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ARO13: Viewing The Holocene: Vegetation History Of Ravelrig Bog, Kirknewton, Edinburgh

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ARO13: Viewing The Holocene: Vegetation History Of Ravelrig Bog, Kirknewton, Edinburgh

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Cover Plate: a view across the bog at Ravelrig.

Contents

List of Figures

List of Plates

List of Tables

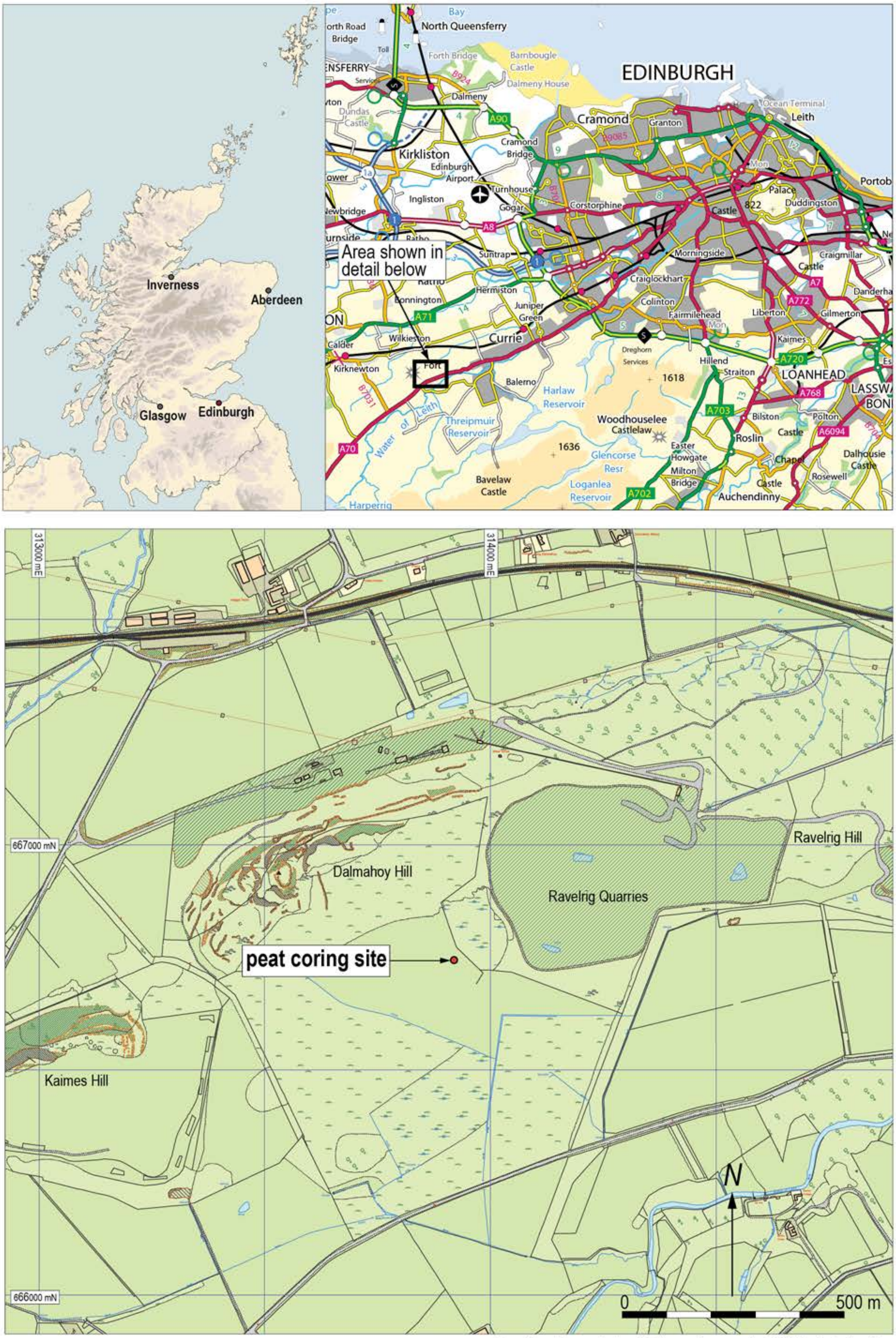

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Figure 1: Location map for the peat coring site.

Summary

A peat core was taken from Ravelrig Bog, Kirknewton that contained palaeoenvironmental material spanning the entire Holocene period. Pollen analysis of the core has shown that that the bog started out as a small lochan, within a rocky hollow that was formed at the end of the last glacial period. Aquatic plants gave way to marshland and finally raised *Sphagnum* bog as natural succession progressed. During the early Holocene, the woodlands of the area were dominated by birch, hazel and willow but developed into mixed oak, elm and hazel woodlands by the mid-Holocene. A clear Elm decline is visible in the pollen record at 5,200 cal BP and there is evidence for multiple Elm declines having taken place. Human impact on the landscape is recorded from the Neolithic onwards, with increasing woodland clearance and agricultural activity in the Bronze Age, and a peak in activity in the pre-Roman Iron Age. Pastoral agriculture was the dominant form of farming in the area, although there is evidence for the cultivation of cereals from the later Bronze Age onwards. These periods of agricultural intensification appear to correspond with known periods of occupation at Kaimes and Dalmahoy hillforts and a nearby prehistoric palisaded enclosure. The last major episode of woodland clearance began around cal AD 1450, with the cleared landscape continuing until the present day. Evidence for an increase in pine pollen at the top of the pollen diagram suggests that the bog surface is intact and so a complete sequence has been analysed.

Plate 1: Ravelrig bog

Introduction

The vegetation history of central Scotland has been extensively studied using palynological and radiocarbon techniques (Boyd 1986; Dickson 1988, Dumayne 1992, 1993a, 1993b, 1998; Ramsay 1995; Ramsay and Dickson 1998; Turner 1965, 1975). However, these studies did not cover the entire period of the Holocene, with most concentrating on the last 3000 years or so of environmental history, with particular emphasis on the effects of human impact on the vegetation. Previous studies have suggested that the first major woodland clearances in central Scotland occurred in the pre-Roman Iron Age, with the cleared agricultural landscape being maintained throughout the Roman period. The extensive industrial and agricultural activity in this region has removed many potential sites of palaeoenvironmental importance over recent centuries, and so there have been few chances to construct a pollen diagram that covers most of the Holocene period.

