Journal of Archaeological Science 38 (2011) 1957–1966

Contents lists available at ScienceDirect

Journal of Archaeological Science

journal homepage: http://www.elsevier.com/locate/jas

Detecting the environmental impact of the Baltic Crusades on a late-medieval (13th–15th century) frontier landscape: palynological analysis from Malbork Castle and hinterland, Northern Poland

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ARTICLE INFO

Article history:
Received 25 January 2011
Received in revised form
14 April 2011
Accepted 15 April 2011

Keywords:
Paleoecology
Human impact
Agricultural intensification
Crusades
Poland
Palynology

ABSTRACT

Palaeoecological analysis of peat deposits from a small bog, combined with pollen analysis of sediments infilling the moat of the nearby Teutonic Order castle at Malbork, have been used to examine the ecological impact of the Crusades on the late-medieval landscape of Northern Poland. Studies of the environmental impact of the Crusades have been almost exclusively informed by written sources; this study is the first of its type to directly investigate the environmental context of Crusading as a force of ecological transformation on the late-medieval Baltic landscape. The pollen evidence from Malbork Castle and its hinterland demonstrate that the 12th/13th–15th centuries coincide with a marked transformation in vegetation and land-use, characterized by clearance of broadleaved woodland and subsequent agricultural intensification, particularly during the 14th/15th centuries. These changes are ascribed to landscape transformations associated with the Teutonic Order's control of the landscape from the mid-13th century. Human activity identified in the pollen record prior to this is argued to reflect the activities of Pomeranian settlers in the area. This paper also discusses the broader palaeoecological evidence for medieval landscape change across Northern Poland.

1. Introduction

In the early-13th century, the Teutonic Order and its allies directed a series of military campaigns framed as crusades against the Prussian tribes in the South–Eastern Baltic region, with the aim of protecting Christian converts in the region. The crusades were initially launched from Polish territory in the Kulmerland (Ziemi Chełminskie), and then proceeded north down the Vistula towards the Baltic coast and subsequently eastwards. The conquest of Prussian tribal lands is documented to have lasted from 1235–1287 (Urban, 2003). The Order ultimately defeated its pagan and Christian enemies and established its own state in the region, which expanded in 1309 with the annexation of Gdańsk (then Danzig) and Pomeralia. The conquest was followed by colonization and the development of networks of towns and settlements, all secured with heavily fortified castles (Urban, 1980; Biskup et al., 2009). Population increased within the Teutonic State following the crusades, particularly with the construction of towns. Estimates suggest that by the start of the 14th century the population of the Order's State stood at around 220,000, comprising a mixture of Prussian, Slavic and German ethnicities (Biskup, 2002); the densest populations clustered developed around the towns and castles.

Construction of the castle at Marienburg (today Malbork in northern Poland; Fig. 1) began in 1280, situated on an outcrop of high ground overlooking the River Nogat in a frontier region between Pomeralia and Prussian Pomesania. In 1309, the Order relocated its headquarters from Venice to this site, which prompted the expansion of the castle over the course of the 14th century into one of the largest fortified structures in the world. The landscape around Malbork was substantially re-organised to meet the requirements of the castle, not only the headquarters for the Order's state in Prussia, but also the centre of an administrative region known as a commandery, stretching from the Baltic coast to the southernmost edge of the forest of Sztum (Fig. 1). By the mid-14th century the castle complex became a key hub of trade and communication for the Order's state, as well as a point of departure for crusading expeditions against pagan Lithuania.

The ecological impact of castles, such as Malbork, have often only been referred to indirectly from a predominantly economic perspective in discussions of provisioning, hunting, water management,

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0305-4403/$ – see front matter
doi:10.1016/j.jas.2011.04.010

