirpus caespitosus* remains
TWH 2002	None	No date available but presumably medieval	Modern (SCP) *S. papillosum*
CFA	Mainly *S. papillosum*	After *c.* AD1400	Increase in Monocot rootlets (possibly R. alsba+ *S. papillosum*
CFB	Mainly *S. papillosum*, *S. Cuspidata*	Temporary decline at about 1667 due to increase in UOM, Ericaceae rootlets and Monocot rootlets	*S. austinii* present at the surface
CFC	*S.* papillosum	*c.* AD 430-620 by *S.* papillosum	Between medieval and modern by *S.* magellanicum
CFD	*S. papillosum*, *S. Acutifolia*	Medieval; due to increase in UOM, Ericaceae rootlets and Monocot rootlets	Modern (after SCP sub-surface peak) by *Myrica gale*
RM 2001	*S. Acutifolia*	Temporary declines troughout the profile due to increase in UOM, Ericaceae rootlets and Monocot rootlets	*S. austinii* present at the surface

Thingsgaard (2002) investigated the genetic similarities of the *S. imbricatum* complex and points out that the very low genetic diversity in *S. austinii* populations is remarkable as well as alarming from a conservation point of view. The author also raises the question why *S. austinii* has become genetically depleted to such an extent. She explains that it could have been possible that the species, re-establishing from refugia in the former glaciated areas, was forced to retreat again during extreme climate fluctuations in the early-Holocene. This would have lead to a serious reduction of populations. In the late Glacial and early Holocene there were few places where this oceanic species could thrive because there were not many ombrotrophic environments with the exception of Ireland (Thingsgaard refers to Mitchell *et al.* 1996). During further migration *S. austinii* could have been dispersed over large areas becoming subject to severe founder effects which include the loss of alleles and excessive homozygosity (for definition see chapter 1, section 1.4). Thingsgaard concludes cautiously that *S. austinii* as a slow growing species with a narrow ecological niche has declined throughout Europe, because genetic depletion has made it unfit to react to environmental changes. Additionally, it seems that there are many other different factors involved in the decline of *S. austinii*, which are also locally variable. For example, in the Pennines the level of pollution is considered to have driven the disappearance of *S. imbricatum* (*austinii*) (Clymo and Hayard 1982). At Cors Fochno, burning and draining accelerated the decline of the species. It may well be that anthropogenic influence accelerated a naturally ongoing process.

8 Conclusions and further research

8.3 Conclusions

The vegetation development on Cors Caron since at least 1936/37, as well as the current poor condition of the vegetation of the Cors Caron West Bog suggest strongly that the peat forming vegetation is suffering from drying out. The dry stage of the Cors Caron West Bog is linked with the absence of a properly developed acrotelm, which is vital for hydrological self regulation of raised bogs. The process of rapid deterioration during the 20th century was probably reinforced by human impact such as peat cutting, which enabled the spread of species which are normally not components of raised bog vegetation

The examination of the history of peat accumulation on Cors Caron confirms the presence of a phase of much slower peat accumulation, the Retardation Layer, present in all three peat domes of Cors Caron. The Retardation Layer appears between *c.* 300 BC on the margins of the West Bog and with some delay on the Southeast Bog centre in *c.* 60 AD. On the margins of the mire expanse there are no data available due to removal of the peat, but if the pattern follows that of the West Bog, then the Retardation Layer may have begun earlier than *c.* 60 AD here as well. The start of the Retardation Layer may be linked to a phase of low effective precipitation reported from other sites in Britain and Western Europe. The formation of the Retardation Layers suggest that the Cors Caron is particular sensitive to disturbances that affect the bog water tables because the bogs reacted by ceasing to form peat rather than switching to hummock peat accumulation. Once the acrotelm of the bogs was degraded, the bogs did not react any further to regional climatic changes such as the onset of the Little Ice Age, which is usually well represented in raised bog peat stratigraphy. Possible causal factors for the very pronounced deceleration in peat accumulation may be determined by the local geomorphology involving changes in the river channel of the Teifi and the spatial restriction of lateral bog expansion by the hillsides of the valley. Additionally, early marginal peat cutting and burning might have contributed to the formation of the Retardation Layer, but there is little evidence for these latter factors.

By *c.* 1800 a pool system began to form on the West Bog but this has now disappeared. Evidence from the macrofossil record suggests that the pool system was possibly a response to the latest phase of the LIA. It is possible that the loss of the acrotelm on parts of Cors Caron West Bog appears to have prevented pool development during the earlier part of the LIA.

The other two study sites Cors Fochno and Raheenmore Bog have a different history of peat formation compared to Cors Caron. Accumulation rates were faster than on Cors Caron and despite a tendency towards slightly drier surface conditions in both raised bogs, there is no comparable deceleration in the rate of peat accumulation as on Cors Caron. The slight increase in dryness could be caused by human impact such as drainage and marginal peat extraction.

The comparison of the pathways of vegetation succession shows, that the succession rate on Cors Caron was much slower over the last two millennia than on Cors Fochno and Raheenmore Bog. On Cors Fochno, three profiles show remarkable similarity in their vegetation succession. However in recent times changes in all three investigated sites exhibit an acceleration in vegetation change. It is assumed that the current vegetation communities are probably less stable than the ones present throughout the past and further rapid change can be expect if the raised bogs remain exposed to human impact.

Most species, which occur in the current raised bog vegetation have been found as macrofossils. However some species such as *Narthecium ossifragum*, *Empetrum nigrum* and *Rhynchospora fusca*, have not been found as macrofossils, highlighting the losses that occur during the preservation of macrofossil assemblages.

Most of the *Sphagnum imbricatum* remains investigated in this project can be identified as *S. austinii*. The species is frequent and sometimes dominant in the macrofossil assemblages but it its record is not continuous and it is not the major peat former in Cors Caron, Cors Fochno and Raheenmore bog. It shares its position as a main peat former with lawn and pool Sphagna earlier in the investigated time span and is associated with Sphagna of the section *Acutifolia* towards the top of many of the investigated profiles. An examination of the history of *S. austinii* supports suggestions in the literature (Stoneman *et al.* 1993) that *S. austinii* disappeared after the onset of wetter conditions on Cors Caron. However since it survived on other sites, it has to be regarded that apart from climatic factors and competition by other species (*S. magellanicum*) that the genetic fitness/diversity of the species may be different on the investigated sites and may also play an important role regarding the survival or disappearance of *S. austinii* on each site/region.

