7.4.4 The landscape and environmental setting for the Pictish monastery at Portmahomack

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Introduction `

This paper contains the results of a pollen analytical investigation that was conducted to set the Pictish monastery at Portmahomack within a wider landscape and environmental context. The interpretation is focussed on relating phases of human activity reconstructed in the pollen record with the sequence of events identified in the archaeological record, although this approach will naturally be inexact, and some offset and overlap between the sequences is likely. A chronological framework for the archaeological sequence at Portmahomack has already been constructed from stratigraphic analysis and radiocarbon dating with Bayesian analysis (see Chapter 3). Given the importance this holds for any environmental reconstruction, a brief résumé follows before beginning a full account of the present study.

The archaeological record at Portmahomack may be divided into six phases. There is Bronze Age and Iron Age activity in *Period 0* (before the 5th century) including a charcoal burner's pit dated AD 170-380. Activity increases in *Period 1* (the late Iron Age; 5th to 7th centuries AD, but still pre-dating construction of the monastery) when there is evidence for a number of long cist burials, iron working, a well and ard marks. At this time it is believed that the valley bottom near the monastery was marshy and unoccupied . The monastery begins in the late 7th century with the construction of a metalled road and a dam across the valley, thereby creating a pond (Chapter 5). The monastery flourished for only a short time (~100-150 years between *ca* AD 650 and 800; designated as *Period 2*) and was raided around AD 800. The pond still held water for the next century or so during which a metal workshop was active at the site (*Period 3A*; AD 800-1000). The pond thereafter was believed to have dried out (Periods 4,5).

The palaeoecological history of the area has been studied using animal, insect and plant and soil micromorphology. The aim of the present investigation was to contribute a wider environmental interpretation for the site using pollen analysis of sediment from the pond and the marsh that preceded it. The sequence was examined by cutting a trench through the deposits postulated as relating to the pond (context 2296) and the marsh (context 2310) (Figs 1 & 2). Two columns of sediment (monoliths) were taken for plant and insect analysis with one monolith made available for pollen analysis (sample numbers 4887-4910). The latter was sub-sampled for pollen analysis and radiocarbon dating in order to: (i) reconstruct the vegetation history around the site and date the main changes; (ii) to confirm the postulated nature of the (pond and marsh) deposit; and (iii) to attempt to identify any human impacts on the environment that could be associated with activities at the monastery.

Methodology

Pollen analysis

Samples for pollen analysis were contiguous slices of 2 cm thickness. These were prepared using standard techniques (Moore et al., 1991) with the addition of an exotic marker (*Lycopodium* tablets) to allow the calculation of microfossil concentrations (Stockmarr, 1971). Samples were mounted on slides and examined using a Nikon E200 light microscope at x400 magnification. A minimum of 500 total land pollen (TLP; trees, shrubs, heaths, and herbs) were counted per sample. Pollen was identified using the keys, photographs and diagrams in Moore et al. (1991) and Fægri & Iversen (1975), and the reference collection held at the University of Aberdeen. Non-pollen palynomorphs (NPPs) were identified with the assistance of the photographs and notes in van Geel (1978) and van Geel et al. (2003) and are assigned the prefix HdV- (Hugo de Vries-Laboratory, Amsterdam) following recommendations outlined in Feeser & O'Connell (2010). Cereal-type pollen was measured and classified according to the categories set out in Andersen (1979).

Charcoal analysis

Microscopic charcoal particles were measured using a microscope eyepiece graticule at x400 magnification. Due to the abundance of charcoal in some samples, only the first 50 fragments encountered in each sample were counted. The charcoal data is presented as charcoal to pollen concentration (C:P) ratio (cf. Patterson et al., 1987).

Numerical analysis

The pollen diagram was constructed using Tilia and Tilia graph software and divided into local pollen assemblage zones (LPAZs) using constrained cluster analysis (CONISS) as an aid to zonation. Pollen is expressed as a percentage of total land pollen (TLP), and NPPs as a percentage of TLP.