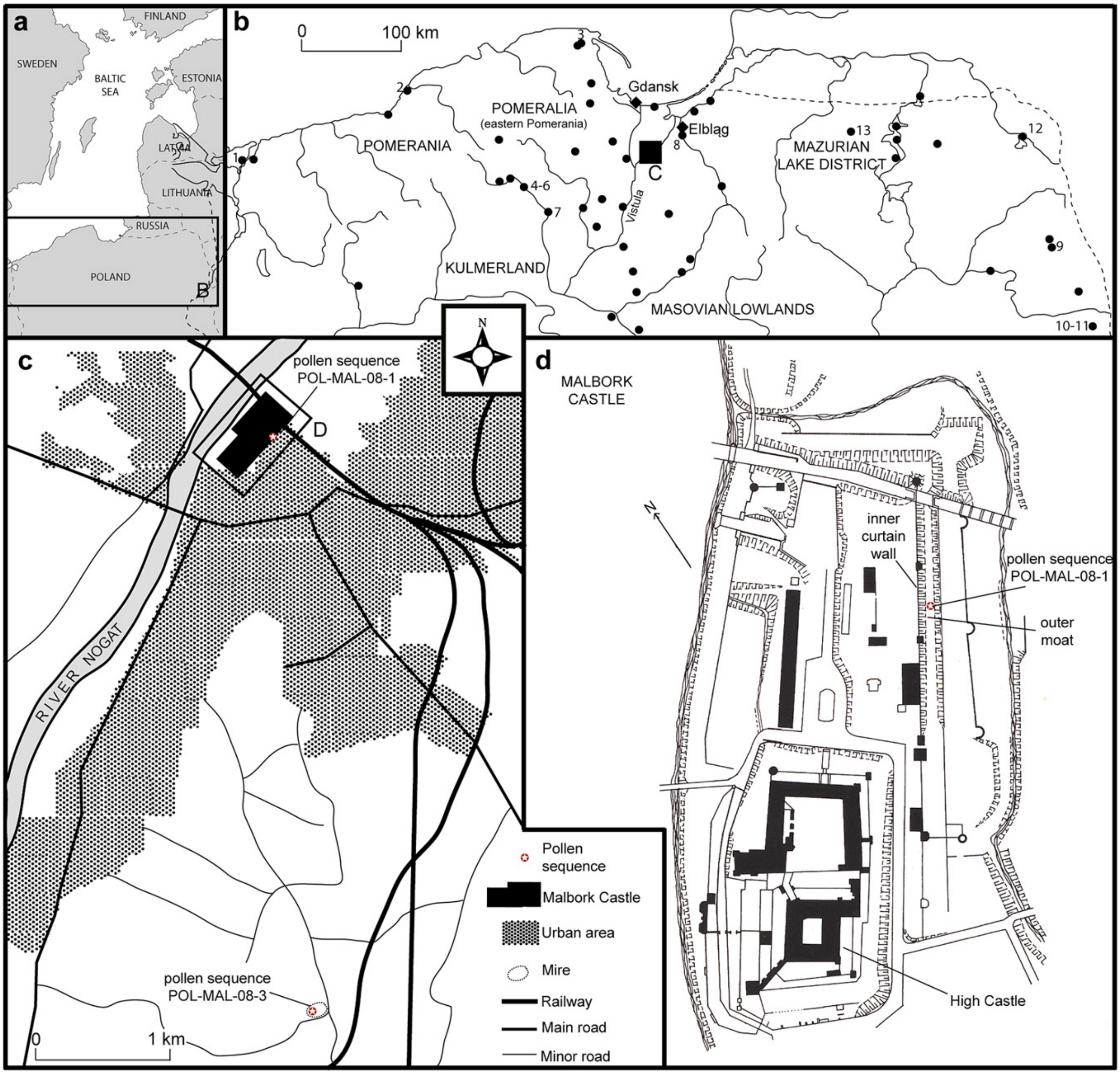

Fig. 1. Map showing: **a** location of that part of Poland (filled in rectangle) shown in b; **b** location of earlier pollen studies (numbered sites named in text) and towns mentioned in text; **c** detailed map of the landscape of Malbork Castle and location of off-site pollen sequence (POL-MAL-08-3); **d** plan of Malbork Castle and location of sequence POL-MAL-08-1. Pollen studies listed in Fig. 1b: 1. Wolin Island (Latałowa, 1992, 1999); 2. Słowinski Błota (Lamentowicz et al., 2009); 3. Darzlubie Forest (Latałowa, 1982); 4. Lake Maly Suszek; 5. Suszek; 6. Kesowo (Berglund et al., 1990; Miotk-Szpiganowicz, 1992); 7. Tuchola (Lamentowicz et al., 2008); 9. Kładkowe Bagno (Kupryjanowicz, 2004); 10–11. Site I and II, Białowieża Forest (Mitchell and Cole, 1998); 12. Lake Wigry (Kupryjanowicz, 2007); 13. Lake Miłkowski (Madeja et al., 2010).

construction materials and fuel. These discussions have almost exclusively been informed by written sources, which predominantly date from the end of the 14th century (e.g. Jóźcwiak and Trupinda, 2007; Chęć, 2007). These sources, often in the form of inventories, demonstrate the diversity and intensity of natural resource exploitation, particularly the importance of fish, animal and agriculture produce (Joachim, 1973). More recently, a range of environmental data recovered from archaeological contexts has been investigated to assess the transformation of the landscape resulting from the dramatic cultural changes following the Crusades of the Teutonic Order and the unfolding of a network of castles, towns and colonizing settlements within its state. From 2007–2009, a series of collaborative projects involved the analysis of faunal assemblages predominantly recovered from the outer bailey or *przedzamcze* of this site (Maltby et al., 2009; Pluskowski et al., 2010). In 2008, this collaboration was extended to include palaeobotanical analysis of cores obtained from the North–Eastern castle moat, the fishpond north of the castle and from peat deposits to the south (Fig. 1). These, and other pilot studies (e.g. Valk et al., 2009) suggest that the period of crusading and colonization coincides with a marked intensification in the exploitation of plant and animal resources, and associated landscape changes in the Eastern Baltic.

This paper demonstrates the contribution that palaeoecological analytical techniques can make to the study of the ecological impact of the Crusades in the South–Eastern Baltic, using as an example Malbork Castle and its hinterland in northern Poland. Particular attention is paid to the palaeoecological evidence for landscape transformation (e.g. woodland clearance) and agricultural intensification. By taking a long-term perspective it will be possible to assess the extent to which local environments in the Baltic were transformed from the 13th–15th centuries as a result of archaeologically and historically documented colonization. To what extent does the crusading movement represent a force of ecological transformation at the frontiers of medieval Christian Europe?

2. History and archaeology of Malbork Castle and hinterland

The Lower Vistula and its tributary the Nogat represented a frontier zone between Slavic Pomeralia (eastern Pomerania) and Prussian Pomesania, which had been settled by the Balts between the 6th–10th centuries AD. The Nogat itself did not mark this boundary as Pomeranian settlements, strongholds and ceramics are noted east of the tributary in the 11th–12th century (including at Malbork), and Slavic place names are recorded around Sztum. In 1236 the area is recorded as a parish linked to the Premonstratensian monastery in Wrocław, granted by the Dukes of Pomerania (Powierski, 1965a). In the 13th century this was a landscape of predominantly Slavic settlement under the political influence of Pomerania and has been mapped by Haftka (1987), with Prussian settlement largely present on the eastern side of the belt of woodland stretching from Kwidzyn to Lake Drużno. The region was a target for missionary activity launched from sites such as Zantyr, which had been given to the first Bishop of Prussia by the Pomeranian Dukes. Prussian expansion resulted in raids on Pomeranian strongholds and shortly after the Teutonic Order arrived, obtained Zantyr around 1236 and established itself at Elbląg the following year. After the war with Duke Sventopelk of Pomerania, the political situation stabilised in the early 1250s and the Order established the commandery (an administrative region) of Zantyr (Powierski, 1965b). In 1279, the castle at Zantyr was relocated down the Nogat to the site of Malbork, which became the centre of the new commandery of Marienburg. Here, the castle was constructed in three phases (Jóczćwiak and Trupinda, 2007, 53–71). The earliest, high castle was established as a square, conventual castle or fortified convent by 1309. In this year the Order annexed Gdańsk and Pomeralia, shifting the frontier of their territory westwards and setting up Malbork as the headquarters of their new Prussian state. This prompted a programme of expansion which lasted into the 15th century. From 1310–1350 an enclosed set of buildings was constructed north of the high castle and came to be referred to as the middle castle, whilst the high castle was rebuilt. Further north, an outer bailey was constructed (defensive wall and enclosed area surrounding the high and middle castle) which included industrial buildings, stables and barns. From the second quarter of the 14th century, an outer wall (the third defensive wall) was built in stages to enclose all three areas of the castle complex. A bridge was also constructed across the Nogat. In 1411–1414, embankments were constructed beyond the outer wall and between 1417 and 1448 new defensive structures were installed in the eastern and southern side of the castle complex, encompassing by then an area of around 21 ha. This was the last phase of castle building and all subsequent modifications have involved refining the existing structure. The castle remained the property of the Order until it was sold to the Polish Crown in 1457 and from the late-19th century it was the object of restoration and conservation which continues into the present day. In 1997 the castle was designated a UNESCO World Heritage Site.

The landscape around Malbork was re-organised to meet the requirements of the castle, not only the headquarters for the Order's state in Prussia, but also the centre of a commandery stretching from the Baltic coast to the southernmost edge of the Forest of Sztum (Fig. 1). The landscape around Malbork was recolonised and developed following the establishment of the commandery. A town grew up around the castle by the mid-14th century and the whole complex became a key hub of trade and communication for the Order's state, as well as a point of departure for crusading expeditions against pagan Lithuania. There is no evidence of continuity between the pre- and post-crusade settlement pattern in the landscape south of Malbork (Haftka, 1987), although the integrity of the Forest of Sztum was respected, indicating careful woodland management by the Order. Hydrological modifications included the construction of a canal, linking Lake Dąbrówka (in turn fed by a number of smaller lakes) to the moat complex at Malbork, 12 km northwest. The canal (Marienburger Mühlgraben 'Marienburg mill race'), which is still visible today, is a major hydrological feature in the landscape, and was constructed as a channel for conduiting water through several mills located along its length (Długokęcki et al., 2004: 17).