Sphagnum magellanicum does not appear in Britain before the widespread disappearance of *S. austinii*. An invasion of Britain by *S. magellanicum* probably occurred in the past, when the conditions for the sporulation of this species were suitable. The wide distribution may have lead to genetically depleted populations similar to *S. austinii*, which could explain why the species did not become dominant on Cors Caron and Cors Fochno although it appeared in the macrofossil record and is also present in the current vegetation. However, on Cors Caron *S. magellanicum* is confined to high hummocks, rather like *S. austinii*.

S. pulchrum and *S. cuspidatum* as well as *S. rubellum* and *S. subnitens* have almost mutually exclusive distribution on the West Bog of Cors Caron. This distribution pattern could be a result of inter-specific species competition between this closely related Sphagna occupying similar ecological niches.

8.2 Further research

8.2.1 Slow down in peat accumulation on Cors Caron

- The results of the macrofossil analysis on Cors Caron suggest that the slow rate in peat accumulation started earlier on the margins of the peat domes and later on the summits. Further research on this feature should include an examination of profiles taken along transects across each peat dome. Additional to macrofossil analysis and radiocarbon dating, testate amoebae analysis could be applied to refine the information on fluctuations in the water level across the bog complex. The results could provide further information about the history of the hydrology of Cors Caron and how far this influenced the shape of the raised water mound in all three bogs.

- Macrofossil analysis of areas known to be subject of frequent burning and areas without burning could help to assess how much charred material remains in the macrofossil record after the occurrence of fires.

- Since the SCP analysis of the short cores TWE 2002 to TWH 2002 does not provide sufficient information about their chronology, radiocarbon and lead dating of these profiles would enhance the results of this project and provide more information on the chronology of the phase of slow peat accumulation. In all dated profiles *S. austinii* disappears after the medieval times which would justify the radiocarbon dating of the rather shallow depths, where the species disappears from the macrofossil record in TWF 2002 and TWH 2002.

- Further short profiles should be taken from areas where the black amorphous peat layer occurs. A closer examination for evidence of burning could be applied to the transition where the black amorphous peat layer marks the disappearance of *S. austinii*. If fires occurred more frequently at the end of the dry phase this could indicate that burning could have been promoted by the increased dryness of the bog surface as also known from Cors Fochno. In this case fire could be also a causal factor for the disappearance of *S. austinii* from Cors Caron.

8.2.2 *Sphagnum* ecology

- Regarding the results of Thingsgaard 2002 it would be interesting to examine systematically the genetic diversity of *S. austinii* populations throughout Europe and to combine it with the history of the species throughout the Holocene. This research could provide information, as to whether there is a difference in the genetic diversity of *S. austinii* across Europe similar to the pattern seen in *S. rubellum* (Cronberg 1998). A genetic study could also highlight the potential refuges of *S. austinii* during the last glaciation. Thingsgaard (2002) mainly studied mainly populations from areas in

Norway. The same approach could be taken in other regions where the species still occurs including Ireland, Wales, Scotland and also Georgia. Dokturovski (1931) reported the presence of *S. imbricatum* (*austinii*) from raised bogs in the western Kolchis. During a visit in 1999 a core and surface samples were taken from the lowland raised bog Ispani near Kobuleti on the coast of the Black Sea. A macrofossil analysis of the core revealed that *S. austinii* forms almost exclusively the upper 4 metres of peat, after a phase where it alternates with *S. papillosum*. In the current surface vegetation it is still among the dominating Sphagna. Since the Kolchis may have importance as a potential refuge during the last glaciation, further research could provide information whether the genetic variability in potential refuges is higher than in regions where the species has become rare.

- A detailed research should be applied on burning and land-use history (compared with growth of population and livestock) on the sites where *S. austinii* disappeared. There may be links between the disappearance of *S. austinii*, the establishment of *S. magellanicum* and land use practice.

- The current study shows that *S. magellanicum*, which is the main competitor of *S. austinii* in many Cumbrian raised bogs did appear on the Welsh study sites but never became an important peat former. Research into the genetic diversity of this species over Europe could reveal, if the populations in Wales are subject to genetic depletion compared to those of other European regions.

- *S. pulchrum* and *S. cuspidatum* almost exclude each other in their distribution on the Cors Caron West Bog as well as *S. rubellum* and *S. subnitens*. Both pairs of Sphagna belong to the same section respectively and occupy the same microforms in bog habitats. Further research could investigate if these spatial exclusions of closely related Sphagna are the result of inter-species competition or not. This should include field studies investigating whether similar exclusions of closely related species also occur on other bogs. Additionally, growing experiments with the species in greenhouses under different ecological conditions could provide information on potential inter-species competition.

8.2.3 Human impact with respect to future development of *Molinia caerulea* and *Betula* spec.

- It is assumed that the currently high atmospheric nitrogen deposition supports the increase in *Molinia caerulea* and *Betula* spp. Measurements of the nitrogen input on both sites, Cors Caron and Cors Fochno could provide information about the specific amount of airborne nitrogen deposition on the sites and if it is potentially detrimental to the raised bog vegetation. Additionally it could be investigated if Cors Caron and Cors Fochno are still nitrogen-limited or if they have switched to phosphorus limitation.

- Bobbink *et al.* (1998), report that cutting the *Molinia caerulea* can help to restore moss growth . Experiments on both, Cors Caron and Cors Fochno could show, if cutting or controlled grazing can be applied in order to support the regeneration of *Sphagnum* in the areas where *Molinia* is currently dominant. If the trials are successful water level measurements could show, whether the water table fluctuations become less extreme with the re-establishment of a *Sphagnum* cover.

8.2.4 Monitoring of bog vegetation

- After the restoration activities on Cors Caron the re-established original quadrats from Godwin and Conway (1939) as well as the re-established grid could be recorded and analysed in several time-intervals in order to monitor future vegetation development and potential success of the restoration measures.