In 2007, the former Glasgow University Archaeological Research Division (GUARD) produced an Environmental Impact Assessment (EIA) for the site of Ravelrig Quarry, by Kirknewton, City of Edinburgh, on behalf of Tarmac Limited ahead of the development of extensions to the existing quarry. The EIA outlined the archaeological/cultural heritage and environmental factors pertaining to the site and provided guidelines for mitigation strategies to deal with any impact that the quarry development would have upon these various aspects. As part of this EIA, a vegetation survey was carried out over a large part of the site and an examination of the peat stratigraphy of an area of raised mire was also undertaken (Eades 2005). The survey of peat stratigraphy indicated that, although the surface of the mire had been damaged by the installation of a drainage system, the peat that remained extended to a depth of over 7 m in places. The peat was characteristic of a raised mire that had developed over a small, rocky basin and held the potential for being an important palaeoenvironmental resource that might provide information on the vegetation history of the area dating back to the early Holocene period. An initial palynological assessment of a core taken from this site showed that pollen preservation was excellent and that the base of the deposit extended back to over 10,000 years cal BP. Tarmac Limited agreed to fund a more extensive palynological analysis of the top 4 m of this core, which was estimated to cover the past 7000 years of environmental and human history of the area.

Site Location, Topography and Geology

Ravelrig Bog (NGR: NT 1434 6696; 55° 53′ 17′′ N, 3° 22′ 16′′ W) was situated within an area that has now been incorporated as an extension to Ravelrig Quarry and the area of peatland is no longer extant. The site was classified as an area of degraded raised mire since an extensive network of drainage ditches had been cut into the mire surface. This resulted in the drying of the peat surface and a loss of the bog plant communities that would inhabited an actively growing raised mire habitat (Eades 2005). Two hill forts, Kaimes and Dalmahoy Hill, together with the present quarry and the site of the long-disused Ravelrig Hill Quarry, form a crescent-shaped ridge also known as Dalmahoy Craigs. The Craigs partially enclose lower lying, poorly drained scrubland, marshland and raised mire to the south, together with two agriculturally improved fields. The ground falls steeply away on the north side of The Craigs, where flatter and better-drained agricultural land occupies the head of the Forth Valley (Plate 1: The bog in its landscape).

The drift geology comprises silts and gravels, with deposits of boulder clay to the south and quaternary peat to the west, whilst the solid geology consists of Dalmahoy sill, dolerite and Devensian till to the south (British Geological Survey Digimap www.digimap.edina.ac.uk).

Peat investigation and sampling were undertaken on 3 July 2009 with a core taken from the area of deepest peat at NGR: NT 13920 66745, located at an altitude of 187 m OD (Figure 1). The vegetation growing on the surface of the raised mire was dominated by heather (*Calluna vulgaris*), hare's-tail cottongrass (*Eriophorum vaginatum*), purple moor-grass (*Molinea caerula*) and wavy hair-grass (*Deschampsia flexuosa),* with a ground cover of various mosses, including occasional *Sphagnum* spp.

Archaeological and Palaeoenvironmental Background

There is archaeological evidence for human occupation of the area surrounding Ravelrig Bog from the prehistoric until the present day. The most significant archaeological sites are two hillforts that occupy the summits of Dalmahoy Hill and Kaimes Hill, both within a distance of 1 km from the coring locality. Dalmahoy Hill is unexcavated but is thought to have been occupied in the pre-Roman Iron Age and again in the Early Historic or 'Dark Age' period (Stevenson 1951), although there are no radiocarbon dates or artefacts to support these assumptions. In contrast, Kaimes Hill has evidence of human activity dating back to the Mesolithic period, with intensification of activity throughout the Bronze Age but was subsequently abandoned during the later Iron Age, when the focus of settlement may have moved to Dalmahoy Hill (Simpson *et al* 2004). Cup and ring marked rocks have been identified from both Dalmahoy Hill and also Kaimes Hill providing further evidence for prehistoric activity in the area.

In addition, there is evidence for a large, palisaded circular enclosure, approximately 1 km to the north/north-east of the coring site (Maguire 2009; Rennie forthcoming). Excavations at this site produced evidence for the use of woodland resources for fuel and building materials, with AMS radiocarbon dating indicating that the main focus of activity was during the period 400 - 800 cal BC, with other outlying radiocarbon dates giving date ranges of 200 - 400 cal BC and a much earlier range of 1600 - 1750 cal BC. This suggests that lower levels of activity may have been taking place on the site for a significant timespan during prehistory.

There is very little palynological or palaeoenvironmental information that has been published for sites in eastern-central Scotland. The nearest published sites in central Scotland lie over 30 km to the west at Drumbow Bog (Dickson 1988, 1992) and Fannyside Muir (Dumayne 1992, 1993a,b). Although there are closer published sites to the south, these are located at much higher altitudes and so are not comparable in terms of the vegetation types and changes that they have recorded. The presence of an area of deep peat in an area that has a rich archaeological record and is also located close to agricultural land provides a unique opportunity to study the environmental history of this area and, in particular, the effects of human activity on the environment.

Methodology

A peat core was collected using a Russian-type corer with chamber dimensions of 50 cm x 8 cm

(Jowsey 1966). The top block of peat (down to 20 cm) was removed with a spade and then fifteen 50 cm core sections were recovered, wrapped in the field and subsequently stored at 3°C prior to analysis.

The cores were visually assessed to determine the gross stratigraphy of the peat deposit and to note any significant changes within the peat stratigraphy as the cores were removed from the ground, prior to any oxidation taking place. In the laboratory, samples of 1 cm thickness were removed for subsequent pollen and macroplant analysis. The core was sub-sampled at 2 cm intervals between 0 – 64 cm, at 4 cm intervals between 64 - 400 cm and at 8 cm intervals between 400 - 770 cm.

A portion of each sample was examined under low magnification to determine the main constituents of the peat at each level and an estimation of the degree of humification was also made. Pollen samples of 1 cm^3 were prepared using the standard methodologies outlined in Moore, Webb & Collinson (1991), with NaOH digestion, followed by acetolysis and embedding in silicone oil. Treatment with HF was not required due to the highly organic nature of the samples. Pollen identification and nomenclature follows Moore *et al* (1991) and Punt (1976), whilst vascular plant nomenclature follows Stace (1997). Cereal type pollen grains were distinguished using grain size >37 µm and annulus diameter of >8 µm (Andersen 1979), and additional notes by Dickson (1988). A minimum of 500 land pollen grains were counted for each level. Microscopic charcoal particles were quantified into the size fractions defined by Tipping (1995), i.e. 10-25 µm, 26-50 µm, 51-75 µm, and >75 µm.

A pollen sum of Total Land Pollen (TLP) was used, which excluded all aquatics, spores and unidentifiable grains. Percentage values for groups of taxa not included within the TLP sum were calculated as TLP + group and charcoal percentages were calculated as TLP + charcoal. The pollen diagram was constructed using TILIA and TGView (Grimm 1991-2011) and zoned using the CONISS statistical package within the TILIA computer program. This generated seven local pollen assemblage zones (LPAZ) that have been labelled RB-1 to RB-7 on the pollen diagrams.

AMS radiocarbon dating was undertaken at eight levels within the core. At each level a 1 cm slice of peat was removed and dried prior to sending for AMS radiocarbon dating at the Scottish Universities Environmental Research Centre (SUERC), East Kilbride. The radiocarbon dates were calibrated using the OxCal v.4.1 calibration program (Bronk Ramsey 2009).