The castle at Malbork has been extensively studied from multiple perspectives, particularly with regards to the conservation and restoration of its architecture. The castle has an impressive archive of written sources, in part reflecting its role as the chancellery of the Order's state and the seat of the Grand Master. Its impact on the environment, however, has often only been referred to indirectly from a predominantly economic perspective in discussions of provisioning, hunting, water management, construction materials and fuel. These discussions have been almost exclusively informed by written sources, which predominantly date from the later period of the castle, i.e. the end of the 14th century (Jóczćwiak and Trupinda, 2007; Chęć, 2007; Chęć and Gancewski, 2009).

3. Study area

The study area extends from Malbork Castle southwards to the northern fringes of the Forest of Sztum (Fig. 1). Malbork Castle (54°02′23″ N, 19°01′40″ E) is located on the South–Eastern bank of the River Nogat, a tributary of the Vistula in the Pomeranian Voivodeship of north-central Poland. It is located on the edge of the Vistula Delta Fens which were drained between the 16th and 19th centuries, significantly altering the landscape between Malbork and the Baltic coast (Kowalik, 2008). Today, the landscape is characterised by a relatively low relief (0–50 m a.s.l), largely composed of intensively cultivated arable land, grasslands and some woodland dominated by *Pinus sylvestris*. The local geology is dominated by late Cretaceous rocks of the Maastrichtian stage (65–70 million years) overlain by brown lessivé and alluvial soils (Wasylikowa, 2004). The climate of northern Poland lies at the transition between oceanic and continental climates, with mean January and July temperatures of −3 to −5 °C and 17 to 18.5 °C respectively. Mean annual precipitation is between 500 and 700 mm.

4. Pollen sample sites

Samples for pollen analysis were taken from two locations to enable comparison of on- and off-site (hinterland) palaeoenvironmental data (Fig. 1). The first core (sequence POL-MAL-08-1; Fig. 1c) was taken along a coring transect from the eastern section of the outer moat adjacent to the inner curtain wall of Malbork Castle where sediments reached a maximum depth of 1.5 m. The outer moat originally encircled the castle to the north, east and south, with the western side facing the river Nogat. Today, the inner moat survives only along the eastern and northern inner curtain wall.

The second core (sequence POL-MAL-08-3; Fig. 1d) was taken from a small filled basin (54°00′ N, 19°02′ E), 3 km south of Malbork Castle; this was the closest wetland deposit identified in proximity

Table 1
AMS radiocarbon dates, sequence PAL-MAL-08-1 and POL-MAL-08-3.

Lab No. [a]	Depth (cm)	Age (B.P)	$\delta^{13}C$ (%)	Age range [b] (cal BP)	Age range [b] (cal AD/BC)
Sequence POL-MAL-08-1 (Malbork Castle moat)					
GU-23112	71.5–72	430 ± 30	−25.4	540–430	AD 1410–1520 (88.2%)
				360–330	AD 1590–1620 (7.2)
Sequence POL-MAL-08-3 (off-site core)					
GU-20432	152–153	245 ± 30	−27.7	430–380	AD 1520–1570 (9.1%)
				320–260	AD 1630–1690 (53.9%)
				190–140	AD 1760–1810 (26%)
				20 ± 10	AD 1930–1960 (6.5%)
GU-20433	160–161	515 ± 30	−28.3	630–600	AD 1320–1350 (7.6%)
				560–500	AD 1390–1450 (87.8%)
Wk-24853	163–165	865 ± 30	−28.5	910–860	AD 1040–1090 (13.6%)
				830–690	AD 1120–1260 (81.8%)
GU-20434	175–176	1115 ± 30	−27.6	1090–930	AD 860–1020
GU-20435	187–188	1380 ± 30	−27.7	1345–1265	AD 605–685
Wk-24854	260–262	9313 ± 44	−28.7	10660–10370	8710–8420 BC (93.9%)
				10320–10200	8370–8350 BC (1.5%)

[a] Material dated: peat, apart from GU-23112 (wood bark).
[b] 2σ range.

to the castle. The basin, now in-filled and covered in scrubby vegetation, is 40 m a.s.l, and is approximately 100 m long by 100 m wide. A coring transect across the basin identified a complex sequence of minerogenic and peat deposits to a depth of over 400 cm (see section 6.1 below). The minerogenic deposits at the base of the sequence were not bottomed as sampling was focused on retrieving late Holocene organic deposits; radiocarbon dating suggests the basal minerogenic deposits are of late-glacial or early Holocene date (Table 1). The sediments were sampled at the point of maximum thickness of peat (160–265 cm depth), including the underlying minerogenic sediments to a depth of 400 cm.

5. Materials and methods

A coring transect was taken across the basin to find the greatest depth of sediments. Half-metre cores were taken using a 10 cm diameter Russian corer. Duplicate parallel cores were taken to give an overlap between core segments. Cores were wrapped in cling film and foil, placed in plastic guttering and refrigerated prior to sampling. Samples for pollen analysis ca. 1 cm^3 in volume were taken from sequence POL-MAL-08-1 (Fig. 3) at 4 cm intervals and at 1–2 cm intervals from sequence POL-MAL-08-3 (Fig. 4). Sampling from POL-MAL-08-1 focused on the organic rich silt layers, rather than intervening medium sands, where pollen was likely to be better preserved. From sequence POL-MAL-08-3, samples were taken between 50 and 200 cm, focussing on sediments dating from the Iron Age to post medieval periods (see section 6.1 and 6.2). Two *Lycopodium* tablets were added to enable calculation of pollen concentrations. Samples were prepared following standard laboratory techniques (Moore et al., 1991) and mounted in glycerol jelly stained with safranin. A minimum of 500 pollen of terrestrial species were counted for each level. Pollen percentages are calculated based on terrestrial plants. Ferns spores, aquatics and *Sphagnum* are calculated as a percentage of terrestrial pollen plus the sum of the component taxa within the respective category. Identification of cereal pollen followed the criteria of Andersen (1979). Indeterminable grains were recorded according to Cushing (1967). The pollen diagram was produced using Psimpoll version 4.10 (Bennett, 2002). Pollen zonation was achieved in Psimpoll based upon a comparison of binary splitting by sum of squares, optimal splitting by sum of squares and constrained cluster analysis (CONISS). Microscopic charcoal was quantified using the point count method of Clark (1982), but is not plotted for core POL-MAL-08-3 as only very occasional fragments were recorded.

Seven ^{14}C AMS dates, six on peat from core POL-MAL-08-3 and one on charcoal from core POL-MAL-08-1, were obtained, two from Waikato, New Zealand and five from SUERC, UK (Table 1). An eighth date, from the base of sequence POL-MAL-08-1 (moat) failed due to insufficient carbon. The ^{14}C dates were calibrated using the program OxCal (ver. 3.10; Bronk-Ramsey, 2004) and the calibration curve of Reimer et al. (2004).