- A similar grid as on Cors Caron could be established on Cors Fochno in order to obtain more detailed information about the vegetation distribution and to monitor future vegetation development. With more sophisticated GPS devices now available this could possibly achieved with less effort than on Cors Caron.

Appendix

	D 0	D 50	D100	D 150	D 200	D 250	D 300	D 350	D 400	D 450	D 550	D 650
Betula + litter					1							
Calluna vulgaris	2	12	30	40	15	25	5	12	10	15	12	2
Erica tetralix	10	4	6	4	4	6	12	4	6	4	6	12
Empetrum nigrum			1	<1		2	6	<1		1	2	1
Andromeda polyfolia		3	3	4	4	4	6	6	4	4	4	5
Vaccinium oxycoccus		10	8	4	3	4	6	6	6	4	<1	6
Vaccinium myrtillus	<1				2	1	<1					
Drosera rotundifolia								<1		<1	<1	<1
Erio. angustifolium		<1	<1	<1	<1	<1	<1	<1	<1	<1	1	<1
Eriophorum vaginatum	3	8	8	8	10	18	18	25	12	15	20	8
Scirpus cespitosus	2	3	1	1	2	3	4	2	4	4	3	10
Rhynchospora alba		<1		<1	1				<1	<1		2
Narthecium ossifragum									1	<1		1
Molinia caerulea	45	5										
Total *Sphagnum*	**0**	**11**	**5**	**11**	**3**	**4**	**5**	**10**	**9**	**8**	**5**	**24**
S. subnitens		4	<1	1	<1	1	2	1				
S. rubellum			1					1		<1		1
S. papillosum		1	2	4	1		1	2	3	2	1	6
S. magellanicum								4	1	outside		
S. pulchrum				1					2	3	2	7
S. cuspidatum		4		3	1	1						
S. tenellum		2	2	2	1	2	2	2	3	3	2	10
Hypnum cupressiforme	10	8	8	8	10	8	10	10	10	10	12	2
Polytrichum strictum		<1										
Leucobryum glaucum		<1		4				2				
Odontoschisma sphagni	2	2	4	6	4	6	4	6	4	6	6	6
Cladonia portentosa	8	8	15	10	5	12	12	15	8	7	4	8
Cladonia ciliata										5	10	
Cladonia unicalis									<1		<1	
Cladonia cenotea		<1										
Cladonia fimbriata			<1	<1	<1	<1	<1		<1	<1		
Grid location	SN 68704 BNG 63881	SN 68658 BNG 63891	SN 68610 BNG 63103	SN 68561 BNG 63923	SN 68515 BNG 63939	SN 68466 BNG 63956	SN 68418 BNG 63971	SN 68371 BNG 63987	SN 68322 BNG 64000	SN 68251 BNG 64024	SN 68182 BNG 64045	SN 68083 BNG 64071

Appendix 1: Vegetation records of transect D.

	E 0	E 50	E 100	E 150	E 200	E 250	E 300	E 350	E 400	E 450	E 500	E 550	E 600	E 650	E 700	E 750
Betula + litter		3														
Calluna vulgaris	6	12	10	4	12	10	30	25	15	18	35	12	10	15	15	3
Erica tetralix	8	6	8	6	6	10	4	4	4	4	6	6	6	6	8	15
Empetrum nigrum				10	4	3	1	2		1	1		outside	outside	2	
Andromeda polyfolia	2	4	2	3	2	4	4	3	4	4	4	4	4	4	3	4
Vaccinium oxycoccus	1	2	4	4	6	8	4	6	4	8	3	4	6	4	6	2
Erio. angustifolium	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1			1
Eriophorum vaginatum	3	10	15	10	12	20	15	20	12	10	15	10	10	8	10	5
Scirpus cespitosus	3	2	3	2	1	4	3	3	1	8	3	2	2	4	3	3
Rhynchospora alba	<1		3		3	2	<1		2	<1	<1	1	<1	<1		20
Narthecium ossifragum					1		<1		4	2	1	<1	<1	<1		6
Molinia caerulea	25															
Total *Sphagnum*	**2**	**1**	**14**	**4**	**15**	**6**	**8**	**4**	**15**	**10**	**12**	**12**	**9**	**7**	**3**	**1**
S. subnitens	1			4	2	1	1						<1		1	
S. rubellum											1	1			1	
S. papillosum		<1		<1		3	7	2	8	5	3	3	3	2	1	<1
S. magellanicum																
S. pulchrum									6	3	2	5	3	3		
S. cuspidatum	<1	<1	5		12	<1	<1	<1								
S. tenellum	1	1	9	<1	1	2	<1	2	1	2	6	3	3	2		1
Hypnum cupressiforme	8	8	6	6	6	8	8	10	8	6	6	6	6	6	8	4
Pleurozium schreberi														<1		
Dicranum scoparium	<1		<1								<1				<1	
Polytrichum strictum					<1											
Odontoschisma sphagni	4	6	6	8	10	8	6	6	6	8	6	8	6	6	6	8
Cladonia portentosa	12	18	8	8	8	5	6	10	4	4	4	10	10	10	15	2
Cladonia ciliata			3	2	2		2		1	4	6	2	5	8		6
Cladonia unicalis										<1		2	1	<1		1
Cladonia cenotea		<1											<1			<1
Grid location	SN 68675 BNG 63788	SN 68635 BNG 63799	SN 68580 BNG 63813	SN 68531 BNG 63828	SN 68483 BNG 63844	SN 68437 BNG 63857	SN 68390 BNG 63874	SN 68342 BNG 63890	SN 68295 BNG 63905	SN 68247 BNG 63919	SN 68199 BNG 63932	SN 68151 BNG 63946	SN 68103 BNG 63964	SN 68053 BNG 63980	SN 68007 BNG 63997	SN 67964 BNG 64015

Appendix 2: Vegetation records of transect E.