Results

Peat stratigraphy

The main stratigraphic changes observed within the core are detailed in Table 1. The basal deposits are fen peat, with a clay mineral component suggesting that the site was under water at least some of the time during early peat formation. The peat stratigraphy then shows a natural succession to fen woodland deposits, with evidence for birch (*Betula*) woodland on the site. Woodland declined as *Sphagnum* moss became more abundant, leading to the formation of a raised bog peat. Drier periods are indicated by increased humification of the peat and the presence of heather type (Ericales) twigs and roots. The main bulk of the raised bog peat was formed by *Sphagnum* moss and cotton grass (*Eriophorum*).

Table 1: The peat stratigraphic record

Depth (cm)	Peat stratigraphy
0 - 10	Highly humified herbaceous peat with monocot stems and roots
10 - 76	Moderately humified *Sphagnum* peat with occasional monocot stems (including *Eriophorum*)
76 - 92	Slightly humified *Sphagnum* peat with occasional monocot stems (including *Eriophorum*)
92 - 100	Highly humified herbaceous peat with occasional *Sphagnum* leaves
100 - 108	Moderately humified *Sphagnum* peat with occasional monocot stems (including *Eriophorum*)
108 - 208	Highly humified herbaceous peat with occasional *Sphagnum* leaves. Ericales stems present at 128 cm, 160 cm, 176 cm, 180 cm. Charcoal c. 4 mm present at 164 cm.
208 - 220	Moderately humified *Sphagnum* peat with occasional monocot stems (including *Eriophorum*)
220 - 352	Highly humified *Sphagnum* peat with occasional monocot stems (including *Eriophorum*). Ericales stems present at 252 cm, 260 cm, 304 cm, 312 cm.
352 - 470	Highly humified herbaceous peat with *Eriophorum* and Ericales woody stems/ roots. Occasional *Sphagnum* leaves/stems also present.

Depth (cm)	Peat stratigraphy
470 - 720	Highly humified herbaceous peat with *Eriophorum*, Ericales woody stems/roots, *Betula* wood
720 – 770	Highly humified herbaceous fen peat with some clay present

Chronology

The AMS radiocarbon dates are detailed in Table 2, together with their calibrated age ranges at the 2σ confidence interval, both as cal BC/AD and cal BP. The age-depth curves (Figures 2a & 2b) show the calibrated dates form a chronological sequence with no evidence for inversions. Although it appears that the top 50 cm of the peat column has either grown very slowly or that some peat has been lost, there were no obvious signs of a hiatus within the visible stratigraphy. Estimated dates used within this report are based on linear interpolation from the age-depth curves.

Table 2: Radiocarbon dates

Laboratory code	Depth (cm)	^{14}C age (radiocarbon yr BP)	$\delta^{13}C$ (‰)	Calibrated date BC / AD (2σ)	Calibrated date BP (2σ)
SUERC-33104	48 - 49	2560 ± 30	-26.5	810 - 550 cal BC	2760 - 2500 cal BP
SUERC-44796	104-105	3037 ± 35	-27.5	1410 - 1135 cal BC	3360 - 3085 cal BP
SUERC-44797	160 - 161	3759 ± 35	-27.9	2290 - 2040 cal BC	4240 - 3990 cal BP
SUERC-44798	216 - 217	4428 ± 35	-28.4	3330 - 2925 cal BC	5280 - 4875 cal BP
SUERC-44802	272 - 273	4795 ± 35	-27.8	3650 - 3520 cal BC	5600 - 5470 cal BP
SUERC-44803	328 - 329	5259 ± 35	-26.9	4230 - 3980 cal BC	6180 - 5930 cal BP
SUERC-22376	384 - 385	6030 ± 30	-27.9	5010 - 4830 cal BC	6960 - 6780 cal BP
SUERC-22377	768 - 769	9425 ± 30	-23.6	8790 - 8620 cal BC	10740 - 10570 cal BP

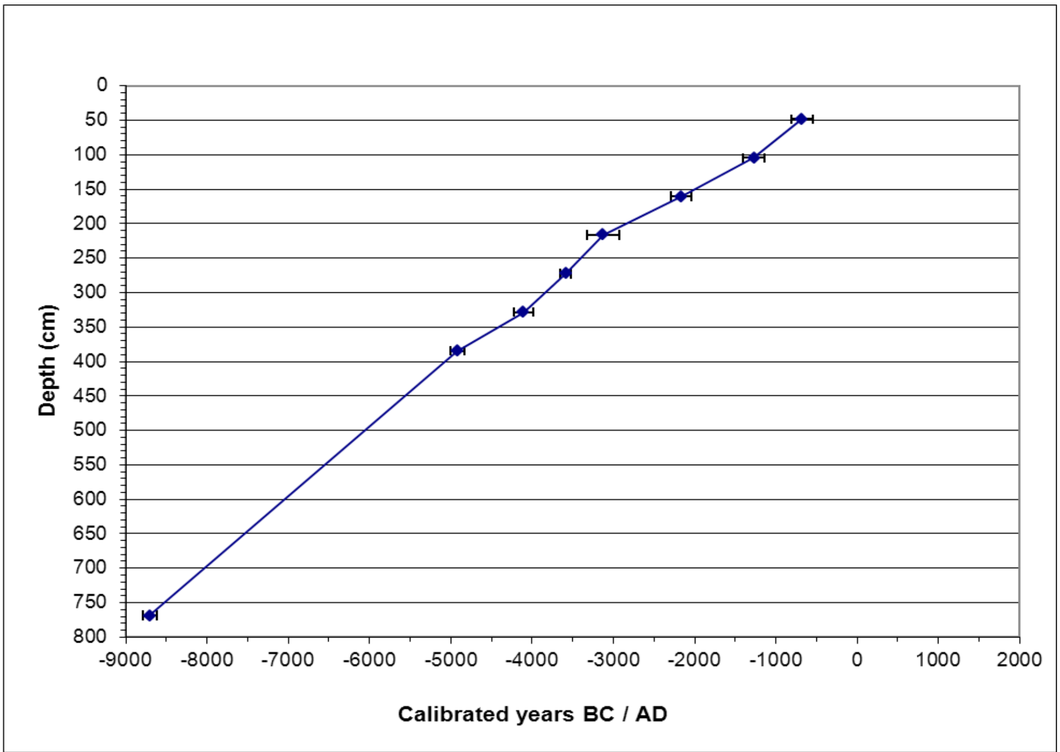


Figure 2a: Radiocarbon age-depth curve for the peat core. The line joins the mid-points of the calibrated date ranges at the 2σ probability (cal years BC/AD).