6. Results

6.1. Sediments

Ten lithological units were distinguished in core POL-MAL-08-1. The sediments principally comprise light brown medium sand

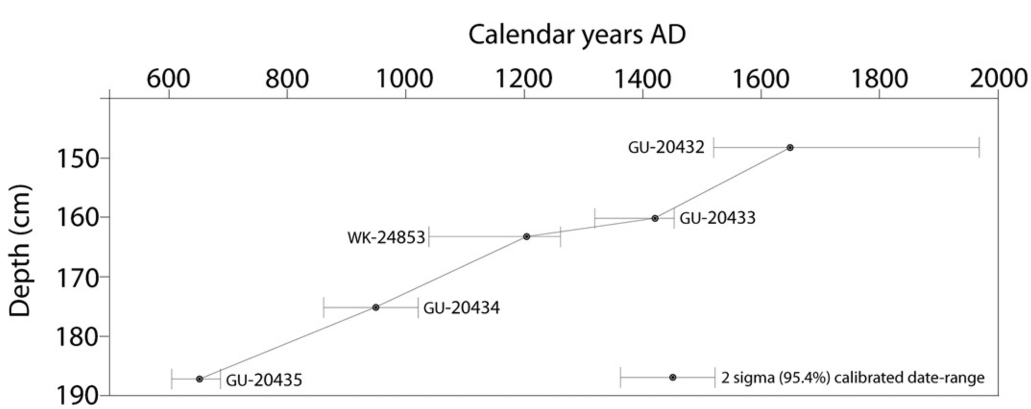

Fig. 2. Age-depth relationship of sequence POL-MAL-08-3.

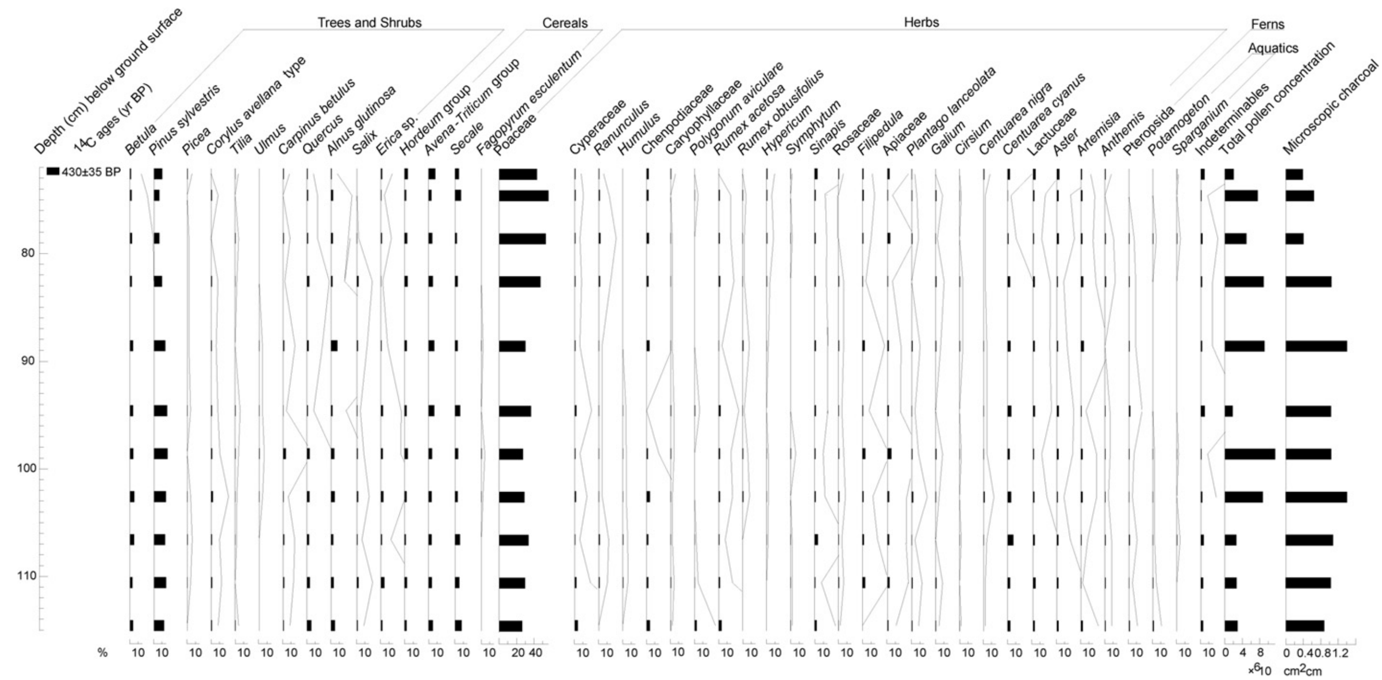

Fig. 3. Pollen percentage diagram, sequence POL-MAL-08-1 (Malbork Castle moat). The black curve represents the percentage of the taxon; the hollow curve shows values exaggerated × 10.

layers (150–117, 88–83, 74.5–73.5 and 71–58 cm) with sharp boundaries to dark brown organic rich silts (117–88, 83–74.5, 73.5–71, and 58–50 cm), containing occasional flecks of charcoal and red brick, overlain by a dark brown compact silt (50–25 cm) and topsoil constituting the uppermost 25 cm.

Eleven lithological units were distinguished in core POL-MAL-08-3. The basal sediments comprised blue sandy loam (400–365 cm), silty loam (365–291 cm) and yellow-brown organic silts (291–265 cm). Above this are wood peat layers (265–192.5, 192–189 and 188–160 cm) and interleaved clayey silt bands (192.5–192 and 189–188 cm), overlain by organic silty clay (160–146 cm) and clay sands (146–50 cm). The top 50 cm of sediment are disturbed, comprising modern refuse mixed with topsoil.

6.2. Chronology

6.2.1. Malbork Castle moat

Although the sample for radiocarbon dating from the basal silt layer failed (117 cm, sequence POL-MAL-08-1), the date for moat construction is well established historically to ca. 1320–1340 (Jóźćwiak and Trupinda, 2007) The AMS date 430 ± 35 BP (GU-23112, cal AD 1410–1520, 88.2%; cal AD 1590–1620, 7.2%), taken at 71.5–72.5 cm from the base of the third of four organic silt bands