	F -50	F 0	F50	F100	F 150	F 200	F 250	F 300	F 350	F 400	F 450	F 500	F 550	F 600	F 650	F 700	F 750	F 800	F850
Betula + litter				R	R														
Calluna vulgaris			6	25	6	10	12	9	25	30	6	8	20	30	15	10	20	30	30
Erica tetralix		1	2	6	6	8	6	8	3	8	8	7	8	4	8	3	4	8	8
Empetrum nigrum						1	1	3	2	3	2	<1	2	3	4	1			
Andromeda polyfolia		2	3	2	3	3	2	3	4	4	4	3	3	3	3	3	4	3	2
Vaccinium oxycoccus				2	<1	3	4	2	4	3	4	2	4	2	3	4	4	1	2
Drosera rotundifolia						<1		<1	<1	<1	+	<1	<1	<1	<1	<1		<1	<1
Drosera intermedia						+													
Erio. angustifolium			+	<1	<1	<1	<1	<1			<1	<1	<1	<1	+	R	+	+	<1
Eriophorum vaginatum		2	6	25	15	15	15	12	12	20	12	12	10	20	12	15	12	10	6
Scirpus cespitosus		2	1	2	4	1	4	3	2		4	3	3	2	4	4	3	2	7
Rhynchospora alba				2	1	1	1	1	<1	<1		1	2				2	<1	1
Narthecium ossifragum						1	2	2	3	<1	1	3	1		2	<1	<1	1	1
Molinia caerulea	75	50	28																1
Total *Sphagnum*	**0**	**0**	**4**	**6**	**16**	**23**	**17**	**6**	**26**	**7**	**1**	**15**	**18**	**8**	**5**	**8**	**21**	**11**	**19**
S. subnitens			4			1	2		12	3									
S. rubellum												4			<1		1	1	2
S. papillosum				<1	1	12	6	5	4	2	1	2	6	7	1	5	2	2	2
S. pulchrum					1	3	8		<1	1		7	9	1	2	2	12	3	3
S. cuspidatum						1	<1		2						1				
S. tenellum				6	14	6	1	1	8	1	<1	2	3	<1	1	1	6	5	12
Hypnum cupressiforme	4	5	6	4	7	4	4	7	6	8	6	5	5	8	6	10	8	10	10
Racomitrium lanuginosum									<1										
Dicranum scoparium				<1	<1											<1		<1	
Polytrichum strictum										<1									
Leucobryum glaucum						2	4			<1					2				1
Campylopus spp.					<1	<1													
Odontoschisma sphagni			2	4	3	6	6	6	5	3	4	8	6	6	5	5	6	6	7
Diplophyllum albicans																			
Cladonia portentosa		4	12	10	10	7	6	7	8	7	15	6	12	8	6	15	10	7	8
Cladonia ciliata					2	1												1	
Cladonia unicalis				<1	<1			<1	2	3		<1			1		<1	<1	2
Cladonia crispata										<1									
Cladonia cenotea																		<1	
Cladonia fimbriata				<1	<1					<1	<1			<1				<1	
Grid location	SN 68693 BNG 63679	SN 68646 BNG 63695	SN 68596 BNG 63711	SN 68549 BNG 63725	SN 68504 BNG 63735	SN 68460 BNG 63756	SN 68412 BNG 63771	SN 68361 BNG 63784	SN 68319 BNG 63799	SN 68267 BNG 63815	SN 68218 BNG 63832	SN 68171 BNG 63843	SN 68123 BNG 63862	SN 68073 BNG 63877	SN 68027 BNG 63892	SN 67978 BNG 63908	SN 67930 BNG 63920	SN 68781 BNG 63936	SN 67834 BNG 63951

Appendix 3: Vegetation records of transect F.

	G-150	G-100	G-50	G0	G50	G100	G150	G200	G250	G300	G350	G400	G450	G500	G550	G600	G650	G700	G750	G800	G850	G900
Potentilla palustris						R																
Calluna vulgaris					12	35	30	25	12	6	10	20	20	30	25	18	28	20	30	27	12	7
Erica tetralix			8	4	10	6	8	6	6	10	6	3	4	4	6	6	8	8	5	8	12	5
Empetrum nigrum					2		2	2			2	3	2	5	2	3	1	<1	1			<1
Andromeda polyfolia			4	2	3	<1	3	3	2	2	3	3	3	3	3	4	4	4	3	2	3	3
Vaccinium oxycoccus						<1	3	4	4	2	2	3	5	3	5	6	6	2	1	1	1	1
Vaccinium myrtillus												+							+			
Drosera rotundifolia							+		<1				<1			+	<1			<1	1	
Erio. angustifolium						<1	<1	<1	<1	<1	<1	+	<1	<1	<1	<1	1	+	+	<1	1	+
Eriophorum vaginatum			2	2	15	10	8	12	25	15	25	15	10	7	8	25	10	10	10	4	8	1
Scirpus cespitosus					1	2	<1	2	2	4	3	4	10	7	4	3	4	12	6	2	3	1
Rhynchospora alba							<1	<1	2	2	<1					<1	<1	<1	<1	3	1	
Narthecium ossifragum									<1	1	<1	1	<1	<1	<1	<1	<1	1		<1	<1	
Molinia caerulea	80	80	75	75	10	1																50
Total *Sphagnum*	**0**	**0**	**0**	**0**	**1**	**0**	**7**	**15**	**9**	**10**	**10**	**15**	**4**	**3**	**10**	**8**	**17**	**6**	**10**	**9**	**28**	**3**
S. subnitens								6		<1		6		2	3		<1		<1		1	
S. rubellum											1					1	<1				6	
S. papillosum							4	9	4		3	5	<1	<1	5	2	11	<1	5	1	1	3
S. magellanicum																						
S. pulchrum										1	2	4	3	1		4	4	6	4	6	20	<1
S. cuspidatum							2	<1	4	4	2							<1		1		
S. tenellum					1		1		1	5	2		1		2	1	2	<1	1	1		
Hypnum cupressiforme	1	1	8	6	8	6	8	6	6	7	8	10	7	7	5	8	8	7	6	9	4	6
Polytrichum strictum												3										
Leucobryum glaucum							1				<1	<1				<1					1	1
Campylopus spp.										<1	<1	<1				<1			<1			
Rhytidiadelphus triquetrus	1					<1																
Odontoschisma sphagni					3	2	6	6	5	5	4	4	3	3	4	4	6	5	5	4	6	13
Cladonia portentosa				12	15	8	10	20	6	4	15	15	12	28	10	10	10	3	10	5	3	6
Cladonia ciliata							1															
Cladonia unicalis											<1			<1	1				<1	<1		
Cladonia crispata						1																
Cladonia cenotea						1																
Cladonia fimbriata													<1			<1						
Grid location	SN 68753 BNG 63548	SN 68711 BNG 63566	SN 68661 BNG 63579	SN 68616 BNG 63590	SN 68568 BNG 63608	SN 68522 BNG 63631	SN 68473 BNG 63647	SN 68425 BNG 63646	SN 68375 BNG 63663	SN 68324 BNG 63698	SN 68284 BNG 63702	SN 68236 BNG 63721	SN 68188 BNG 63728	SN 68140 BNG 63752	SN 68091 BNG 63766	SN 66841 BNG 63774	SN 67996 BNG 63799	SN 67949 BNG 63810	SN 67901 BNG 63830	SN 67849 BNG 63831	SN 67807 BNG 63852	SN 67747 BNG 63869