Results

Chronology

Calibrated AMS ^{14}C dates were provided by Martin Carver (pers. comm.) and are reproduced in Table 1. The dates come from two parallel profiles taken from the marsh, including that from which the pollen samples were drawn.

Table 1. Radiocarbon dates from the marsh/pond. Dates were calibrated using OxCal v.3 (2σ confidence limits).

Zone (LPAZ)	Depth (cm)	Lab code	^{14}C date	Calendar date	Period	Material dated
PMH-4	4	S-14995		AD 650-840	**Period 3** 9th-11th century AD. Post monastic farm and metalworkshops.	Latest pool deposit
PMH-3	-	S-13276		AD 650-780	**Period 2** Pictish monastery (650-800 AD)	Stake by the dam.
	26	S-14994		AD 590-760		Radiocarbon date on birch twig from the earliest part of the pool deposit.
PMH-2	-	S-13277		AD 640-770	**Period 1** Late Iron Age 5th-7th century	Stake in marsh
	28	S-14989		AD 600-760		Latest marsh deposit
PMH-1	48	S-14990		720-380 BC	**Period 0** Prehistoric	
	?	S-13264		770-400 BC		

There is significant overlap in the calibrated ages of radiocarbon dates from the pond across *periods 1, 2 and 3*, when compared with the terrestrial (archaeological) evidence, where these periods appear stratigraphically distinct. This makes it difficult to place dates on changes appearing in the pollen record, or to correlate these precisely with events in the archaeological record. On the basis of both the chronological sequence from the marsh/pond and the microfossil content of samples, phases of activity identified in the pollen record (as LPAZs, discussed below) have been assigned to *periods 0-3* as shown in Table 1, although the temporal boundaries supporting this framework should be regarded as somewhat tentative.

Palynology

A percentage pollen diagram displaying selected taxa is presented in Figure 1. The main features of the four LPAZs are described in Table 2.

Table 2. Description of the local pollen assemblage zones (LPAZs) from Portmahomack.

LPAZ	Description
PMH-1 43-46cm	Dominated by pollen from Cyperaceae (~40% TLP). Significant amounts of Brassicaceae (~2-5%), *Artemisia*-type (~2%) and Lactuceae (~5-10%). Relatively little pollen from trees and shrubs (<20%). High levels of charcoal and coprophilous fungal spores (HdV-55A and -113). The lowest sample in this zone is dated 770-400 BC.
PMH-2 27-43cm	Arboreal pollen percentages remain low. Cyperaceae increases slightly and exceeds 60% in some samples. *Calluna* frequencies rise and approach 10%. Poaceae decreases throughout most of the zone but values begin to recover above 30 cm. Levels of charcoal are reduced relative to the base of PMH-1. *Plantago lanceolata* (≤5%) and Lactuceae (~1-6%) are consistently present at low frequencies.
PMH-3 11-27cm	This zone sees an increase in shrubs and heaths, especially *Corylus* (~2-5%) and *Salix* (≤3%). There is a sharp decrease in Cyperaceae matched by an increase in Poaceae at the PMH-2/3 zone boundary. Brassicaceae (~3-10%) increases after reduced occurrence in the previous zone. Traces of pollen from obligate aquatic plants (*Typha latifolia, Stratiotes aloides*) are recorded. Cereal pollen is consistently recorded at 2-3%. Coprophilous fungal spores (particularly HdV-55A) increase and large numbers of *Anthostomella fuegiana*-type spores are recorded. A birch twig in the sample just above the PMH-2/3 zone boundary is

	dated cal AD 590-760.
PHM-4 0-11cm	Poaceae and Cyperaceae remain constant. *Filipendula* (~5%) has the highest levels seen in the profile. Several other fen herbs are prominent (e.g. Apiaceae, Ranunculaceae, *Potentilla*-type). *Artemisia* increases to a profile peak (~10%) mid-zone but reduces towards the top of the profile. Cereal-type pollen declines in importance close to the end of the zone, as do Brassicaeae and coprophilous fungal spores. A sample near the top of the zone returned a date of cal AD 640-810.