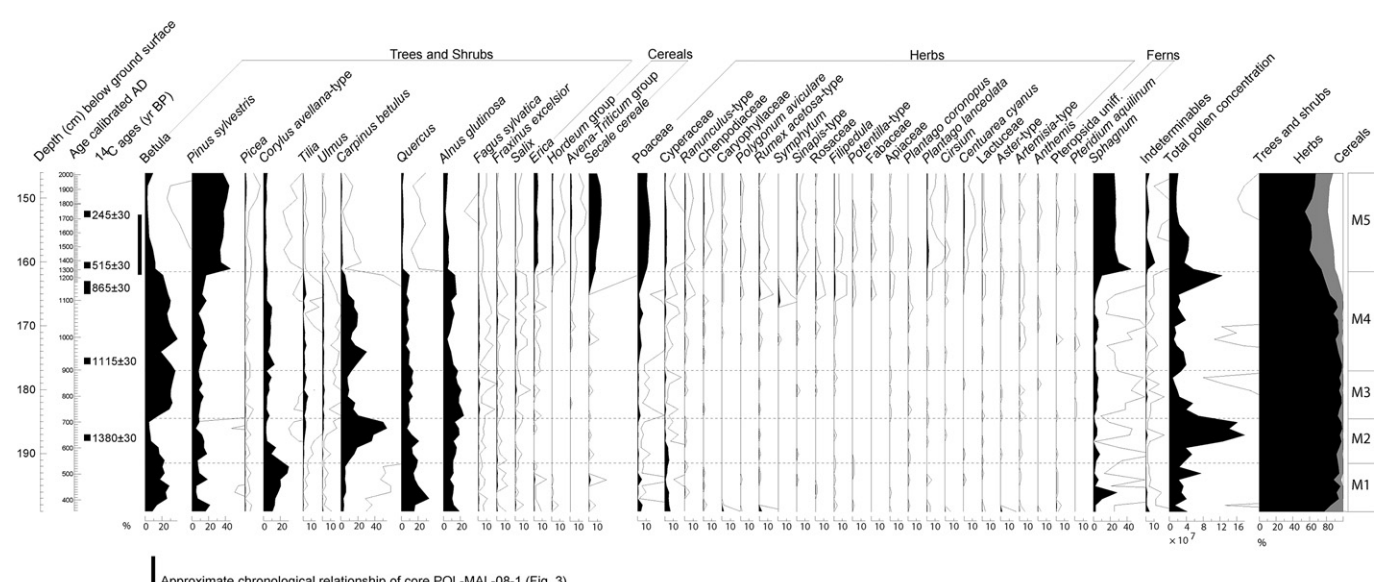

Fig. 4. Pollen percentage diagram, sequence POL-MAL-08-3 (off-site profile). The black curve represents the percentage of the taxon; the hollow curve shows values exaggerated × 10.

(Table 1), suggests the basal 75 cm of sediment most probably accumulated from the early/mid-14th to early 16th century. There is no evidence for cutting or cleaning of the moat during this time. A fourth silt band (50–50 cm) has not been dated, but is presumably of 15th–17th century date.

6.2.2. Malbork hinterland sequence (POL-MAL-08-3)

The AMS dates from sequence POL-MAL-08-3 cover a considerable period of time from 8710 cal BC to cal AD 1960 (Fig. 2; Table 1). Although this paper is primarily concerned with the vegetation history of the late 1st and 2nd millennia AD, the ^{14}C dates at 262–260 cm (9313 ± 44 BP; 8710–8350 cal BC) and 189–188 cm (1380 ± 30 BP; cal AD 605–685) would suggest that there is a significant hiatus in the sequence somewhere between 189 and 262 cm, or that the basal ^{14}C date relates to the incorporation of organic material into the peat from an early Holocene context. The upper peat (188–160 cm) accumulated over a period of as little as 635 years between cal AD 605–1450. Peat accumulates at a relatively uniform average rate between 188 and 165 cm (2.2–2.3 mm/yr), but at a much slower average rate between 165 and 160 cm (8.8 mm/yr), most probably a result of compaction from overlying minerogenic sediments (Fig. 2). The ^{14}C date 245 ± 30 BP (cal AD 1520–1960) suggest the organic silty clay sealing the peat accumulated from the 15th century, with the overlying 1.5 m of sediment most likely deposited since the 19th century.

6.3. Pollen analysis, Malbork Castle moat (sequence POL-MAL-08-1; Fig. 3)

The pollen record from the inner moat at Malbork castle focused on the organic rich silt layers. These are considered to reflect the ponding of fine sediments within a low energy environment, separated by sand bands deposited under higher energy environments, perhaps related to periodic flushing of the moat.

Pollen within the organic rich silts is characterized by high non-arboreal pollen (NAP) values, particularly Poaceae, and low arboreal pollen (AP) values. Arboreal pollen is represented primarily by *Pinus sylvestris*, which constitutes the main component of the remaining woodland within a predominantly open, cultivated landscape, with stands of *Alnus glutinosa*, *Salix* and *Betula* most probably growing on wetter soils with marshy areas and along the banks of the river Nogat. Significantly, high values for cereal-type pollen occur within the moat sediments (*Secale*, *Avena-Triticum* group, *Hordeum* group and occasional grains of *Fagopyrum esculentum*) (Fig. 3), in addition to a range of herbaceous taxa (*Centaurea cyanus*, *Centaurea nigra*, Ranunculus, *Rumex acetosa*, *Plantago lanceolata*, Lactuceae, *Plantago lanceolata*, *Aster*-type). Microscopic charcoal is present through the sequence in moderate values.

6.4. Pollen analysis, Malbork Castle hinterland (sequence POL-MAL-08-3; Figs. 4 and 5)

6.4.1. Zone M1 (199–191.5 cm). ca. 5th–6th century AD

High arboreal pollen (AP) values (*Quercus*, *Corylus avellana*-type, *Betula* and *Pinus sylvestris*) and low non-arboreal pollen (NAP) values indicate a heavily woodland landscape. Small percentages of Poaceae, *Secale*, *Plantago lanceolata*, Ranunculus-type and *Centaurea cyanus* strongly imply some cereal cultivation in the vicinity, perhaps within small clearings in the surrounding woodland.

6.4.2. Zone M2 (191.5–184.5 cm). 6th–7th century AD

This zone is marked by an increase in Carpinus, peaking 1 cm after the ^{14}C date 1380 ± 30 BP (cal AD 605–685), but declining sharply by 184 cm. *Corylus avellana*-type, *Betula* and *Quercus* decrease, whilst values for *Alnus glutinosa*, *Tilia* and *Ulmus* increase towards the top of the zone. NAP values decrease further, although occasional pollen grains of *Secale* imply continued, small-scale, agriculture in the vicinity.

There is a broadly synchronous increase in the pollen concentrations of all plant taxa (Fig. 5) that most probably reflect a lower peat accumulation rate at 184–188 cm. The concentration and percentage curves for arboreal taxa are broadly synchronous, apart from *Betula*, *Corylus avellana*-type and *Quercus*, whose percentage frequencies decrease markedly relative to concentration, most probably in response to an increase in *Carpinus* as a component of the surrounding vegetation.