Appendix 4: Vegetation records of transect G.

	H-50	H0	H50	H100	H150	H200	H250	H300	H350	H450	H500	H550	H600	H650	H700	H750	H800	H850	H900
Calluna vulgaris		1	40	20	12	9	15	12	7	2		8	35	35	12	18	28	8	25
Erica tetralix	3	3	3	5	5	10	4	4	6	6	5	6	8	6	6	6	4	8	6
Empetrum nigrum			1	<1	4	2	<1		6	1		1	1	2		1			
Andromeda polyfolia			3	3	3	3	4	5	6	1	4	3	3	4	4	4	2	5	3
Vaccinium oxycoccus			2	<1	5	4	2	2	15	2	3	6	4	4	6	2	2	2	1
Vaccinium myrtillus										<1									
Drosera rotundifolia					R		<1	<1	<1			<1	<1	1	1	<1	<1	<1	
Erio. angustifolium		<1	<1	<1	<1	<1	+	<1	<1		<1	+	+	+	<1	<1			
Eriophorum vaginatum	4	5	10	10	20	10	18	20	30	5	6	15	15	15	12	12	8	20	6
Scirpus cespitosus	<1	4	2	4	5	5	4	5	1	<1	2	5	1	2	2	8	12	5	8
Rhynchospora alba					+	<1	2	<1							<1	<1			
Narthecium ossifragum				2	1	<1	2	1		<1		4	2	1	5	<1	<1	<1	1
Molinia caerulea	80	50					2			27	50								
Total *Sphagnum*		7	**10**	**20**	**21**	7	**14**	11	**14**	3	**11**	**11**	**13**	**15**	**26**	**14**	**21**	**25**	7
S. subnitens		<1		11	3	<1	3	<1	5	>1	5			1			3	1	
S. rubellum					1				<1		3	4	2		10				
S. papillosum		1	10	7	13	2	5	3	3	<1	3	<1	8	5	1	1	12	11	1
S. pulchrum												5		8	15	10	4	7	3
S. cuspidatum				2	2	1	6	6	6	<1				1				3	
S. tenellum		6			2	2	<1	2	<1	<1		2	3			3	2	3	3
S. fimbriatum									1										
Hypnum cupressiforme	5	6	6	7	5	10	7	8	8	3	5	5	6	6	8	8	6	6	5
Pleurozium schreberi			6				3			<1									
Racomitrium lanuginosum										<1									
Dicranum scoparium						<1				<1									
Polytrichum strictum						<1				3	<1	<1							
Polytrichum commune						<1													
Aulacomnium palustre										<1			<1						
Leucobryum glaucum		<1				<1				<1		<1		<1					<1
Campylopus spp.						<1					<1	<1	<1	<1	<1			<1	
Odontoschisma sphagni		6	8	6	5	7	8	8	6	5	6	9	8	7	7	6	6	5	5
Diplophyllum albicans																			
Cladonia portentosa		5	16	9	10	11	10	18	10	7	15	12	13	9	6	8	5	4	3
Cladonia subfurcata						<1													
Cladonia unicalis													<1		1	1			
Cladonia crispata						<1													
Cladonia fimbriata			<1	<1	<1	<1				<1				<1			<1		
open Waterpools						<1				<1									
Grid location	SN 68633 BNG 63480	SN 68590 BNG 63493	SN 68535 BNG 63512	SN 68489 BNG 63521	SN 68438 BNG 63546	SN 68389 BNG 63558	SN 68344 BNG 63567	SN 68290 BNG 63585	SN 68248 BNG 63608	SN 68153 BNG 63633	SN 68105 BNG 63642	SN 68064 BNG 63664	SN 68011 BNG 63672	SN 67965 BNG 63691	SN 67919 BNG 63720	SN 67863 BNG 63727	SN 67832 BNG 63745	SN 67769 BNG 63754	SN 67726 BNG 63764

Appendix 5: Vegetation records of transect H.

