RADIOCARBON AGE-DEPTH MODELING PREVENTS MISINTERPRETATION OF PAST VEGETATION DYNAMICS: CASE STUDY OF WIERCHOMLA MIRE (POLISH OUTER CARPATHIANS)

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ABSTRACT. An age-depth model based on radiocarbon dates was produced from a Holocene profile collected from a rich fen situated in the Beskid Sądecki Mountains (the Outer Western Carpathians, southern Poland). The model is compared against the results of palynological and loss on ignition (LOI) analyses supplemented by the identification of organic deposits. Five distinct palynological episodes are detected. These potential palynological age markers are critically compared with the results of age-depth modeling and other dated profiles. The results presented distinctly show that using palynological episodes as age markers for age-depth construction may be highly misleading.

INTRODUCTION

Paleoecological studies allow reconstructing shifts in the composition and abundance of plant communities as well as migration routes (Feurdean et al. 2007b), which are significant past biogeographical processes that determine the modern distribution of plants. Among several paleoecological techniques, palynological analysis plays an important role in researching those processes and providing information about local and regional vegetation in the past. Important areas for those processes are mountain ranges, which might be a barrier to those migrations, but conversely, they can provide corridors to facilitate such migrations. The Carpathians are one of the most important European mountain ranges involved in postglacial migrations of plants. Several areas in the Carpathians were investigated by palynologists researching different aspects of postglacial vegetation dynamics (Buczkó et al. 2009). Among them, a very important issue is how to establish accurate chronologies for palynological profiles. If the last 12,000 yr are considered, radiocarbon dating is the most universally applied technique to establish accurate, absolute ages for palynological time series. The use of absolute age modeling in the area is increasing (e.g. Feurdean et al. 2007a, 2008; Margielewski et al. 2011; Tanţuă et al. 2011; Hájková et al. 2012; Dudová et al. 2013; Fărkaş et al. 2013). However, only a few peat profiles from the Carpathians area have been subjected to advanced methods of age-depth model construction, especially Bayesian statistical methods (Margielewski et al. 2011; Michczyński 2011; Hájková et al. 2012). In the Polish part of the Carpathians, more than 30 palynological profiles are supported by ^{14}C dating, leading to one of the highest values per surface unit among Carpathian countries (Buczkó et al. 2009). However, few of these profiles were published along with an age-depth model.

This article presents results of age-depth modeling carried out for a profile from the Polish Carpathians (Beskid Sądecki Mountains), combined with palynological analyses. We focus on the potential mistakes that can occur when biogeographical processes (e.g. migration of forest taxa) are reconstructed using palynological data with insufficient numbers of corresponding ^{14}C dates. The

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authors present potential negative consequences of misusing "palynological" events as the age benchmarks for producing an age-depth model when the regional biogeographical background is poorly recognized.

MATERIAL AND METHODS

The mire selected for research developed in a landslide depression 60 m long and 50 m wide in Wierchomla village, Poland. The site is situated in the eastern part of the Beskid Sądecki Mountains (Outer Western Carpathians), in the Jaworzyna Krynicka Range (49°26.540′N; 20°50.275′E; 867 m asl), which is built of flysch rock of the Magura Unit. The landslide was formed within the southern slope of Mt. Lembarczek (Figure 1) in thick-bedded Magura sandstones, as a result of headward erosion developed in the uppermost part of the Wierchomla Mała stream spring area. Core W3, with a total length of 400 cm, was collected in the central part of the mire in 2011 using a Russian corer 8 cm in diameter and 50 cm long. The spot was previously recognized as containing the thickest organic deposits of the mire.

