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Succession of arboreal taxa during the Late Glacial in south-eastern Poland: Climatic implications

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ABSTRACT

This paper presents and discusses vegetation changes between ca. 14,910 and 11,620 cal. BP, which are recorded in the deposits of a small mire located in south-eastern Poland. Particular attention is paid to arboreal taxa. Changes in arboreal vegetation are reconstructed on the basis of pollen analysis, including pollen accumulation rate (PAR), and analysis of plant macrofossils, these being supported by radiocarbon chronology. Before the onset of the GI-1 warming (14,910 ± 310–14,810 ± 280 cal. BP) a mosaic of *Pinus* and *Betula* wood patches and/or isolated stands of trees, along with heliophilous *Juniperus* thickets were dispersed within patches of herb steppe and tundra communities. Thermal amelioration at the GS-2–GI-1 transition (ca. 14,810 ± 280–14,510 ± 200 cal. BP) led to the spread of *Salix* and to a lesser extent of tree birches (*Betula*), pines (*Pinus*) and *Hippophaë rhamnoides*. In the light of PAR values, from ca. 14,550 ± 210 cal. BP there were open pine–birch woodlands there, which ca. 14,270 ± 160 cal. BP turned into dense forests. Cold-oscillations such as GI-1d, GI-1c2 and GI-1b, dated in the profile at ca. 14,190 ± 120–13,870 ± 140, 13,740 ± 120–13,490 ± 80 and 13,120–12,870 ± 60 cal. BP respectively, are visible as declines in the PAR of arboreal taxa. From ca. 13,770 ± 120 cal. BP *Picea abies*, whose nearest glacial refugia were located in the Western Carpathians, probably reached the site surroundings (50°N). In the Younger Dryas (GS-1) climate deterioration caused a decline in birch population in the first phase, a slight retreat of forests and the simultaneous expansion of *Artemisia*–Poaceae steppe communities and *Juniperus* thickets. The PAR values reflect a division of the Younger Dryas into two distinct phases: an older phase, more severe for tree populations, probably due to longer and cooler winters, and a younger phase with milder winters which begun ca. 11,960 ± 110 cal. BP.

1. Introduction

Palaeoecological records preserved in different kinds of deposits can provide an insight into functioning of past ecosystems, long-term plant population and dynamics of plant communities (e.g. Prentice, 1988; Rull, 1990). In particular, the vegetation dynamics of glacial/interglacial cycles has been the subject of much research using various palaeoecological techniques (e.g. Ralska-Jasiewiczowa et al., 2003; Feurdean et al., 2007; Wacnik, 2009; Veski et al., 2012). The general trend of such cycles in the temperate zone of Europe was that during advances of the Scandinavian ice-sheet forest vegetation retreated to isolated areas relatively close to the ice-sheet (e.g. Stewart and Lister, 2001; Willis and van Andel, 2004; Bhagwat and Willis, 2008) and/or occurred in more extended refugia in Central-Southern and Southern Europe (e.g. Huntley and Birks, 1983; Bennett et al., 1991; Tzedakis et al., 2002). The former type of refugium is known as cryptic refugium because it is hardly detectable or even undetectable by palaeobotanical techniques (Stewart and Lister, 2001). The proximity of tree (cryptic) refugia, physical barriers to plant dispersal and the different migration rate of individual species were amongst the most significant factors in the timing of the appearance and taxonomic diversity of pioneer woodlands after the ice-sheet retreat.