Interpretation and Discussion

LPAZ PMH-1 (broadly equivalent to Period 0)

Prior to the occupation of the area, the landscape surrounding the site was largely treeless. Relatively low percentages of tree and shrub pollen are recorded during this LPAZ. Low frequencies of *Alnus* and *Salix* pollen may represent wet woodland or vegetation communities along river banks and floodplains, whilst *Quercus*, *Betula*, *Ulmus* and *Corylus* may have occupied drier soils. These low percentages are indicative of either long-distant transport or the occurrence of small local stands of trees. The percentages of trees and shrubs remains low throughout the remainder of the diagram (LPAZs PMH 2-4) suggesting that woodland cover was consistently sparse with no clear evidence for any woodland regeneration.

Pollen and spores of apophytes – taxa favoured and spread by human activity; *sensu* Behre (1988) – appear in PMH-1. Pollen assemblages are consistent with a landscape characterised by a mixed farming regime. Evidence for pastoral farming is provided by relatively high percentages of *Plantago lanceolata* (ribwort plantain) and Poaceae, which reach 10% and 20% TLP respectively, and the occurrence of a suite of herbs typical of rough pasture or meadows including Asteraceae, *Cirsium*-type, Caryophyllaceae, Lactuceae, Ranunculaceae, *Potentilla*-type and *Rumex acetosa* (Brown et al., 2007). Indicators of broken or disturbed ground, and arable 'weeds' are possibly represented by pollen from Apiaceae, Brassicaeae, Chenopodiaceae and *Artemisia*-type (Brown et al., 2007). The charcoal record shows C:P ratio peaks in the lowermost sample (46 cm) which may point to purposeful burning to clear land for agriculture, and/or a contribution from domestic fires.

Coprophilous (dung) fungal spores are also recorded in this zone, including relatively high levels of *Sporormiella*-type (HdV-113) and *Sordaria*-type (HdV-55A), plus the occurrence of *Tripterospora*-type (HdV-169) (van Geel et al., 2003). HdV-55A and -113 are considered to be very reliable indicators for the presence of large herbivores (Baker et al., 2013). *Sporormiella* spores do not disperse far from source (Raper & Bush, 2009) and their high abundance, together with those of HdV-55A, strongly suggests that grazing occurred close to the site.

The small decrease in arboreal pollen across the LPAZ PMH-1/2 boundary is probably the result of a local expansion of the marsh, as Cyperaceae and *Equisetum* percentages increase. An association between Cyperaceae pollen and *Gaeumannoyces* (HdV-126) may be justified on the basis of broadly parallel changes in both microfossils. Pals et al. (1980) and van Geel (2001) suggest that HdV-126 spores are indicative of the local presence of *Carex* species (a member of the Cyperaceae). *Carex* spp. are common amongst fen vegetation and also often play a role in lake margin communities and the shallow phases of lakes. A number of NPPs indicative of shallow pools are recorded during LPAZ PMH-1 and the first part of PMH-2 including heterocysts of *Rivularia*-type, HdV-140, HdV-314 and HdV-341. *Rivularia*-type is a cyanobacterium that blooms in eutrophic, nitrogen-depleted shallow waters (van Geel et al., 1996) and their occurrence can often be explained by increased phosphorus (P) concentrations. The presence of *Rivularia*-type could be an indication of increased nutrient loading which might be derived from animal dung/manure or from weathering of phosphorus-rich bedrock and/or fertilisers (Mighall et al., 2012). However, percentages of herbs indicative of human activity and the abundance of the coprophilous fungi decrease simultaneously with the decline in tree pollen, suggesting that land use became less intense at this time.