	I-200	I-150	I-100	I-50	I0	I50	I100	I150	I200	I250	I300	I350	I400	I450	I500	I550	I600	I650	I700	I750	I800	I850	I900
Betula + litter																			1				
Calluna vulgaris				4	15	5	25	12	7	6	10	15	4	7	2	1	18	10	20	20	30	25	30
Erica tetralix				5	3	4	5	4	5	5	6	5	6	3	10	8	6	4	10	7	6	8	8
Empetrum nigrum						1		2	2	4	3	1			<1		2	2	2	4	3	3	
Andromeda polyfolia				3	2	3	3	3	4	5	3	4	2	2	4	4	2	2	2	3	2	3	4
Vaccinium oxycoccus					1	3	2	2	2	6	4	6	8	8	10	6	3	5	10	8	6	3	4
Vaccinium myrtillus												1	5	10	<1								
Drosera rotundifolia															1			<1	1	<1	<1	<1	<1
Erio. angustifolium					<1	<1	<1	+	<1	<1	+					<1	<1	<1	1	<1	<1	<1	<1
Eriophorum vaginatum				4	20	18	20	18	12	8	12	20	12	5	3	3	18	12	18	20	8	10	10
Scirpus cespitosus				<1	1	4	2	2	3	12	7					2	2	2	1	2	4	3	5
Rhynchospora alba						<1	<1	1		<1							<1	<1	1	<1	<1	1	2
Narthecium ossifragum				<1		<1			1	<1	1				2	4	1	1	<1		<1	<1	<1
Molinia caerulea	4	70	75	65								3	20	10	30	25							
Total *Sphagnum*	**0**	**1**	**0**	**3**	4	**9**	**9**	**4**	**4**	**7**	**8**	**9**	**1**	**1**	**21**	**2**	**14**	**15**	**25**	**10**	**14**	9	19
S. subnitens						<1		<1			<1	9			6	<1							<1
S. rubellum				2									1	1	11		8	4	<1				3
S. papillosum				1	1	2	8	3	1	4		<1			2	1	2	1	16	6	3	6	10
S. magellanicum																							
S. pulchrum						1									2	1	1	6	3	2	6	1	2
S. cuspidatum					2	3	1	1	3	2	8	<1				<1			4			1	<1
S. fallax		1																					
S. tenellum					1	3			<1	1	<1	<1					3	4	2	2	5	1	4
S. fimbriatum	30																						
Hypnum cupressiforme			3	6	6	6	6	5	6	8	4	10	2	4	6	4	6	6	10	10	10	10	10
Pleurozium schreberi												3	8	10	<1						<1		
Racomitrium lanuginosum												1											
Dicranum scoparium													<1			<1	<1	<1		<1		<1	
Polytrichum strictum										<1		10	18	6									
Polytrichum commune	1																						
Aulacomnium palustre															1								
Leucobryum glaucum				2			1															1	1
Campylopus spp.						<1																	
Odontoschisma sphagni				2	4	6	5	5	4	4	3	6	<1	2	4	4	5	4	6	7	6	6	6
Cladonia portentosa				6	10	12	18	20	15	5	10	10	5	10	5	8	6	9	6	12	10	10	2
Cladonia ciliata																		1			2		8
Cladonia unicalis																					<1	<1	
Cladonia cenotea								<1															
Cladonia fimbriata							<1	<1	<1				<1				<1		<1	<1	<1		
Grid location	SN 68744 BNG 63342	SN 68696 BNG 63357	SN 68651 BNG 63375	SN 68602 BNG 63390	SN 68554 BNG 63403	SN 68507 BNG 63416	SN 68460 BNG 63432	SN 68412 BNG 63450	SN 68364 BNG 63464	SN 68317 BNG 63478	SN 68268 BNG 63493	SN 68221 BNG 63508	SN 68174 BNG 63524	SN 68123 BNG 63541	SN 68077 BNG 63553	SN 68030 BNG 63572	SN 67979 BNG 63586	SN 67932 BNG 63599	SN 67882 BNG 63615	SN 67838 BNG 63630	SN 67788 BNG 63644	SN 67742 BNG 63659	SN 67695 BNG 63675

Appendix 6: Vegetation records of transect I.

	J-150	J-100	J-50	J0	J50	J100	J150	J200	J250	J300	J350	J400	J450	J500	J550	J600	J650	J700	J750	J800	J850	J900	J950
Calluna vulgaris		2	5	12	25	25	6	5	6	<1	3	7	6	8	30	35	30	10	10	8	20	30	2
Erica tetralix		4	6	4	5	5	5	5	6	6	5	6	8	2	6	8	8	5	6	8	7	6	6
Empetrum nigrum						1	2	1	3				+		5	<1	3	4	2	1			
Andromeda polyfolia		4	3	4	4	3	4	5	3	2	4	4	1	1	4	3	3	4	3	3	3	3	3
Vaccinium oxycoccus		3	3	5	4	5	8	6	4	1	6	6	2	6	10	6	3	6	5	3	2	2	
Vaccinium myrtillus									1			1	1	2			1						
Drosera rotundifolia			<1	<1													<1		<1	<1	<1	<1	<1
Erio. angustifolium		<1	<1	<1	<1	<1	<1	<1	+								<1	<1	<1	<1	1	<1	<1
Eriophorum vaginatum		2	15	12	12	15	20	18	30	5	10	5	4	6	3	5	20	23	15	25	15	10	1
Scirpus cespitosus		1	1	3	3	3	4	2	1	1	<1		<1	<1			3	3	4	1	3	4	6
Rhynchospora alba			3	<1	<1	<1	<1											<1	1	<1	<1	1	<1
Narthecium ossifragum						1	<1	<1	<1				<1			1			1		<1		
Molinia caerulea	75	40						<1	<1	30	18	30	22	15	30	25	<1						15
Total *Sphagnum*	**0**	**0**	**16**	**4**	**6**	**8**	7	**2**	**8**	**0**	**5**	**5**	**2**	**0**	**9**	**4**	**5**	**19**	**25**	**16**	**21**	**32**	**21**
S. subnitens			2			<1	4	1	7		5		2				<1		1				5
S. rubellum			8		2	5						5	<1	<1	9	4		14	5	3		<1	
S. papillosum			1	3	1	2		1			<1				<1	<1	<1	1	3	6	17	<1	5
S. pulchrum																		1	14	6	1	28	
S. cuspidatum			5										<1									1	8
S. tenellum				1	3	1	3		1							<1	5	3	2	1	3	3	3
S. fimbriatum																							
Hypnum cupressiforme	4	6	4	12	10	10	10	12	10	8	12	12	4	8	8	9	8	10	10	8	6	10	2
Pleurozium schreberi												<1	2	28									
Dicranum scoparium									1				<1	<1									
Polytrichum strictum								4	2				<1	1	5	4	4						
Aulacomnium palustre									<1						<1								
Leucobryum glaucum									<1	<1	1	2	<1	<1		1				<1		1	1
Campylopus spp.					<1																		1
Odontoschisma sphagni			4	4	6	6	6	6	8	2	2		2	3	1	5	6	5	6	6	5	6	3
Cladonia portentosa		6	3	10	10	6	5	11	6	20	5	10	6	8	8	12	25	12	10	18	10	5	5
Cladonia ciliata																				2			
Cladonia unicalis																					<1		
Cladonia cenotea																				<1		1	
Cladonia fimbriata				<1	<1	<1	<1	<1	<1	<1			<1			<1	<1		<1	<1			
Grid location	SN 68669 BNG 63266	SN 68621 BNG 63275	SN 68562 BNG 63293	SN 68524 BNG 63307	SN 68475 BNG 63322	SN 68427 BNG 63333	SN 68378 BNG 63350	SN 69330 BNG 63367	SN 68285 BNG 63386	SN 68236 BNG 63042	SN 68188 BNG 63418	SN 68142 BNG 63433	SN 68096 BNG 63447	SN 68047 BNG 63465	SN 68000 BNG 63476	SN 67953 BNG 63494	SN 67908 BNG 63508	SN 67850 BNG 63521	SN 67810 BNG 63533	SN 67764 BNG 63554	SN 67715 BNG 63571	SN 67667 BNG 63586	SN 67621 BNG 63600

Appendix 7: Vegetation records of transect J.