Environmental changes during the last deglaciation in south-eastern Poland, an area relatively distant from the maximum Weichselian ice sheet margin (ca. 400 km; comp. Marks, 2012) and relatively close to the Carpathian, Moravian and Pannonian refugia of forests (comp. Willis et al., 2000; Willis and van Andel, 2004; Kuneš et al., 2008; Magyari et al., 2011), are still poorly recognised and therefore poorly understood. The presence of full-glacial tree populations in the area of the northern Carpathians is explained by the sheltered topography which provided suitable stable microclimates and ground moisture (Stewart and Lister, 2001; Kuneš et al., 2008). However, the lowland area of south-eastern Poland (north of the Carpathians) was more exposed to northerly winds from the ice-sheet, which posed the major challenge to survival of trees and shrubs. Unfortunately, there is a notable deficiency of palynological profiles to provide a continuous record of Late Pleniglacial and/or the Late Glacial from south-eastern

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Poland (comp. Mamakowa, 1962; Bałaga, 2007a, b; Kołaczek, 2007, 2010, 2011). Moreover, sequences are poorly supported or even completely unsupported by absolute chronologies (comp. Mamakowa, 1962; Bałaga, 2007a, b), so they are almost useless in uncovering various aspects of tree population dynamics. Up until now, Lake Perespilno (Bałaga, 2004) and Lake Miłkowskie (Wacnik, 2009) seem to be the only well-dated palynological sequences from the eastern belt of Poland which more or less record the entire Late Glacial with the Late Pleniglacial sections at their bottoms.

The aim of this article is to reconstruct vegetation changes special attention being paid to woodland dynamics, on the basis of palynological data, including the pollen accumulation rate (PAR), and plant macrofossils. The use of PAR presented in this paper is, to the best of our knowledge, the first applied to the entire Late Glacial in Poland. This method was chosen to provide input into a discussion about the potential presence of particular taxa, with an approximate determination of the density of local woodlands (comp. e.g. Seppä and Hicks, 2006; Hicks, 2007; Hättestrand et al., 2008; Theuerkauf and Joosten, 2012), and to look at changes in thermal conditions (comp. Barnekow et al., 2007; Huusko and Hicks, 2009; van der Knaap et al., 2010). New data from the area of the northern fringe of the Carpathians should make a valuable contribution to the current knowledge of the extension and functioning of tree (cryptic) refugia, and tree population dynamics in this region during the decline of the Pleistocene.

2. Study site

The investigated profile was collected in Kobylnica Wołoska (KW), a village located in the Tarnogród Plateau (220–280 m a.s.l., south-eastern Poland, Fig. 1). The place of coring is a rich fen (without a local name) that developed within a small depression (<0.1 ha), situated at ca. 215.5 m a.s.l. in the valley of the Szkło river. The origin of this basin was probably connected with the melting of permafrost (A. Wójcik, personal communication). The vegetation overgrowing this fen comprises mainly a reed bed dominated by *Phragmites australis*. The Tarnogród Plateau is built of sands deposited during the Miocene, which are overlain by Quaternary tills and sands, and loess cover (Kondracki, 2002). The soil cover of the Plateau is dominated by luvisols (lessive soils) and endoeutric cambisols that developed on clayey sands, till and dusts of varying origin. To a lesser extent there are rusty podsols and podsols that developed on sands, clayey sands of glacigenic accumulation and/or former accumulation terraces, fluvisols and hydromorphic soils e.g. gleysols and histosols (Dobrzański et al., 1972). The climate of the area is under continental influences, some of the strongest in Poland (comp. Degórski, 1985). During the period between 1996 and 2000 the mean annual temperature measured was 7.5 °C, the mean July temperature 17.5 °C and the mean of January −3 °C. Annual precipitation ranged between 700 and 800 mm (Lorenc, 2005). The mire is situated in an open area where cultivated fields and mown meadows prevail. However, forest complexes composed of mixed and coniferous forests where Scots pine (*Pinus sylvestris*) is dominant with an admixture of pedunculate oak (*Quercus robur*), silver birch (*Betula pendula*) together with black alder (*Alnus glutinosa*) occur and there are also willows (*Salix* sp.) in wetter habitats (on the basis of maps available on http://geoportal.gov.pl). The potential natural vegetation in the vicinity of the site would be mainly a poor variant of *Tilio–Carpinetum* forests, with patches of *Querco–Pinetum* woodlands on the poorest, sandy grounds, and *Fraxino–Alnetum* forests in damp depressions and on the lowest terraces of river valleys (Matuszkiewicz, 2008).