6.4.3. Zone M3 (184.5–177 cm). 8th–10th century AD

The zone is characterised by reduction in percentages and concentrations for *Carpinus* and an increase in *Betula* and *Corylus*

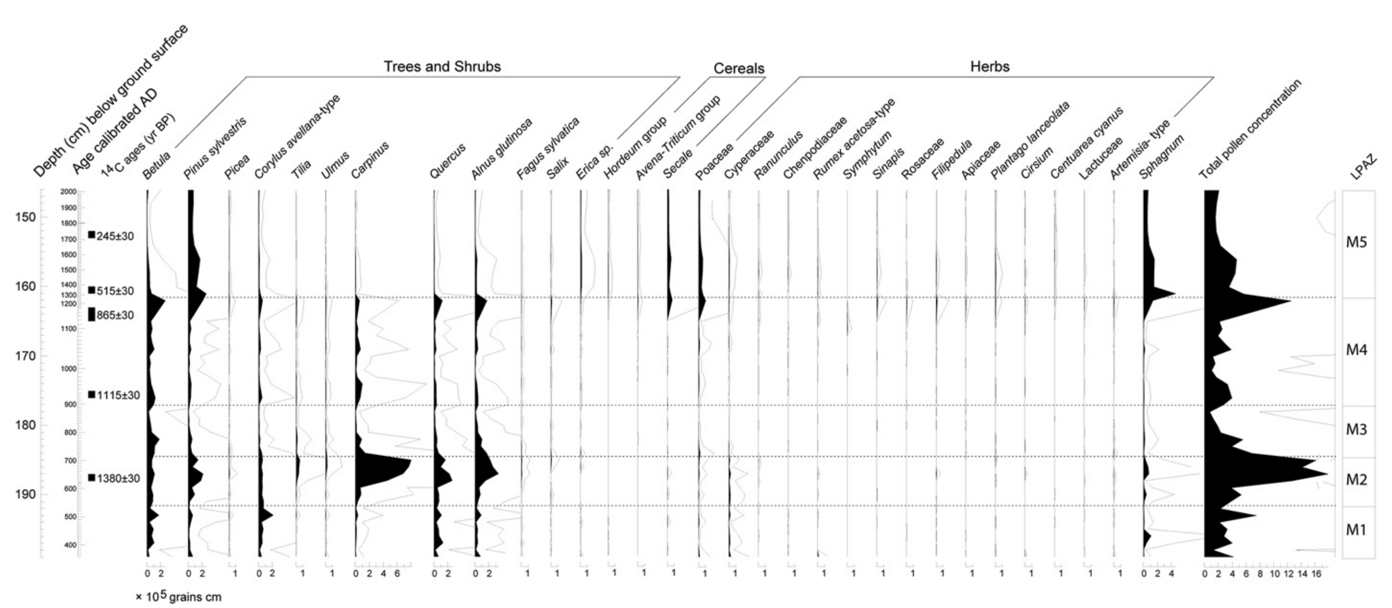

Fig. 5. Pollen concentration diagram, sequence POL-MAL-08-3 (off-site profile).

avellana-type (Figs. 4 and 5). *Pinus sylvestris* and *Quercus* are stabilized around 10%, whilst *Tilia* values fluctuate and *Ulmus* decreases from ca. 180 cm. *Alnus glutinosa* decreases through the zone. NAP values remain low (ca. 5%).

6.4.4. Zone M4 (177–161.5 cm). 9th–14th century AD

Low NAP values and high AP values (*Betula, Carpinus, Quercus* and *Pinus sylvestris*) at the base of the zone suggest a predominantly wooded environment. However, AP values decline through the zone (98–68% AP), gradually at first from 175 cm, ^{14}C dated 1115 ± 30 BP (cal AD 800–1020), then more steadily from 166 cm, just before the level ^{14}C dated to 865 ± 30 BP (cal AD 1040–1260). The decline in AP is most pronounced in *Carpinus*, *Corylus avellana*-type and *Betula*; values for *Pinus sylvestris* and *Quercus* remain relatively stable. NAP increases correspondingly, in many case only one or two grains of individual taxa, but particularly Poaceae from 175 cm and cereal pollen (*Secale*, *Avena-Triticum* and *Hordeum*-type) from 162 cm. The increase in the latter taxa is equidistant between the levels ^{14}C dated to 865 ± 30 BP (cal AD 1040–1260) and 515 ± 30 BP (cal AD 1320–1450). Pollen concentrations of all plant taxa increase from 164 cm (Fig. 5), reflecting a lower peat accumulation rate apparent also in the time-depth curve (Fig. 2).

6.4.5. Zone M5 (161.5–146 cm). 14th-early 19th century AD

The base of the zone, ^{14}C dated 515 ± 30 BP (cal AD 1320–1450) is characterised by a reduction in arboreal pollen percentages and concentrations of all deciduous species and a significant increase in *Pinus sylvestris* (Figs. 4 and 5). The increase in *Pinus sylvestris* reflects the ability of this species to expand in disturbed habitats, representing the most common component of woodland stands in Poland since the 15th century (Ralska-Jasiewiczowa et al., 2004). The reduction in AP of deciduous species and increasing NAP percentage and concentration values (Poaceae, *Plantago lanceolata*, *Centaurea cyanus*, *Sinapis*, Chenopodiaceae, Caryophyllaceae), including cereal-type pollen, particularly *Secale*, indicates large-scale clearance of the surrounding deciduous woodland and an expansion in arable, grazed and disturbed habitats. An expansion in grazed land is further suggested by an increase in *Erica* sp. from 162 cm. *Secale* pollen values reach their peak at the level ^{14}C dated to 245 ± 30 BP (cal A.D. 1520–1960).

7. Discussion

7.1. The environment of Malbork castle and its hinterland

The pollen evidence from both on- (POL-MAL-08-1) and off-site (POL-MAL-08-3) cores provides important data for reconstructing the landscape context, and ecological impact of, the Teutonic Order castle at Malbork. The core from the outer moat at Malbork provides a picture of the landscape within the immediate surroundings of the castle over a relatively defined time period (14th–16th century). The off-site hinterland sequence provides an important context for the pollen data from the moat, providing a picture of vegetation change at a broader spatial and temporal scale (ca. 5th–19th centuries). Pollen data from sequence POL-MAL-08-3 demonstrates that the landscape surrounding the sampling site was heavily wooded in the late Iron Age, dominated in zone M1 (ca. 4th–6th centuries AD) by *Quercus* and *Corylus avellana*-type on drier soils with *Alnus glutinosa* most probably growing on waterlogged soils within the wetland. Because of their wide ecological preferences, *Betula* is equally likely to have formed a component of the woodland canopy on both dry and waterlogged soils.

Evidence for human impact is apparent during this time in the form of occasional cereal pollen grains of *Secale*, associated with small increases in pollen of Poaceae, *Rumex acetosa*-type, *Aster*-type and *Plantago lanceolata*, suggesting some mixed pastoral-arable land-use in the vicinity. Interestingly, the curves for *Pinus sylvestris* and *Betula* in zone M1 show an inverse relationship. *Pinus sylvestris* increases during periods of anthropogenic activity, most probably reflecting the ability of this species to expand in disturbed habitats, followed by increases in *Betula*, perhaps reflecting periods of deciduous woodland regeneration that out-competed *Pinus*; *Betula* is often one of the first trees to recolonize cleared areas of woodland (Faliński, 1997).

Carpinus forms the dominant component of the local woodland canopy from the ca. 6th century AD, reaching its greatest Holocene distribution at this time across northern and western Poland (Ralska-Jasiewiczowa et al., 2004; Fig. 36). The expansion of *Carpinus* is argued to reflect a period of general forest regeneration following the migration period (Makohonienko, 2004). *Carpinus* remains an important woodland component in sequence POL-MAL-08-3, declining gradually, along with *Betula* and *Corylus avellana*-type type from ca. AD 1000. A gradual decline in *Carpinus* is likewise visible in pollen sequences across Poland from ca. 1000–100 BP (Ralska-Jasiewiczowa et al., 2004).