	K0	K50	K100	K150	K200	K250	K300	K350	K400	K450	K500	K550	K600	K650	K700	K750	K800	K850	K900
Betula + litter	5																		
Calluna vulgaris	3	12	10	5	15	4	4	9	14	4	35	8	10	20	30	30	10	6	10
Erica tetralix	4	8	8	5	8	10	6	4	4	6	3	4	6	6	4	3	7	10	8
Empetrum nigrum	<1	3	3	<1	3	2	1	2				1	1	5	1	<1	1	<1	1
Andromeda polyfolia	<1	3	4	<1	3	4	3	4	<1	4	3	3	3	3	4	3	3	5	4
Vaccinium oxycoccus	1	5	6	1	4	6	6	8	1	4	6	6	8	5	5	6	4	4	2
Vaccinium myrtillus	<1	<1									1	4	<1						
Drosera rotundifolia	<1		+											<1	<1	<1	<1	<1	
Erio. angustifolium	<1	<1	<1	<1	<1	+	<1			+		<1	<1	+	<1	<1	<1	<1	<1
Eriophorum vaginatum	4	18	15	8	18	18	4	7	9	30	15	35	40	18	15	12	12	8	6
Scirpus cespitosus	<1	3	<1	3	3	4		2		1	<1	<1	3	5	1	2	3	1	2
Rhynchospora alba		<1	<1	<1	<1	<1									<1		2	1	4
Narthecium ossifragum				<1	<1	<1				<1		<1	<1	2	1	<1	2	4	
Molinia caerulea	34		<1				25	15	27										
Total *Sphagnum*	**1**	**9**	**11**	**7**	**13**	**5**	**4**	**4**	**<1**	**1**	**4**	**8**	**7**	**11**	**16**	**11**	**13**	**9**	**16**
S. subnitens		<1		<1	8	<1	4	4	<1	1	1	4	<1		3				
S. rubellum	<1	2		3					<1			3		1		1			
S. papillosum	1	7	**7**	<1	1	2	<1		<1	<1	<1	1	3	<1	4	3	2	1	1
S. pulchrum														7	6	3	9	2	10
S. cuspidatum	<1		2	3	3	3		<1	<1					2				1	1
S. angustifolium							<1				1	<1							
S. tenellum			2	<1	1	<1					2		4	1	3	4	2	5	4
Hypnum cupressiforme	5	10		5	10	10	10	10	4	10	12	12	11	8	8	8	10	8	6
Pleurozium schreberi	<1								2			1							
Dicranum scoparium	<1	<1		<1					<1									<1	
Polytrichum strictum			<1				<1		<1		<1								
Aulacomnium palustre										<1		<1							
Leucobryum glaucum		1	<1	<1	<1				<1		1				<1		1		<1
Campylopus spp.				<1	<1														
Odontoschisma sphagni	2			3	4	5	6	6	2	6	6	6	8	6	6	7	6	4	6
Cladonia portentosa	4	8	10	8	10	10	12	15	10	25	15	12	12	18	10	5	8	10	4
Cladonia ciliata					2	1										10	3	7	
Cladonia subfurcata				<1															
Cladonia unicalis													1			<1	<1		1
Cladonia cenotea					<1													1	
Cladonia fimbriata	<1	<1	<1	<1		<1	<1		<1	<1	<1		<1					<1	
open Waterpools				<1															
Grid location	SN 68494 BNG 63212	SN 68448 BNG 63229	SN 68400 BNG 63242	SN 68353 BNG 63259	SN 68306 BNG 63273	SN 68254 BNG 63268	SN 68208 BNG 63303	SN 68158 BNG 63319	SN 68114 BNG 63328	SN 68063 BNG 63348	SN 68017 BNG 63367	SN 67966 BNG 63375	SN 67919 BNG 63391	SN 67875 BNG 63407	SN 67826 BNG 63421	SN 67780 BNG 63437	SN 67726 BNG 63451	SN 67683 BNG 63467	SN 67638 BNG 63482

Appendix 8: Vegetation records of transect K.