LPAZ PMH-2 (broadly equivalent to Period 1)

The increase in Cyperaceae and *Equisetum*, and the presence of Apiaceae, Ranunculaceae, Rubiaceae, *Filipendula* pollen and *Sphagnum* spores throughout LPAZ PMH-2 suggest an expansion in marshland communities across the site. NPPs indicative of shallow water (as described earlier for PMH-1) are also recorded in the first part of this LPAZ. With the exception of *Gaeumannoyces*, their presence fades out by 35 cm suggesting that the marsh became drier for a short period during the late Iron Age and that standing pools of water across the surface were less common. *Selaginella*, commonly found on damp grass or mossy ground (Clapham et al., 1987), is present in the latter half of the zone and the first occurrence of *Typha latifolia*, Spermatophores of Copepoda (HdV-28) and Zygnemataceae (HdV-58) at the very end of the LPAZ suggests a return to slighter wetter conditions just prior to the PMH-1/2 boundary dated ~AD 600-760.

Pollen assemblages in PMH-1 and PMH-2 provide supporting evidence for arable farming at the site in this period. Traces of cereal pollen are recorded at the PMH-1/2 boundary and this is consistent with evidence for the early ard-plough marks at the site which preceded the monastery. Cereal pollen is often under-represented in pollen diagrams, only occurring in small amounts, as cereals produce relatively little pollen for most are self-pollinating (Maguire, 1983) and are also poorly dispersed due to their large size (Edwards *et al.*, 2005). Heim (1963) suggested that cereal percentages of 3-4% were indicative of arable farming within 2 km of a site, whereas percentages of 4-5% are sufficient to suggest cultivation occurred within a few hundred meters. Alternatively the cereal pollen could represent the processing of crops brought onto the site.

Evidence for both arable and pastoral farming diminishes through LPAZ PMH-2 suggesting the intensity of land-use decreased during this period. Many of the taxa with cultural affinities described earlier only occur in trace amounts. A marked but gradual reduction in Poaceae percentages occurs and cereal-type pollen is largely absent. There is also a relative reduction in the percentages of some herbs often interpreted as agricultural 'weeds' (e.g. *Artemisia*-type, Brassicaceae and Lactuaceae) and coprophilous fungi. Lower levels of microscopic charcoal also imply that burning, either natural or anthropogenic, occurred less frequently.

LPAZ PMH-3 (broadly equivalent to Period 2)

Sharp changes in the frequencies of many pollen types and NPPs occur across the PMH-2/3 zone boundary. In particular, Cyperaceae, *Equisetum*, *Selaginella* and *Gaeumannoyces* percentages fall, whilst Poaceae and cereal-type values rise. A suite of herbs are more abundant (e.g. Brassicaceae, Caryophyllaceae and Chenopodiaceae), and *Sordaria*-type, *Sporormiella*-type and *Anthostomella fuegiana* percentages also increase. Acute biostratigraphic changes are often indicative of a hiatus in sediment accumulation. Although a pond was created in the valley at the beginning of the monastic phase, deep and open standing water is not strongly reflected in the pollen and spore assemblages. In the lower section of PMH-3, between 27-23 cm, the most commonly occurring NPPs are indicators of drier conditions: *Gelasinospora* species (HdV-1&2) and *Coniochaeta xylariispora* (HdV-6). There are, however, trace amounts (<2%) of pollen from both *Typha latifolia* (bulrush) and *Stratiotes aloides* (water-soldier) – these are largely absent from earlier LPAZs – which could indicate the local presence of reedswamp fringing a shallow pond. In this LPAZ there is also a reduction in pollen from fen plants, notably Cyperaceae, and a large increase in Poaceae pollen. While the latter may largely be reflective of a more intensively managed agricultural landscape (discussed in more detail below), the common reed (*Phragmites australis*) is also part of the grass family, and it may be the case that some of the Poaceae pollen recorded here belongs to this plant. Yet as the pond was likely to be the main source of drinking water for the monastery, and was surrounded by a stone wall, it may be a reasonable assumption that it was kept largely clear of vegetation.