3. Materials and methods

3.1. Fieldwork and chronology of the profile

The profile from the Kobylnica Wołoska mire (labelled KW1) was collected using a Russian type sampler (5-cm in diameter) in 2002 from a spot as close to the mire centre as was possible (50°00′10″N 23°07′30″E, 215.5 m a.s.l.). Then the core was cut into 1-cm slices in the laboratory. For the purpose of the study presented in this paper a section between 90 and 299 cm was selected for analysis. The layer of sediments above a depth of 90 cm revealed traces of anthropogenic disturbances and, therefore, was excluded from further interpretation. Description of the deposits and absolute chronology (based on the Bayesian age–depth model constructed on the basis of six out of eight radiocarbon dates) follows Kołaczek et al. (in press; Fig. 2). Sedimentation rate varied between 0.05 and 0.08 cm yr^{-1} (Fig. 2), so that each 1-cm slice represented time-span between ca. 13 and 21 years.

To facilitate a further description of the results and discussion, the age of events is presented as the mean value of the range of modelled age (μ) expressed by cal. BP (i.e. before AD 1950) ± standard deviation (σ), both rounded to tens.

3.2. Palaeobotanical analysis

59 samples, each 1 cm^3 in volume, were prepared for pollen analysis using standard preparation procedures and then acetolysis was applied (Berglund and Ralska-Jasiewiczowa, 1986). A *Lycopodium* tablet ($N_{spores} = 10687$; produced by Lund University) was added to every sample for calculation of pollen concentrations (Stockmarr, 1971). The samples has been selected in intervals of 1-cm (299–295 cm, continuous sampling), 2- or 3-cm (295–270 cm; ca. 25–39 years between neighbouring samples) and 5-cm (275–100 cm, ca. 52–106 years between neighbouring samples). The lowest resolution of pollen analysis characterises the section between 100 and 90 cm (ca. 200 years between two neighbouring samples). More than 500 arboreal pollen (AP) grains per sample were counted, although in samples with a concentration <20,000 grains cm^{-3}, the sum of counted AP varied between 200 and 500. The pollen taxa were identified with the assistance of the modern pollen slide collection of the Władysław Szafer Institute of Botany, Polish Academy of Sciences as well as keys and atlases (e.g. Moore et al., 1991; Beug, 2004). The percentages of pollen taxa that constitute the total pollen sum (TPS) = AP (arboreal pollen) + NAP (non-arboreal pollen excluding ferns and lycophytes) was calculated as the ratio of each individual taxon to the TPS. The calculation of the pollen accumulation rate (PAR; measured as grains cm^{-2} yr^{-1}) follows the formula proposed by Davis and Deevey (1964) i.e. $PAR = C_t \times S$, in which C_t is the concentration of a taxon [grains cm^{-3}] and S is the sediment accumulation rate [cm yr^{-1}] (Fig. 2).

Macrofossil analysis was performed on 1 cm thick sections of the profile, with a volume of ca. 5 cm^3. Every sample was sieved under a stream of warm water on sieves with a mesh size of 0.25 mm. Macroremains were identified using a stereoscopic microscope with the assistance of atlases (Katz et al., 1965; Tobolski, 2000) and the reference collection of the Department of Biogeography and Palaeoecology, Adam Mickiewicz University in Poznań. Given the subject of this article only arboreal taxa are presented; herb macrofossils are the subject of the paper by Kołaczek et al. (in press).

The results of pollen and macrofossil analyses are presented as diagrams (percentage and raw data, respectively) drawn using the POLPAL software package (Nalepka and Walanus, 2003). Zonation was carried out only for pollen diagrams using traditional methods based on arbitrary assessment of zones (Janczyk-Kopikowa, 1987), and then cross-validated by ConSLink method (Birks and Birks, 1980).

4. Results and interpretation: terrestrial vegetation changes

The results of pollen analysis revealed six local pollen assemblage zones (LPAZs; labelled from KW1-1 to KW1-6, Fig. 3) comprising a mixture of woodlands or isolated trees together with cold herb steppe and tundra which were corroborated by ConSLink method. These are