There is a gradual decline in arboreal pollen from the mid-11th century, accompanied by increasing herbaceous pollen frequencies and the start of a continuous cereal pollen curve, perhaps reflecting the activities of archaeologically-attested Pomeranian settlers within the surrounding landscape (Powierski, 1965a,b). However, evidence for human activity in the pollen record is comparatively limited in scale until the late 12th/13th century, broadly contemporary with the Crusades, when there is a significant increase in cereal pollen, particularly rye, and other anthropogenic indicators characteristic of arable and grazed land. The occurrence and increase in *Centaurea cyanus* pollen, in particular, is argued to strongly reflect the presence of permanent field systems (Vuorela, 1986). Agricultural intensification is accompanied by the development of heathland in the 14th/15th centuries, typically maintained through grazing activity. There is little evidence to suggest that fire formed a component of land-use practises; microscopic charcoal was only very occasionally recorded through core POL-MAL-08-3. Despite the evidence for woodland clearance, there is a significant increase in *Pinus sylvestris*, forming the primary component of Polish woodlands from the 14th/15th century. This reflects the ability of pine as a pioneer tree to expand within disturbed habitats, and in the last 200 years through sivicultural practises, as the primary planted tree in Poland (Latałowa, 2004).

The pollen evidence from the inner moat at Malbork (POL-MAL-08-1; Fig. 3) suggests an environment similar to that apparent from equivalent dated deposits from sequence POL-MAL-08-3 (Fig. 4). However, the comparatively low levels of arboreal pollen, although similarly dominated by *Pinus sylvestris*, suggest woodland had been largely cleared from the landscape immediately surrounding the castle. Pollen grains of the full range of cereals occur, in addition to pollen taxa strongly associated with cultivation (*Centaurea cyanus*, *Centaurea nigra*) and pastureland (*Ranunculus*, *Rumex acetosa*, *Plantago lanceolata*, Lactuceae, *Plantago lanceolata*, *Aster*-type), though these taxa can also occur in waste ground. Although the pollen assemblage suggests the nearby presence of arable fields, cereal pollen and other plant taxa indicative of cultivated and grazed ground, may equally derive from agricultural waste deposited into the moat. Likewise, other herbaceous pollen could derive from discarded food waste, including cultivated species of Apiaceae (c.f. *Coriandrum sativum*, *Pastinaca sativa*, *Anethum graveolens*) and *Sinapis*-type (c.f. *Sinapis alba*, *S. nigra*). Microscopic charcoal is recorded in consistently high levels, but is also likely to be derived from a variety of contexts relating to activity both within and in the immediate landscape surrounding the castle.

The region south of the castle, surrounding the northernmost stretches of the Forest of Sztum, sees a general discontinuation of the Iron Age settlement pattern during this time and the establishment of new, more intensive settlement on either side of the Nogat (Haftka, 1987). With the incorporation of Pomeralia into the Teutonic Order's state in 1309, this region ceases to represent an active frontier, and is re-defined as part of the heartland of the Ordensstaat. However, the changes in vegetation, particularly reflecting localized deforestation, are most likely to be typical of the impact on the landscape between the Order's castles and significant areas of woodland, such as the Forest of Sztum, which are documented as actively managed landscapes in the 14th and 15th centuries (Chęć and Gancewski, 2009). The Forest of Sztum was surrounded by a number of Teutonic Order sites: on its western side by outposts at Zantyr and Benowo, and a manor at Ryjewo; on it eastern side by the procurator's castle at Szthum and a manor at Barlewice and on its northern side by the castle and town at Malbork. Whilst colonizing settlements appear to have respected the pre-existing forest boundaries, this distribution may, in part, reflect the lack of detailed archaeological investigations within wooded areas. However, the analysis of faunal assemblages from the outer bailey at Malbork and from Biała Góra (tentatively identified as the outpost at Zantyr; Sawicki pers. comm.) confirm the continued exploitation of woodland species such as bear, polecat, marten and cervids, wetland species such as beaver and a diverse range of fish (Maltby et al., 2009; Pluskowski et al., in press).

7.2. Vegetation change in northern Poland during the late-medieval period

Although there is evidence from Polish pollen sequences for human activity throughout prehistory, what marks the top of many pollen profiles is the evidence for substantial vegetation and land-use change on a scale not previously encountered (Ralska-Jasiewiczowa et al., 2004). Earlier phases of woodland clearance and cultivation are typically smaller in scale and often more limited in duration, followed by woodland regeneration. Vegetation and land-use changes in the medieval period are characterized by a substantial decline in woodland, particularly broadleaved species, an intensification of agricultural activity, marked by a continuous cereal pollen curve (particularly rye) with little subsequent evidence for woodland regeneration. These changes in many ways define the modern vegetation landscape of Poland.

However, there is poor radiocarbon coverage of this horizon, with dates available on only 23 cores with medieval deposits from across northern Poland (Fig. 1b). Despite this poor coverage, a clear distinction in the dating and extent of major woodland clearance and cultivation can be observed between North–Western and North–Eastern Poland, albeit with some variability. The earliest dates for substantial woodland clearance and cultivation generally occur in North–Western Poland from c. AD 1000, primarily in Pomerania and along the southern Baltic coast between the Orda estuary and Vistula delta, connected with the development of urban ports from the 9th century. Pollen cores from several locations on Wolin Island, North–Western Poland (Fig. 1b, no. 1), reveal substantial deforestation and intensive cultivation of rye, wheat, barley, oat, buckwheat and hemp, associated with the construction of a large urban port that flourished between the 9th–11th centuries (Latałowa, 1989, 1992, 1999). However, a much earlier continuous increase in rye was recorded from a sequence in the Darzlubie Forest, eastern Pomerania (Fig. 1b, no. 3), dating to the 7th century (Latałowa, 1982), whilst at Słowińskie Błota (Fig. 1b, no. 2), cereal pollen does not increase significantly until AD 1300 (Lamentowicz et al., 2009). By the late 13th century, the densely populated, already deforested western regions became increasingly important in the production of rye for export to Western Europe and Scandinavia, with shipments of grain up the Vistula, bound for England, recorded from the early 14th century (Hybel, 2002).