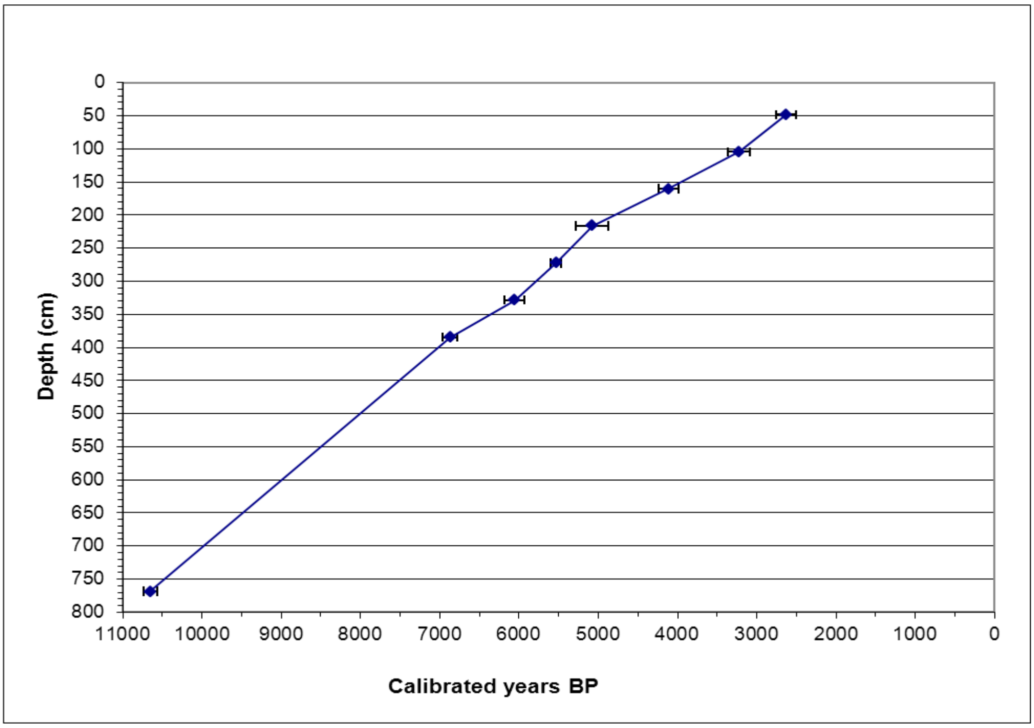


Figure 2b: Radiocarbon age-depth curve for the peat core. The line joins the mid-points of the calibrated date ranges at the 2σ probability (cal years BP).

Charcoal

Charcoal fragments were counted alongside pollen during the analysis of the prepared slides. They were initially allocated to 4 size categories, 10–25 µm, 26–50 µm, 51–75 µm, and >75 µm, but it was clear that any significant changes in charcoal abundance were represented across all four size categories and so only a total charcoal curve has been included within the pollen diagrams (Figures 3 and 4).

Pollen analysis

The pollen diagrams have been zoned using the CONISS stratigraphically constrained sums of squares method, within the TILIA program. The pollen diagram has been presented in two forms. The conventional presentation of pollen diagrams has the primary y-axis representing depth. However, the slow peat growth within the top 50 cm of the core means that this presentation makes it extremely difficult to resolve the changes in pollen types that are occurring during the time period covered by this depth of peat. It was decided, therefore, to present the pollen results additionally as a pollen diagram in which the depth axis has been replaced as the primary y-axis by one that represents time. This makes it possible to determine more clearly any anthropogenic changes that have occurred in the last 2000-3000 years. The pollen diagram with depth as the primary y-axis is shown in Figures 3a and 3b, whilst the pollen diagram with time as the primary depth axis is shown in Figures 4a and 4b. The presence of rare types (<1% TLP) is indicated by a 'plus' on the pollen diagrams. Any pollen types that only had a single 'rare type' occurrence have been omitted from the pollen diagrams but are listed in the Appendix for completeness.

Figure 3a: Selected pollen taxa (y-axis scaled for depth)

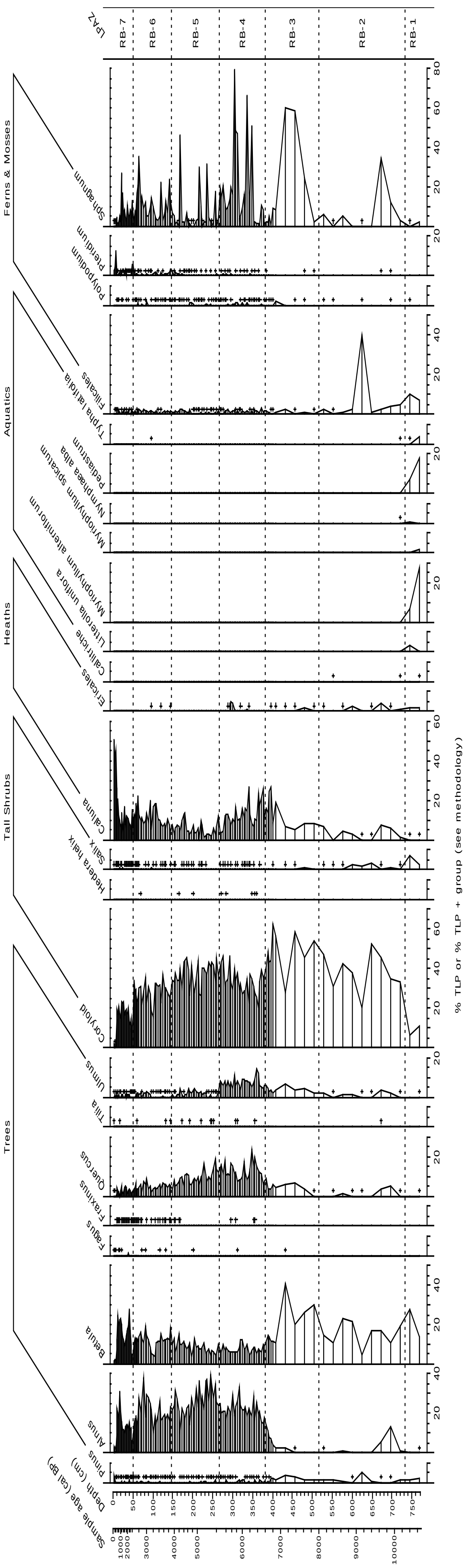


Figure 3b: Selected pollen taxa (y-axis scaled for depth)