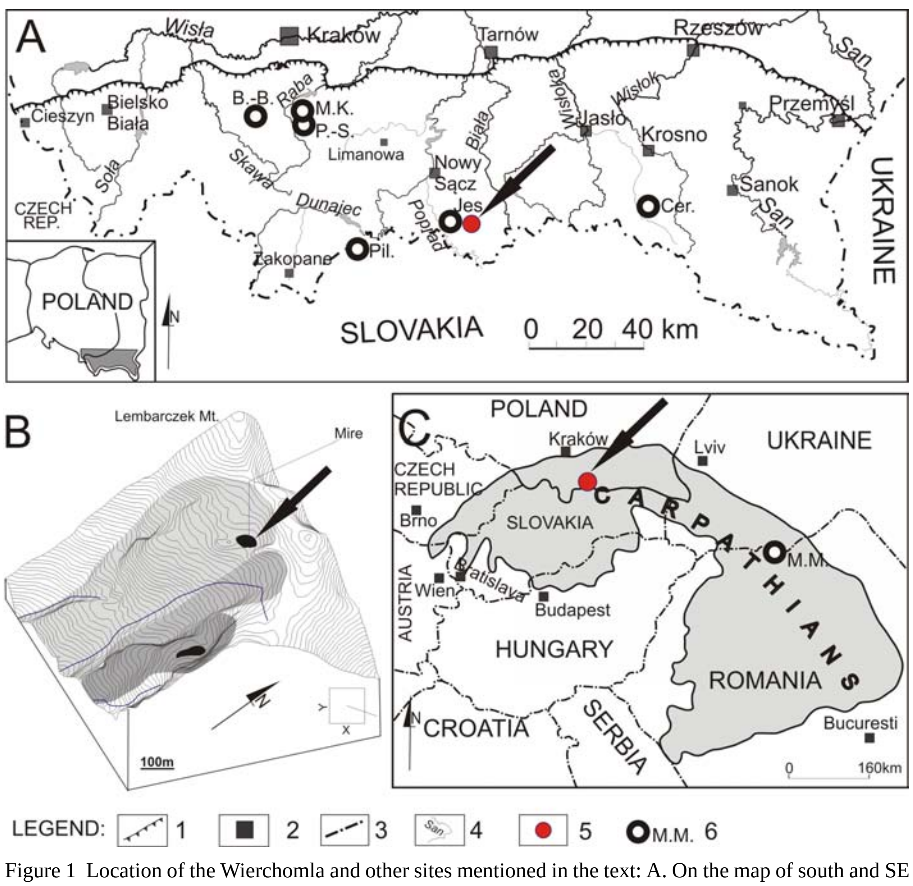

Figure 1 Location of the Wierchomla and other sites mentioned in the text: A. On the map of south and SE Poland; B. 3D model of the slope where the Wierchomla landslide is situated; C. In the Carpathians. Legend: 1 – north boundary of the Carpathians in subfigure A; 2 – towns and cities; 3 – country borders; 4 – rivers; 5 – location of the site; 6 – Sites cited in the text: B.-B. – Bogdanówka-Beło (Margielewski 2006); Cer. – Cergowa (Szczepanek 2001); Jes. – Jesionowa (Margielewski et al. 2011); M.M. – Maramureş¸ Mountains (Fărkaş et al. 2013); M.K. – Mt. Kamiennik (Margielewski et al. 2010a); Pil. – Pilsko (Obidowicz 2003); P.-S. – Pcim-Sucha (Margielewski et al. 2010b).

Nine samples from the Wierchomla peat core were dated using both accelerator mass spectrometry (AMS) and conventional ^{14}C dating techniques. The choice of dating technique depended on the amount of material available for ^{14}C dating. The results, together with information about sample composition, are presented in Table 1. All the dates were calibrated using OxCal v 4.1 (Bronk Ramsey 2009) based on the IntCal09 calibration curve (Reimer et al. 2009). One of the dates (GdS-1343; 4555 ± 65 BP) was identified as an outlier during age-depth model construction (based on the low value of individual agreement index), so it was excluded from the final age-depth model construction (see Results section for details).

Table 1 ^{14}C dates from Wierchomla W3 peat core. The column "Calendar age 2" presents results of calibration of ^{14}C dates, whereas the column "Modeled calendar age 2σ" shows intervals connected with these ^{14}C dates obtained as a result of the age-depth model construction. Calculations were done using OxCal v 4.1 (Bronk Ramsey 2009) and the IntCal09 calibration curve (Reimer et al. 2009). Laboratory code GdA indicates samples dated using AMS, whereas code GdS are samples dated using LSC.

Sample	Depth (cm)	Material	Lab code	^{14}C age (BP)	Calendar age 2σ (BC)	Modeled calendar age 2σ (BC)
W3/15-17.5/a	15–17.5	Small wood fragment	GdA-2615	2710 ± 20	905–810 (95.4%)	905–810 (95.4%)
W3/80-82.5	80–82.5	Wood fragment	GdA-2692	3435 ± 40	1885–1635 (95.4%)	1895–1710 (95.4%)
W3/95-97.5	95–97.5	Peat	GdA-2616	3735 ± 20	2205–2120 (62.7%) 2095–2040 (32.7%)	2205–2120 (62.7%) 2095–2040 (32.7%)
W3/136-139	136–139	Wood fragments	GdS-1271	4340 ± 60	3325–3235 (4.4%) 3115–2870 (90.9%)	3005–2865 (63.6%) 2815–2675 (31.8%)
W3/222.5-225	222.5–225	Peat	GdA-2693	5035 ± 45	3955–3710 (95.4%)	3965–3795 (95.4%)
W3/240-243	240–243	Wood fragments	GdS-1262	5280 ± 75	4325–4290 (3.5%) 4265–3965 (91.9%)	4110–3935 (94.7%) 3860–3840 (0.7%)
W3/300-305	300–307.5	Peat	GdS-1343	4555 ± 65	3485–3310 (21.0%) 3295–3285 (2.2%) 3275–3265 (2.6%) 3240–3105 (42.4%)	Not included in the age-depth model
W3/328-333	328–333	Wood fragments	GdA-2695	5675 ± 45	4670–4635 (2.1%) 4620–4440 (86.7%) 4425–4370 (6.6%)	4695–4485 (95.4%)
W3/387	387	Charcoal	GdA-2500	7010 ± 30	5990–5835 (94.0%) 5825–5810 (1.4%)	5985–5800 (95.4%)