Moving east towards the Vistula Basin (the heartland of the Teutonic Order), the dates for large-scale woodland clearance are progressively later. Pollen sequences from three lakes in Bory Tucholskie, eastern Pomerania (Lake Mały Suszek, Suszek and Kęsowo; Fig. 1b, nos. 4–6), and from Tuchola (Lamentowicz et al., 2008; Fig. 1b, no. 7), show a gradual increase in cereal pollen from the 11th century, with arable activity intensifying in Bory Tucholskie in the 12th and 13th centuries and the almost complete disappearance of deciduous woodland (Berglund et al., 1990; Miotk-Szpiganowicz, 1992). Buckwheat, which produces only small quantities of poorly dispersed pollen, occurs in significant quantities in the Kęsowo sequence, suggesting cultivation in the immediate vicinity of the lake, which is surrounded by numerous settlements, including strongholds at Gostycyn, Obrowo and Raciąz. A similar pattern of deforestation and cultivation, although undated, is apparent from the upper portions of the pollen sequence from Lake Druzno, 5 km south of Elbląg (Zachwicz and Kepińska, 1987; Fig. 1b, no. 8). Elbląg, like Malbork, is a 13th century Teutonic Order foundation. Situated on the banks of the Vistula, it was the administrative headquarters of the Order's state in the 13th–14th centuries, and a key port in the rye trade (Latałowa et al., 2007). The greater proportion of the plant remains from 13th to 14th century occupation deposits were derived from habitats outside the town, indicative of meadows, pasture and arable land, but also included finds of nutmeg, originating from Indonesia, and figs, from the Mediterranean, pointing towards longer distant trade routes at this time (Latałowa et al., 2003).

From the 13th century onwards, large quantities of Baltic timber were also exported through harbours at Elbląg, Gdańsk and Konigsberg to Western Europe, where it was prized for ship building, but also oak panelling used in paintings and sculptures (Wazny, 2005). The source of wood used in art-historical objects across Western Europe has recently been investigated though a comparison with detailed oak dendrochronologies constructed from archaeological sited across Poland (Haneca et al., 2005). The dendro-provenancing data provides additional supporting evidence for patterns of woodland clearance visible in the pollen record from Malbork and across northern Poland. Wood from North–Western Poland is rarely found in art-historical objects, most probably reflecting the earlier clearance of woodland west of the Vistula and the lack of suitable timber by the 13th century. The majority of tree sequences before AD 1450 show a distinct correlation with the regional chronologies for northern Poland around Gdańsk (eastern Pomerania and Warmia), including Malbork, and to the south within the Masovian lowlands. Documentary records detailing the timber trade show that from 1389 to 1415 the Teutonic Order transported almost one and half million pieces of timber, most along the Vistula from Masovia. Customs records from Biała Gora, 15 km southwest of Malbork, indicate that most of this timber was in the form of wainscots (high-quality oak boards), rather than logs or beams (Wazny, 2005). Trees felled after AD 1450 show a stronger correlation with the regional chronologies of the Podlasie lowlands of eastern Poland (Haneca et al., 2005). This suggests that as demand for high-quality timber grew by the late 14th and early 15th century, the primary source of timber moved from the denuded woodlands of northern Poland to the dense woodlands of eastern Poland.

The few dated pollen sequences from North–Eastern Poland suggest, in common with the dendro-provenancing evidence, that woodland clearance and agricultural activity occurred at a later date, and at a lower intensity than that experienced to the west. Today, the area remains dominated by large swathes of woodland, including the Puszcza Augustowska, Puszcza Knyszyńska and Białowieża Forests, considered to be the last remnants of primeval forest that once covered large parts of central Europe. Within the Puszcza Knyszyńska forest, close to the border with Belarus, pollen analysis from Kładkowe Bagno bog shows that clearance of woodland for arable and pastoral activities did not occur on a large-scale until the 16th century, following successive invasions of the region from the 13th to mid 15th centuries that had led to significant disruption of the settlement pattern in the region (Kupryjanowicz, 2004). Similarly, there is little disturbance related to human activity within the Białowieża Forest until the 15th century and evidence for cultivation is extremely sparse (Mitchell and Cole, 1998; Fig. 1b, nos. 10-11). Palynological analysis in the vincinty of lake Wigry, located within the Puszcza Augustowska Forest (Fig. 1b, no. 12), likewise suggested low-intensity human activity during the late-Medieval period (Kupryjanowicz, 2007).

However, palynological from Lake Miłkowski (Fig. 1b, no. 13) produced evidence for substantial anthropogenic impact on the vegetation around the lake from cal AD 1000–1150, prior to the Teutonic Order, linked to indigenous Galindian settlement (Madeja et al., 2010). Although this suggests a degree of spatial variability in the intensity of human activity within the more sparsely populated North–Eastern areas of Prussia, it remains the case that those sites along the eastern frontier (close to the current Belarus and Lithuanian borders), where substantial woodland survives today, experienced lower intensities of human activity than sites located further to the west.

8. Conclusions

The study described in this paper highlights the contribution of palaeoenvironmental analytical techniques towards the study of historic landscapes otherwise more typically informed through written sources. This research shows that the 12th/13th to 15th centuries witnessed a fundamental change in the nature of the vegetation landscape and land-use of Malbork, from one dominated by deciduous woodland, with only limited evidence for human impact, to an increasingly open landscape with evidence for intensive cultivation of cereals, particularly rye, with pastureland and heathland. Evidence for human activity prior to the 13th century is likely to reflect the activities of archaeologically-attested Pomeranian settlers in the landscape. Subsequent vegetation change during the 13th–15th centuries, characterized particularly by the evidence for agricultural intensification, coincides with the construction of the conventual castle at Malbork in the last decades of the 13th century, the establishment of its commandery and the dramatic expansion of the castle complex over the course of the 14th century until the early decades of the 15th century. The two waves of colonization within this frontier region can therefore be linked to two phases of exponentially increasing landscape transformation. Faunal evidence from nearby Biała Gora for the continued exploitation of woodland species, as well as later written sources, also demonstrate, however, that whilst large areas were deforested, woodland in other parts of the castle commandery was carefully retained and managed as an important resource. This highlights the importance of combining analysis of on-site environmental date with that contained within off-site sequences, ideally from multiple locations within the castle commandery, thereby enabling critical investigation of spatial variability in land-use. This study therefore points the way forward for further comparative studies of land-use within the Malbork landscape focused on testing hypotheses of woodland continuity and management.

The broader palaeoenvironmental record from northern Poland suggests that the 13th–15th centuries represent an important ecological horizon in the vegetation history of those lands most closely associated with the Teutonic Order. The continued development of ports like Gdańsk, the foundation of new towns by the Teutonic Order, and the growth of the Hanse and pan-European trading networks, progressively opened up the Polish hinterland to foreign knights, settlers and traders. These linked processes resulted in deforestation and farming on an increasingly intensive scale from the 13th century. This pattern, based on an admittedly restricted number of radiocarbon dated pollen sequences, is supported by a growing body of zooarchaeological, dendro-provenancing and documentary data, but nonetheless requires further testing through targeted analysis and dating of late Holocene palaeoenvironmental sequences.

Acknowledgements

The project was funded by grants to Aleks Pluskowski from the British Academy and the University of Reading. Additional radiocarbon dating (GU-20432 to GU-20435) was funded by a research grant to the authors from the School of Human and Environmental Science, University of Reading. The authors would like to thank Dr Zbigniew Sawicki, Dr Waldemar Jaszczyński and Dr Janusz Trupinda for their continuing support and hospitality at the Castle Museum in Malbork. We would also like to extent our thanks to Dr Helena Burg and Chantel Summerfield who contributed to the fieldwork leading up to this publication. We are grateful to Dr Lisa-Marie Shillito, two anonymous referees and the editor, Chris O Hunt, for helpful comments on the draft text.

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