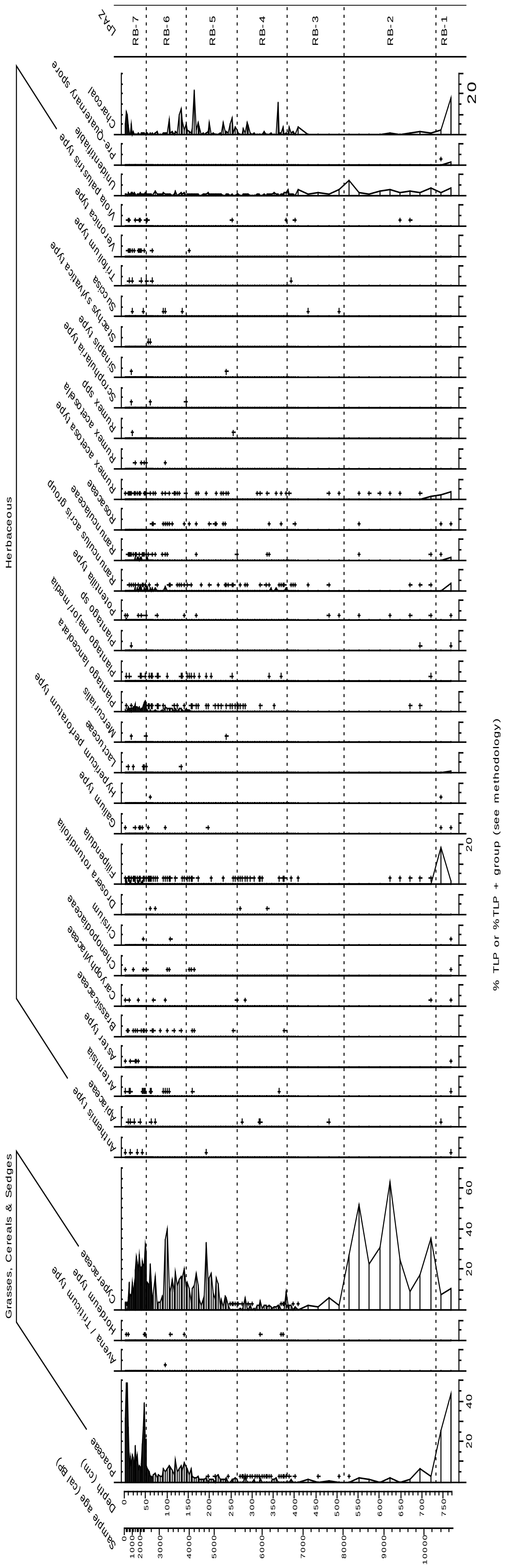


Figure 4a: Selected pollen taxa (y-axis scaled for time)

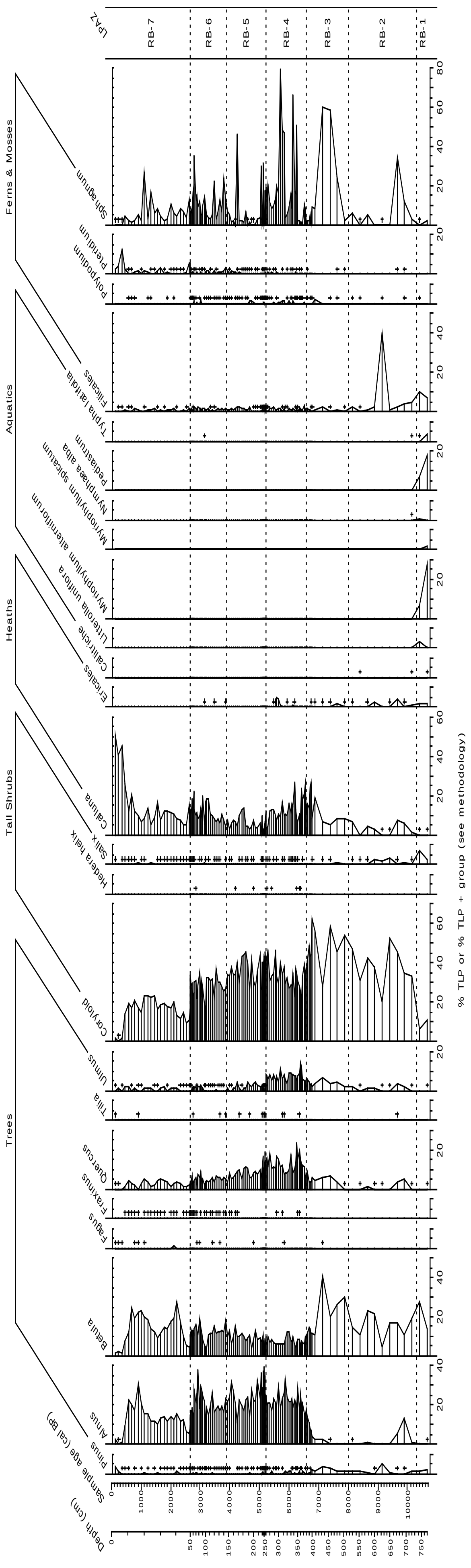
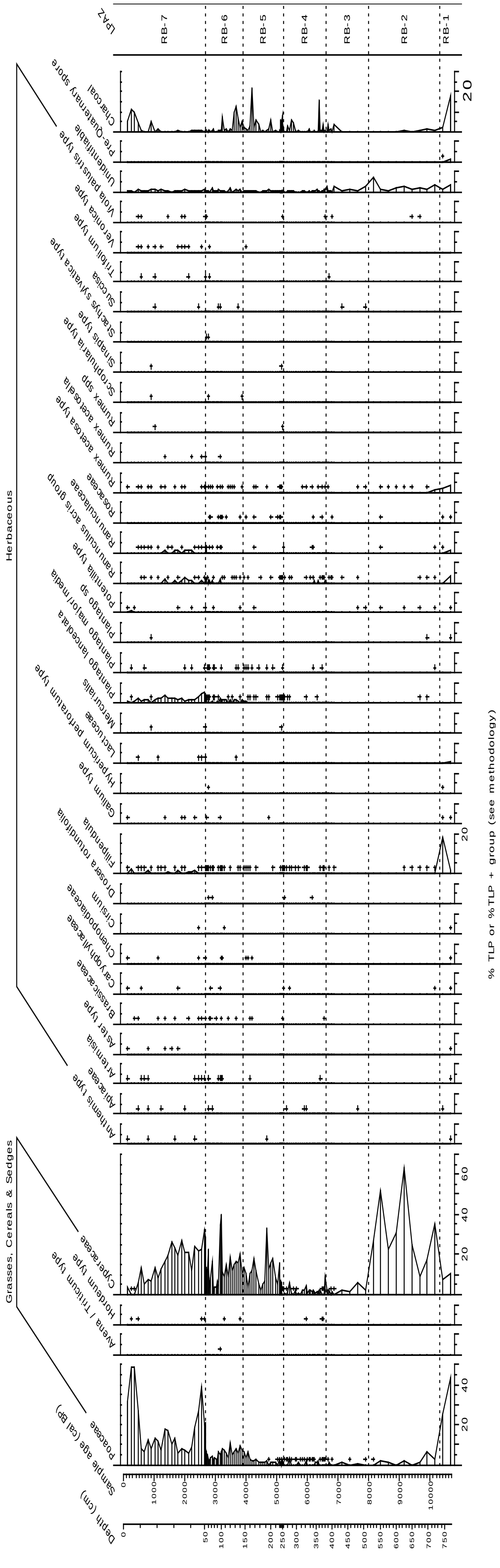