	L-100	L-50	L0	L50	L100	L150	L200	L250	L300	L350	L400	L450	L500	L550	L600	L650	L700	L750	L800	L850
Betula + litter						<1														
Calluna vulgaris		3	9	50	8	10	7	15	12	5	6	8	6	25	8	10	15	40	10	5
Erica tetralix		8	6	6	6	8	3	6	8	4	4	3	4	5	6	4	6	4	8	6
Empetrum nigrum			<1	<1	<1	<1	2	<1	3		<1		1	<1	2	3	2	1		
Andromeda polyfolia		1	3	3	3	3	3	3	4	4	6	5	5	3	3	3	4	3	4	4
Vaccinium oxycoccus			3	2	4	6	2	3	4	8	6	6	8	3	4	3	6	5	4	1
Vaccinium myrtillus	<1					1				<1	2	1		<1		<1				
Drosera rotundifolia		<1	<1	<1		<1							<1	<1	<1	<1		<1	<1	1
Erio. angustifolium		<1	<1	<1	<1		<1	<1	<1	<1	+	<1	<1	<1	<1	<1	<1	<1	<1	<1
Eriophorum vaginatum		2	15	7	10	20	4	25	20	20	25	25	20	22	20	18	12	8	10	5
Scirpus cespitosus		<1	4	1	2	3	<1	2	2	4	1	2	3	1	2	3	4	4	4	6
Rhynchospora alba					1	1							<1			<1	<1	1	2	1
Narthecium ossifragum			<1	<1	2	1		1	<1	2	2	<1		1	<1		<1	<1	1	<1
Molinia caerulea	75						25				2		<1							2
Total *Sphagnum*	**0**	**1**	**5**	**0**	**17**	**12**	**0**	**4**	**2**	**1**	**2**	**9**	**18**	**9**	**6**	**13**	**4**	**9**	**17**	**21**
S. subnitens								3			2	3	2	1						<1
S. rubellum																2	1	1		
S. papillosum		1	1	<1	1	6		<1	<1			2	5	3	2	1			1	1
S. magellanicum													1							
S. pulchrum															1	5		3	6	12
S. cuspidatum			3		12	3	<1	1	1	<1	<1	2	1			1	1		2	6
S. tenellum		<1	1	<1	4	3		<1	1	1	<1	2	9	5	3	4	2	5	8	2
Hypnum cupressiforme	4	6	10	12	8	10	8	12	12	12	12	10	10	12	12	10	12	10	10	4
Pleurozium schreberi	<1			<1																
Dicranum scoparium						<1							<1					<1		<1
Leucobryum glaucum			<1		1							<1	<1			<1	<1			4
Odontoschisma sphagni		1	6	6	4	6	5	4	4	4	4	4	8	6	6	6	6	8	6	6
Cladonia portentosa		4	4	15	4	8	8	7	6	8	12	15	12	12	3	10	8	8	5	2
Cladonia ciliata								1							10	1	2	2		
Cladonia unicalis															2			2	<1	
Cladonia cenotea												<1								
Cladonia fimbriata							<1	<1	<1	<1	<1			<1		<1				
Grid location	SN 68556 BNG 63084	SN 68510 BNG 63099	SN 68462 BNG 63120	SN 68412 BNG 63129	SN 68367 BNG 63149	SN 68320 BNG 63159	SN 68272 BNG 63176	SN 68223 BNG 63191	SN 68174 BNG 63204	SN 68128 BNG 63223	SN 68097 BNG 63241	SN 68033 BNG 63252	SN 67987 BNG 63270	SN 67939 BNG 63286	SN 67891 BNG 63301	SN 67846 BNG 63316	SN 67797 BNG 63330	SN 67751342 BNG 63	SN 67704 BNG 63356	SN 67658 BNG 63371

Appendix 9: Vegetation records of transect L.

	M-100	M-50	M0	M50	M100	M150	M200	M250	M300	M350	M400	M450	M500	M550	M600	M650	M700	M750	M800	M850
Betula + litter																			<1	
Calluna vulgaris			20			12	15	12	18	5	12	6	10	20	12	30	30	15	3	10
Erica tetralix	2	2	15	1	15	4	6	8	4	6	6	8	6	6	8	8	6	6	8	8
Empetrum nigrum						1	1	1	1	2	2	1	<1	<1	<1					
Andromeda polyfolia		<1	2	1	2	3	3	3	4	3	3	4	3	4	3	3	3	2	4	3
Vaccinium oxycoccus			2		12	4	6	5	8	6	5	5	5	2	4	<1	<1	3	10	2
Vaccinium myrtillus								<1			<1									1
Drosera rotundifolia												<1				<1		<1	<1	
Erio. angustifolium	+	<1	2	+	3	1	<1	<1	<1	<1	<1	<1	<1	1	<1	<1	1	<1	<1	<1
Eriophorum vaginatum	<1	<1	30	2	7	18	23	18	20	20	20	15	18	15	15	10	8	8	40	15
Scirpus cespitosus		<1	5		7	1	1	1	2	2	3	3	3	3	2	4	5	2	2	4
Rhynchospora alba					<1	1				<1		<1	2	1	2	2	2	1		1
Narthecium ossifragum			<1		<1	<1	2	<1	<1	1	2	1	<1	1	1			<1		<1
Molinia caerulea	75	30		70																
Total *Sphagnum*	**0**	**0**	15	**0**	**14**	**7**	**4**	**3**	**4**	10	**5**	**12**	**13**	10	**9**	**10**	11	11	**12**	**25**
S. subnitens					1			<1	1			1	1						<1	
S. rubellum											<1	<1	<1							
S. papillosum			5		5	3	1	<1	1		2	<1		1	4	1	3	4	5	<1
S. magellanicum													1							
S. pulchrum													1	2					4	
S. cuspidatum			5		4	2	2	1	2	3	2	3	3		2	2	1	3	2	3
S. tenellum			5		4	2	1	2	<1	7	1	8	7	7	3	7	7	4	1	22
Hypnum cupressiforme	1	4	5	7	6	4	8	10	12	12	8	10	6	8	10	8	8	8	6	8
Dicranum scoparium								<1						<1		<1				<1
Polytrichum strictum																				<1
Leucobryum glaucum								<1		2		1			<1	1	<1	1	<1	
Campylopus spp.					<1					<1										
Odontoschisma sphagni		<1	2		5	6	6	6	7	6	5	6	6	6	6	6	6	4	6	6
Diplophyllum albicans			<1																	
Cladonia portentosa		15	15	7	5	4	10	12	12	12	6	8	6	6	6	4	12	25	4	7
Cladonia ciliata						<1		1		1										
Cladonia unicalis																		<1		
Cladonia cenotea										1										
Cladonia fimbriata					<1	<1	<1	<1		<1		<1			<1					
Grid location	SN 68536 BNG 62983	SN 68482 BNG 63000	SN 68436 BNG 63018	SN 68390 BNG 63028	SN 68336 BNG 63046	SN 68289 BNG 63063	SN 68241 BNG 63078	SN 68196 BNG 63092	SN 68148 BNG 63110	SN 68099 BNG 63123	SN 68054 BNG 63142	SN 68006 BNG 63157	SN 67958 BNG 63174	SN 67912 BNG 632186	SN 67863 BNG 63208	SN 67806 BNG 63226	SN 67768 BNG 63237	SN 67721 BNG 63255	SN 67673 BNG 63269	SN 67625 BNG 63283

Appendix 10: Vegetation records of transect M.

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