Above 21 cm, NPPs indicative of wetter conditions (including shallow water environments) also increase in frequency and occurrence. *Anthostomella fuegiana,* which is well represented in this LPAZ*,* grows on *Eriophorum vaginatum*, a species of sedge commonly found on acid mires (van Geel, 1978). The sharp peak in *A. fuegiana* at 17 cm suggests that *E. vaginatum* was growing on, or very close to, the sampling location. A small increase in *Salix* may reflect the development of willow carr, possibly fringing the pond. *Corylus* can grow on damp soils and it is also relatively prominent throughout PMH-3 relative to the earlier LPAZs.

Farming appears to have intensified during PMH-3. This seems in agreement with stable isotope investigations of human bone which suggest that the monastic community had a terrestrial diet containing little or no marine foods (Curtis-Summers, pers. comm.) and that the monks were largely reliant on the land to provide their food. Pollen from grasses (Poaceae) increases as do herbaceous taxa typical of pastures and meadows such as Asteraceae, *Cirsium*-type, Caryophyllaceae, Lactuceae and *Plantago lanceolata*. Relatively high percentages of *Sporormiella*-type and *Sordaria*-type, and the occasional appearance of *Podospora*-type and *Tripterospora*-type – all coprophilious spores – suggest that animals grazed within tens of meters of the sample site (Baker et al, 2013). Cereal-type pollen occurs in every sample and increases to around 2%. Rachis fragments found in a ditch (Hall & Kenward, unpublished) suggest on-site threshing of various cereals such as wheat (*Triticum*), barley (*Hordeum*) and rye (*Secale cereale*). Robinson & Hubbard (1977) found that hulled cereal grains can also carry cereal pollen and it is possible that this process has contributed to the elevated cereal-type pollen values recorded here. The regular occurrence of pollen from 'weeds' of cultivation (e.g. *Artemisia*-type, Brassicaeae, Chenopodiaceae) is also strongly indicative of arable activity; these taxa are also typically associated with footpath and ruderal communities, and broken or disturbed ground (Behre, 1981). The increase in Brassicaceae (cabbage family) pollen to 10% in PMH-3 raises the possibility that vegetables may have been cultivated (Foster, 2004).

The availability of wood and timber would have been important to the monks at Portmahomack for building and as a fuel for metalworking and other activities. Although peat may have been a viable fuel for domestic activities, metalworking would require large quantities of charcoal (Church et al., 2007) and this may have contributed to the increased C:P ratio in this LPAZ, possibly more so than burning in domestic settings (cooking, heating) and natural fires. There are suggestions from the archaeological record that woodland management (such as coppicing) may have been practiced at Portmahomack as hurdles and rods used to construct wattle have been recovered (Hall & Kenward, unpublished). The identification of charcoal from mature trees (*ibid.*) suggests that fuel provision was well organised rather than *ad hoc*, yet the pollen record demonstrates that the landscape was very open and largely treeless at this time. Low pollen percentages of *Alnus glutinosa* (alder), *Betula* (birch), *Pinus* (pine), *Quercus* (oak) and *Ulmus* (elm) could be either the result of long distance transport (Gregory, 1978) or derived from small local stands of trees, and it may have been the case that most wood and timber used on the site was brought in, i.e. sourced from locations some distance from the monastery. *Corylus* (hazel) does increase in PMH-3 which could reflect management of this shrub. Coppicing, pollarding and shredding have been practiced for thousands of years as a method of producing fodder, fuel and building materials (Rackham 1990; Out et al., 2013). Studies and simulations within areas of woodland that are still actively managed show that coppicing cycles can ultimately lead to enhanced pollen production for both hazel and alder (Waller et al. 2012). There are difficulties in the identification of such practices in the pollen record as factors such as the length of rotation cycles, woodland composition and the properties of the depositional environment from which the pollen samples are taken will each have an influence on the composition of assemblages. Furthermore, the temporal resolution of the samples from Portmahomack (2 cm thickness) may make it impossible to distinguish any such short term events with any degree of certainty.