Figure 4b: Selected pollen taxa (y-axis scaled for time)



RB-1: 10,800 - 10,300 cal BP (8850 - 8350 cal BC)

The earliest pollen zone dates from approximately 10,800 cal BP and represents the vegetation that was growing in and around this site shortly after the end of the Loch Lomond re-advance (Younger Dryas) cold period. It appears that the site contained standing water at this time, probably in the form of a small lochan within a rocky hollow. The aquatic nature of the site is indicated by the presence of abundant alternate water-milfoil (*Myriophyllum alterniflorum*) pollen and the presence of a suite of other aquatic taxa including water starwort (*Callitriche*), white water-lily (*Nymphaea alba*) and pondweed (*Potamogeton*). These aquatic types are indicative of standing water e.g. a lochan, rather than flowing water. Bulrush (*Typha latifolia*) and shoreweed (*Littorella uniflora*) which both prefer shallow water, were probably growing around the edges of the lochan.

Much of the local area appears to have been covered with grassland, with a diverse range of forbs (herbaceous plants other than grasses, sedges and rushes), in particular buttercups (Ranunculaceae) and docks (*Rumex acetosa* type) growing within these open habitats. Areas of wetter grassland are indicated by the high representation of meadowsweet (*Filipendula*), suggesting that there may have been an area of marshy grassland surrounding the lochan.

Although much of the landscape would have been open, some woodland did grow in the vicinity of the site, and included trees of birch (*Betula*), hazel (*Corylus*) and willow (*Salix*). Microcharcoal levels were high at the base of this zone, suggesting that wildfires may have been frequent within the low growing scrub woodland or on drier areas of grassland. However, there is no indication that these fires were a result of human activity in the area.

RB-2: 10,300 - 8000 cal BP (8350 - 6050 cal BC)

The early Holocene shows a continuing presence of birch within the local woodland but there is a very significant increase in the representation of hazel, with values approaching 60% TLP. Several other tree taxa began to colonise the area during this zone. Oak (*Quercus*) and elm (*Ulmus*) are present at very low levels throughout, whilst alder (*Alnus*) shows a significant local presence in the lower half of the zone before declining and finally becoming absent by the top of it.

The most significant change from the zone below is the sudden and enormous shift in the composition of the open ground taxa, from being dominated by grasses (Poaceae) to being dominated by sedges (Cyperaceae). It is likely that the open grasslands present in RB-1 have become colonised by birch/hazel woodland and that the significant increase in sedges is representative of sedges growing very locally on the developing fen. Evidence for fen development is seen in the decline in aquatic taxa to trace levels suggesting that the area of open water has been reduced to a few small pools and that the site is now a fen dominated by sedges. *Sphagnum* moss also becomes more abundant, probably becoming a significant component of the fen ground cover vegetation.

There is a decline in the diversity of herbaceous types that are present in this zone, with only cinquefoils (*Potentilla* type) and docks (*Rumex acetosa* type) consistently present throughout. Meadowsweet declines and is absent by c.9000 cal BP, suggesting the loss of suitable habitat for this taxon.

Microcharcoal levels are very low, indicating that the ground was probably too wet for wildfires to break out. The highest levels of unidentifiable pollen grains also occur in this zone, suggesting that the soils may have still been relatively biologically active, resulting in degradation of the grains. Raised mire sediments are relatively inert in terms of biological activity and so this suggests the site was still a fen and had not yet transformed into a raised mire.

RB-3: 8000 - 6600 cal BP (6050 - 4650 cal BC)

This zone is characterised by an increase in woodland taxa, with birch, oak and elm becoming more abundant to many of the other recorded Elm Declines recorded in pollen diagrams from central Scotland. Grasses and open ground taxa are very low throughout most of this zone, indicating that the area was now more or less covered with woodland, although the site itself was probably an open area of raised bog. The pollen evidence suggests that the fen vegetation on site had become colonised by *Sphagnum* moss, increasing the waterlogging on site and resulting in the formation of an actively growing raised bog. This is further evidenced by the sudden decline in sedge pollen at the start of this zone, which continues to remain at very low levels throughout this period. An increase in heather (*Calluna vulgaris*) is probably indicative of heather growing on drier hummocks on the bog surface. Further evidence for heather growing on the bog itself is evidenced by macrofossil remains of heather stems / roots within the peat cores covering this zone. Aquatic types are completely absent, indicating that few, if any, pools of open water remained by this time. There are several peaks in microcharcoal but these may be evidence of natural burning of the heather on the bog surface.

RB-4: 6600 - 5200 cal BP (4650 - 3250 cal BC)

This zone is characterised by a further increase in certain woodland taxa, with both oak and elm reaching their highest levels and alder increasing from the beginning of the zone to levels of >20% TLP for most of the time period covered. However, there is a decline in birch, probably as a result of pioneer birch woodland being replaced by oak and elm woodland as the woodland succession progressed.

Grasses and open ground taxa generally remain low throughout most of this zone, although there are slight increases in some of the herbaceous taxa associated with agriculture e.g. ribwort plantain (*Plantago lanceolata*), meadow buttercup type (*Ranunculus acris* type) and docks (*Rumex acetosa* type). In addition, bracken (*Pteridium aquilinum*) starts showing a continuous presence, which suggests that small areas of clearings within the woodland may have been present at this time. Traces of barley type (*Hordeum* type) pollen were also recorded from two separate levels within this zone, suggesting that early farmers may have already started clearing small patches of woodland in order to grow crops.

There are several peaks in microcharcoal in this zone, which may be the result of natural burning of the heather on the bog surface but could also be an additional indication of human occupation in the local area.

RB-5: 5200 - 3900 cal BP (3250 - 1950 cal BC)

The most significant woodland change in this zone is a sudden decline in elm pollen at the start of it, c. 5200 cal BP, which is comparable in date to many of the other Elm Declines recorded in pollen diagrams from central Scotland. However, at Ravelrig Bog the elm still continues to be a minor, but significant component of the woodland throughout the rest of this zone rather than all but disappearing as is the case at other sites in the area. There is also a gradual decline in oak pollen but little significant change in the remaining tree types. Ash (*Fraxinus*) also makes its first appearance in this zone but never reaches more than trace levels in this, or any of the later zones.

There is a slight indication towards the top of the zone that there may be some increase in agricultural activity in the area. There is a small increase in grasses, coupled with an increase in the presence of ribwort plantain pollen to levels >1%. There also seems to be a slight increase in other herbs associated with grassland habitats, which might suggest an increase in open grassland that was utilised by grazing animals.

There is a single peak in microcharcoal towards the end of this zone, which may also indicate increased human activity in this area. However the levels on either side of this peak are very low and so a more local, natural source for the charcoal cannot be ruled out.

RB-6: 3900 -2600 cal BP (1950 - 650 cal BC)

This zone shows much more definitive evidence for human impact on the landscape. There is a significant decline in woodland cover, with oak, elm and hazel particularly affected with a corresponding increase in bracken (*Pteridium*). This is also an indicator of woodland clearance as bracken spore production increases when the woodland canopy is opened up allowing more light to reach the woodland floor.

There is also a corresponding increase in the presence of grasses and the diversity of herbaceous agricultural indicators. In particular, ribwort plantain (*Plantago lanceolata*) shows significant increases, suggesting that pastoral agriculture was being practiced in the vicinity of the site from 3900 cal BP onwards. Trace levels of cereal pollen are also noted, with both oat/wheat (*Avena/Triticum*) type and barley (*Hordeum* type) present. This suggests that cereal growing was taking place in the vicinity of the site, but that pastoral agriculture was also contributing an important element to the overall vegetation of the area.

RB-7: 2600 cal BP - present (650 cal BC - present)

The final zone shows the greatest amount of human impact recorded in the pollen sequence. At the beginning of the zone, c. 2600 cal BP (650 cal BC), there is a sudden and extremely large rise in the representation of grass pollen and a corresponding decline in all the trees and tall shrubs. In addition, there is a small peak in bracken, again indicating woodland clearance. Ribwort plantain reaches its highest representation of the whole sequence and there is an increasing diversity of arable and ruderal weed types. The changes in these anthropogenic indicators suggest a sudden intensification of agriculture at this time. Barley type pollen is also present but pastoral agriculture was probably dominant in the local area.

This period of intensive agricultural activity does not last and by c. 2300 cal BP (350 cal BC) grass pollen had fallen to the same levels as were seen in RB-6. A moderate increase in agricultural activity occurs during the period between c. 1500 - 1300 cal BP (cal AD 450 - 650), when there is an increase in grass pollen and a significant decline in birch. This might suggest that areas of scrub birch woodland that had grown over previous agricultural land were cleared to make the land available for use again. The final major phase of woodland clearance began c. 500 cal BP (cal AD 1450) and resulted in the cleared grassland landscape that is present today. It is notable that heather is the other main pollen taxon that shows a corresponding sudden increase at the same time as grass. This suggests that the bog surface may have started to dry out, perhaps as a result of early attempt at water management on the site or in the immediate area.

There appears to be a small increase in pine pollen during the last 200 years according to the time-scaled pollen diagram. This is probably a result of large scale conifer plantations and provides evidence that the top of the pollen sequence is intact and that it is valid to allocate a present day date to the very top of the peat sequence.

Discussion

The pollen sequence from Ravelrig Bog, Kirknewton, covers the period from the beginning of the Holocene until the present day, although the rate of peat deposition slowed significantly over the last two millennia and so the degree of temporal resolution within the pollen diagram was not consistent throughout the core.

The beginning of the Holocene shows a warming of the climate after the end of the last glacial period, with woodland beginning to colonise the area but with significant areas of open grassland habitats still present in the region. The woodlands were composed of pioneer species such as birch and willow, with hazel beginning to form a significant part of the woodland flora by 10,000 years ago. This displacement of birch and willow by hazel is seen to happen at around 10,000 - 10,500 cal BP at many sites across central Scotland, including Shewalton (Boyd 1982), Linwood (Boyd 1982, 1986), Girvan (Jardine 1962, 1975), Dubh Lochan (Stewart, Walker & Dickson 1984) and at Black Loch in Fife (Whittington *et al* 1991a). The consistent dating of this event suggests that climatic factors were largely responsible for the sudden increase in the ability of hazel to colonise much of the lowland landscape.

The analyses have shown that the site of Ravelrig Bog was a lochan that had formed within a rocky hollow at the end of the last glacial period. This original body of water supported a diverse range of aquatic plant species, in particular alternate-leaved water milfoil, which is often associated with peaty water (Ros 1981). The lochan was surrounded by fringing vegetation composed of bulrushes, meadowsweet and sedges, with evidence for species of docks and buttercups also present. Natural succession occurred over the next 2,000 years within the lochan and the open water slowly infilled to form a sedge-rich fen environment.

Beyond the immediate area of the fen vegetation, woodland cover increased but was still dominated by birch and hazel, with small amounts of alder probably forming fringing woodland around the edges of the fen. The early appearance of alder in this locality suggests that the damp, waterlogged conditions that prevailed around the fen allowed alder to colonise areas that would normally have been utilised by other tree taxa. Alder seems to have been present in this area from at least 10,000 years ago, which is in accordance with evidence produced by Bennett and Birks (1990), who suggest that the date of colonisation by alder was extremely site specific in the UK and cannot be inferred from the type of standard isochrone maps produced for other tree taxa in the UK (Birks 1989).

By around 8,000 years ago, the structure of the woodlands began to change, with oak and elm taking over from birch as the main woodland canopy formers, although hazel still remained an important component of the woodland understorey vegetation. The climatic conditions within central Scotland had ameliorated by this time, allowing these thermophilous tree taxa to colonise the area. The native woodland composition reflected in the pollen diagram is consistent with that which would have been expected for this area from the potential woodland cover maps of Bennett (1989). The low diversity of herbaceous pollen types within the pollen diagram at this time may be a result of the closed nature of the woodland canopy surrounding the site. The main pollen inputs to the site would be from the vegetation growing on the site (local component), from the trees forming the bulk of the mature woodland trees (canopy component) and from the more regional pollen rain. This would have reduced the amount of pollen from low growing herbaceous plants that grown on the woodland floor (trunk space component) that would have managed to reach the middle of the mire (Moore *et al* 1991). The fen itself had begun to develop into a true raised mire by this time and the surface vegetation became dominated by *Sphagnum* moss, cotton grass and heather. Cotton Grass (*Eriophorum)* is not specifically identifiable in the pollen record but is visible in the plant macrofossil remains from the peat core stratigraphic analysis.

A notable change in the woodland composition occurred approximately 5,200 cal BP (3250 cal BC) with a sudden decline in the representation of elm pollen within the pollen diagram. The mid-Holocene Elm Decline is a phenomenon that is seen in pollen diagrams throughout the British Isles. It is also one of the most frequently radiocarbon dated events in these diagrams. A synthesis of this dating evidence by Parker *et al* (2002) has suggested a start date for the Elm decline of 6325 ± 18 cal BP and an end date of 5265 ± 25 cal BP. Much of the timespan between these dates is a result of the inherent errors in the method of radiocarbon dating and it is thought that the Elm decline was a more or less synchronous event over Britain as a whole. The date of 5,200 cal BP for the Elm Decline at Ravelrig Bog is at the very youngest end of the suggested date range but is still consistent with that range. There is no evidence for an anthropogenic cause for this Elm Decline and disease (e.g. Dutch Elm Disease) is considered a more probable reason for the sudden and catastrophic reduction of this species within the woodland flora in the UK. At Ravelrig Bog, elm appears to make a slight recovery after the main Elm Decline but there is a second and possibly third episode of decline during the period 4 - 5000 cal BP. Multiple elm declines were also noted by Whittington *et al* (1991b) at Black Loch, Fife, and these were thought to represent further outbreaks of disease rather than any specific anthropogenic impact that affected elm alone.