LPAZ PMH-4 (broadly equivalent to Period 3)

The agricultural activities described for PMH-3 continue into PMH-4, although a small reduction in Poaceae, cereal-type pollen, herbs and NPPs representative of pasture is recorded, which suggests a shift to a less intense farming regime. At the top of PMH-4 many of the taxa indicative of farming reduce to trace amounts. Low frequencies of pollen and spores from aquatic taxa and NPPs indicative of wet substrates and shallow pools persist. For example, *Typha latifolia*, *Equisetum*, *Stratiotes*, *Selaginella* and the NPPs *Rivularia*-type, HdV-314, HdV-341, and HdV-342 are all present at varying frequencies.

The reduction in agricultural pollen is consistent with the end of the intensive phase of farming witnessed in PMH-3. Moderate percentages of Cyperaceae and increased representation of tall wetland herbs (e.g. *Filipendula*, Apiaceae, Ranuculaceae and Rubiaceae) may reflect a re-expansion of minerotrophic fen communities across the site. This pattern might be expected if the pond had fallen into disuse and had largely filled with sediment.

Conclusion

The pollen record has provided valuable evidence regarding the vegetation history and land use changes in the Portmahomack area prior to, during, and after the period the monastery was in use. The earliest evidence for human impact is registered at the base of the core and dates from the Late Iron Age (early first millennium AD; within *Period 0*) with traces of cereal pollen recorded by the 7th century AD (*Period 1*) at the latest. A period of intensive farming followed with an emphasis on grazing, although the intensity of cereal cultivation probably also increased. This apparently broadly coincided with the occupation of the monastery in the 8th century (within *Period 2*). There is evidence that farming continued following the destruction of the monastery but the pollen record suggests that it was either less intensive or activity was occurring at greater distance from the sampling site. This is consistent with the use of grain drying and shift in cultivation further south in *Period 3* (~9th and 10th centuries) and the subsequent abandonment of the area.

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References

Andersen, S.T. 1979. Identification of wild grass and cereal pollen. *Geol Undersøgelse Arbog*. pp69-92.

Baker, A.G., Bhagwat, S.A. & Willis, K.J. 2013. Do dung fungal spores make a good proxy for past distribution of large herbivores? *Quaternary Science Reviews* 62, 21-31.

Behre, K-E. 1981. The interpretation of anthropogenic indicators in pollen diagrams. *Pollen et Spores* 23, 225-245.

Behre, K-E. 1988. The rôle of man in European vegetation history. In: Huntley, B. & Webb, T. III (eds) *Vegetation history*. Dordrecht: Kluwer, pp.633-672.

Brown, A. G., Carpenter, R.G. & Walling, D.E. 2007. Monitoring fluvial pollen transport, its relationship to catchment vegetation and implications for palaeoenvironmental studies. *Review of Palaeobotany and Palynology* 147, 60-76.

Carver, M. 2004. An Iona of the east: the early-medieval monastery at Portmahomack, Tarbat Ness. *Society for Medieval Archaeology* 48, 1-30.

Carver, M. 2008. *Portmahomack monastery of the Picts*. Edinburgh: Edinburgh University Press.

Church, M.J., Dugmore, A.J., Mairs, K.A., Millard, A.R., Cook, G.T., Sveinbjarnardóttir, G., Ascough, P.A. & Roucoux, K.H. 2007. Charcoal production during the Norse and Early Medieval periods in Eyjafjallahreppur, southern Iceland. *Radiocarbon* 49, 659-672.

Clapham, A.R., Tutin, T.G. & Moore, D.M. 1987. *Flora of the British Isles* (3rd ed.). Cambridge: Cambridge University Press.

Edwards, K.J. & Hirons, K.R. 1984. Cereal pollen grains in pre-elm decline deposits: implications for the earliest agriculture in Britain and Ireland. *Journal of Archaeological Science* 11, 71-80.

Edwards, K.J., Whittington, G., Robinson, M. & Richter, D. 2005. Palaeoenvironments, the archaeological record and cereal pollen detection at Clickimin, Shetland, Scotland. *Journal of Archaeological Science* 32, 1741-1756.

Fægri, K. & Iversen, J. 1975. *Textbook of pollen analysis, 3rd edition*. Oxford: Blackwell.