The first potential evidence for human impact on the landscape occurs around 4,700 cal BP (2750 cal BC) with a slight, but sustained, increase in grassland taxa. There are some trace finds of barley type pollen in the diagram at levels dated to approximately 6600 cal BP (4650 cal BC) and 5900 cal BP (3959 cal BC) but these very early records of cereal type pollen may be from the wild grass *Glyceria*, rather than from barley itself (Andersen 1979) since there is little, if any, corroborating evidence for agricultural activity in the pollen diagram at these times.

More definitive evidence for human impact, in the form of woodland clearance and farming activity, occurs from approximately 4,100 cal BP (2150 cal BC). There are small, but significant, increases in grass and other open ground taxa, particularly the weedy types associated with land used by grazing animals. Bronze Age clearances have been noted from pollen diagrams from elsewhere in central Scotland (Ramsay 1995; Turner 1975) but these are often only temporary episodes of clearance (Turner 1975), whereas the clearances at Ravelrig appear to be more permanent in nature. The intensification of agriculture during the Bronze Age at Ravelrig may be associated with the intensification of activity noted at Kaimes hillfort during the Bronze Age.

There is a sudden, large increase in agricultural activity at approximately 2,600 cal BP (650 cal BC), which corresponds well with the evidence for wide-spread Iron Age woodland clearances in west-central Scotland (Ramsay 1995; Ramsay and Dickson 1998; Dumayne 1992, 1993a, b) and, consequently, provides further evidence for extensive woodland clearance throughout the central belt of Scotland during the pre-Roman Iron Age. The Iron Age occupation of Dalmahoy hillfort (Stevenson 1951) and the recently excavated palisaded enclosure at Ravelrig may be associated with this agricultural intensification. The radiocarbon date range for the majority of activity at the palisaded enclosure was 400 - 800 cal BC, which corresponds extremely closely to this period of agricultural intensification recorded in the pollen diagram. Although there was a significant amount of woodland clearance for agriculture, the evidence in the pollen diagram is for pastoral, rather than arable agriculture being practiced in the immediate area. It can be difficult to detect arable agriculture in pollen diagrams since cereals are self-fertile and so release little pollen into the air. However, the carbonised plant remains identified from the palisaded enclosure (Ramsay unpublished) contained only traces of cereal grain, which may provide further evidence for a local Bronze Age economy based on pastoral rather than arable agriculture.

The wood used for fuel at the palisaded enclose did not appear to have been selected for specific burning properties, since at least nine taxa were present in contexts associated with hearths or hearth waste. However, constructional material seemed to have been deliberately selected as oak and willow wood were dominant within the outer enclosure ditch and hazel and alder were commonest in the inner enclosure ditch. From the pollen diagram it is clear that all woodland trees showed a decline at this time, lending evidence to the assumption that the palisaded enclosure was built using local resources. The abundance of willow in the outer enclosure ditch, and the low levels of willow pollen in the diagram, might suggest that the inhabitants of the palisaded enclosure had to travel slightly further to collect this wood type than any of the others. However, the low levels of willow pollen might be evidence for the management of willow as coppice woodland, with thin willow wands cut before they were old enough to produce significant numbers of pollen-bearing catkins.

There appears to be a slight decline in agricultural activity around 2000 - 1800 cal BP (250 cal BC - cal AD 150), which could be the result of the abandonment of Dalmahoy hillfort and could also be associated with the Roman invasion of the area during this period. Birch pollen levels increase significantly, suggesting that land that was previously farmed was abandoned and was gradually colonised by birch woodland - birches being pioneer species that colonise open ground prior to climax tree species, such as oak and elm, which colonise the wooded area later in the succession.

There is a slight increase in agricultural activity for a short period between approximately 1350 - 1550 cal BP (cal AD 400 - 600), which might correspond with the proposed reoccupation of Dalmahoy hillfort in the Early Historic period (Stevenson 1951). There is a further decline in agriculture and a recolonisation of land by alder and birch during the period 500 - 1350 cal BP (cal AD 600 - 1450). This adds to the evidence obtained from other sites in central Scotland for a widespread decline in agriculture, with a corresponding regeneration of woodlands during much of this period (Ramsay 1995; Dumayne 1998; Stewart *et al* 1984). It is not clear what the cause of this agricultural decline might be but further work may be able to determine a more precise date range for this event. Lamb (1977) suggests that there were some reversions to a colder and wetter climate during the sixth to ninth centuries AD, which could explain why areas once suitable for agriculture perhaps became too wet to grow crops and agriculture had to be moved to sites with better drainage. This explanation could account for the significant increase in alder (a tree of wetter areas and river banks) that is seen at Ravelrig during this period.

The final major phase of woodland clearance began at approximately 500 cal BP (cal AD 1450), with huge increases in grass pollen and corresponding declines in all the major trees and tall shrubs. There are traces of barley type pollen present but little evidence for any degree of intensive arable agriculture in the vicinity of the site. Much of the cleared land was probably used for grazing animals. Heather also shows a significant increase at this time and so it is probable that this is when the bog surface started to dry out, perhaps as a result of early attempts to drain the wetter ground around the site to provide further pasture land. There is also a significant peak in charcoal, which may also indicate a drying of the bog surface and natural or deliberate burning of the heather that had colonised the bog surface. A large peak in bracken spores during the last 300 years is probably evidence of bracken that encroached onto the bog surface as it dried out, rather than representing widespread growth of bracken in the area.

A small increase in pine pollen during the last 200 years is probably evidence of the planting of large scale conifer plantations and is a good indication that the top of the peat and pollen sequence is intact, albeit with a much reduced degree of temporal resolution due to the slow peat growth during this latter period.

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Appendix

Table A1: Pollen taxa with only a single, trace occurrence that are not shown in the pollen diagrams.

Pollen taxon	Depth (cm)
Trees	
Ilex	216 - 217
Tall shrubs	
Ulex	552 - 553
Herbs	
Chamaenerion angustifolium type	768 - 769
Fabaceae	380 - 381
Fumaria	120 - 121
Linum	62 - 63
Lysimachia vulgaris type	136 - 137
Rhinanthus	768 - 769
Thalictrum	50 - 51
Valeriana	744 - 745
Aquatics	
cf Butomus umbellatus	720 - 721
Menyanthes trifoliata	576 - 577
Potamogeton	744 - 745
Utricularia	600 - 601
Pteridophytes	
Cryptogramma crispa	768 - 769
Lycopodium	552 - 553
Selaginella selaginoides	768 - 769

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