Feeser, I. & O'Connell, M. 2010. Late Holocene land-use and vegetation dynamics in an upland karst region based on pollen and coprophilous fungal spore analyses: an example from the Burren, western Ireland. *Vegetation History and Archaeobotany* 19 (5-6) 409-426.

Foster, S.M. 2004. *Picts, Gaels and Scots*. London: B.T Batsford.

Gregory, P.H. 1978. Distribution of airborne pollen and spores and their long distance transport. *Pure and Applied Geophysics* 116, 309-315.

Heim, J. 1963. Recherches sue les relations entre la vegetation actuelle et le spectre pollinique recent dans les Ardennes Belges. *Bulletin de la Société Royale de Botanique de Belgique* 96, 5-92.

Johnston, E. & Soulsby, C. 2000. Peatland conservation in Buchan, north-east Scotland: the historic context and contempory issues. *Scottish Geographical Journal* 116, 283-298.

Maguire, D.J. 1983. The identification of agricultural activity using pollen analysis. In: Jones, M. (ed.) *Integrating the subsistence economy*. British Archaeological Reports, International Series 181, 5-18.

Mighall, T.M., Foster, I.D.L., Rowntree, K.M. & Boardman, J. 2012. Reconstructing recent land degradation in the semi-arid Karoo of South Africa: a palaeoecological study at Compassberg, Eastern Cape. *Land Degradation & Development* 23 (6) 523-533.

Moore, P.D., Webb, J.A. & Collinson, M.E. 1991. *Pollen analysis, 2nd edition*. London: Blackwell.

Out, W.A., Vermeeren, C. & Hänninen, K. 2013. Branch age and diameter: useful criteria for recognising woodland management in the present and past. *Journal of Archaeological Science* 40, 4083-4097.

Pals, J.P., van Geel, B. & Delfos, A. 1980. Paleoecological studies in the Klokkeweel Bog near Hoogkarspel (Prov. Of Noord-Holland). *Review of Palaeobotany and Palynology* 30, 371-418.

Patterson, W.A., Edwards, K.J. & Maguire, D.J. 1987. Microscopic charcoal as a fossil indicator of fire. *Quaternary Science Reviews* 6, 3-23.

Rackham, O. 1990. *Trees and woodland in the British landscape, 2nd edition*. London: Dent.

Raper, D. & Bush, M. 2009. A test of *Sporormiella* representation as a predictor of megaherbivore presence and abundance. *Quaternary Research* 71, 490-496.

Robinson, M. & Hubbard, R.N.L.B. 1977. The transport of pollen in the bracts of hulled cereals. *Journal of Archaeological Science* 4, 197-199.

Tipping, R. 1994. The form and fate of Scotland's woodlands. *Proceedings of the Society of Antiquaries of Scotland* 124, 1-54.

van Geel, B. 1978. A palaeoecological study of Holocene peat bog sections in Germany and the Netherlands. *Review of Palaeobotany and Palynology* 25, 1-120.

van Geel, B., Buurman, J., Brinkkemper, O., Schelvis, J., Aptroot, A., van Reenen, G. & Hakbijl, T. 2003. Environmental reconstruction of a Roman period settlement site in Uitgeest (The Netherlands), with special reference to coprophilous fungi. *Journal of Archaeological Science* 30, 873-883.

van Geel, B. 2001. Non-pollen palynomorphs. In: Smol J.P, Birks., H.J.B, Last W.M. (eds) Tracking environmental change using lake sediments. Volume 3 terrestrial, algal and siliceous indicators. Kluwer, Dordrecht, pp 99–119.

Van Geel, B., Kink, A.G., Pals, J.P. & Wiegers, J. 1986. An upper Eemian lake deposit from Twente, Eastern Netherlands. *Review of Palaeobotany and Palynology* 47, 31–61.

Waller, M., Grant, M.J. & Bunting, M.J. 2012. Modern pollen studies from coppiced woodlands and their implications for the detection of woodland management in Holocene pollen records. *Review of Palaeobotany and Palynology* 187, 11-28.