For palynological analysis, 81 samples (1 cm^3 in volume) were selected and prepared using a standard procedure followed by acetolysis (Berglund and Ralska-Jasiewiczowa 1986). More than 500 arboreal pollen (AP) grains per sample were counted, except for 5 samples in which 390–499 AP grains were the basis for calculation due to a low concentration of pollen. The pollen and spore taxa were determined with the assistance of special keys and atlases (e.g. Moore et al. 1991; Beug 2004). In each sample a percentage value of taxon included within the total pollen sum (TPS) = trees and shrubs (AP) + herbs (NAP, excluding cryptogams, aquatic and wetland plants) were calculated as a ratio of this taxon to the TSP. The pollen diagram was plotted using POLPAL software (Nalepka and Walanus 2003) and was related to chronozones *sensu* Mangerud et al. (1974) with calibration of their boundaries by Walanus and Nalepka (2010). The palynological site closest to Wierchomla, supplemented by ^{14}C dating, which could be the most reliable reference for chronology verification, is located in Jesionowa (Margielewski et al. 2011), about 7 km to the NW. Moreover, the Jesionowa site lies at a similar altitude and has a southern exposure like the Wierchomla mire (Margielewski 1997). These 2 profiles are the only available sources of information about vegetation development during the Holocene in the Beskid Sądecki Mountains.

Loss on ignition (LOI) analysis was carried out at every 2.5 cm of the profile, at a temperature of 550 °C, based on sequential heating of the samples in a muffle furnace for 4 h (Heiri et al. 2001). The results are expressed as percentage curves (see Figure 3).

RESULTS

Chronology Based on an Age-Depth Model

Our chronology of the Wierchomla peat bog is based on the OxCal *P_Sequence* model (Bronk Ramsey 2008). Eight ^{14}C dates presented in Table 1 were used for construction of this age-depth model. Use of the *P_Sequence* function requires the estimation of the *k* parameter, which describes a magnitude of fluctuations from a constant deposition rate. Previous investigations made by the authors for another landslide's peat bogs (Margielewski et al. 2010b, 2011; Michczyński 2011) suggested that a value of the *k* parameter should be assumed equal to ~1 cm^{-1}. Finally, in this model the *k* parameter of *P_Sequence* function is assumed to be 0.75 cm^{-1}, because such a value can guarantee that an overall agreement index of the model amounts to >60% (suggested critical value).

Another important element of the age-depth model construction was to point out such levels where sudden and significant changes in the deposition rate might have taken place. Similar to the analysis of the Jesionowa landslide's peat bog (Margielewski et al. 2011), we assumed at the beginning that these levels correspond to horizons with a relatively high amount of mineral component in the deposit. We then pointed out 2 levels where the LOI values were the lowest (292 and 92.5 cm depths) and we included in our model 2 *Boundary* commands that were assigned to the mentioned depths. However, the age-depth model constructed using the above-mentioned assumptions was not satisfactory (the overall agreement index had a value of ~40%). Therefore, after analysis of collected data and photos of the core, we supplemented our model with an additional *Boundary* command at 230 cm depth. We made that decision because the layer between about 230 and 300 cm contains a large amount of larger wood fragments and differs significantly from the layers located above and below it. Finally, the constructed age-depth model assumes 3 levels where sudden and significant changes of the deposition rate might have taken place—at depths of 92.5, 230, and 292 cm—and the *k* parameter equal to 0.75 cm^{-1}. Moreover, the interpolation parameter of the *P_Sequence* function has a value equal to 1 cm^{-1}. The overall agreement index of this model amounts to 60.9%. The determined age-depth relation is presented in Figure 2.

On the basis of the age-depth relation presented in Figure 2, we calculated probability distributions of modeled calendar age for selected events connected with the development of local vegetation and other environmental changes. Because these distributions usually have a symmetrical shape with a single maximum, we decided to present the modeled ages using their mean value (μ) and dispersion (σ) in the form: age(μ) ± error(σ).

Development of Local Vegetation in Wierchomla Inferred from Palynological Analysis

At the beginning of deposition in the landslide depression, the slope was covered by hazel (*Corylus avellana*) thickets and/or short-stemmed forest that probably formed stands with small-leaved lime (*Tilia cordata*). Hazel values exceed 50%. The moist surroundings of the depression were overgrown by elm (*Ulmus*) and alder (*Alnus*) woodlands. From around 6000 ± 70 cal BC, Norway spruce (*Picea abies*; maximum values reaching 71%) started to expand, limiting hazel and afterwards lime stands. Nonetheless, both taxa were still important components of woodlands/forests during the Atlantic and Early Subboreal. Pollen values reaching 5% indicate that maple (*Acer*) expanded during that time, and it might have been a crucial element of patches of elm-lime-maple forests in the

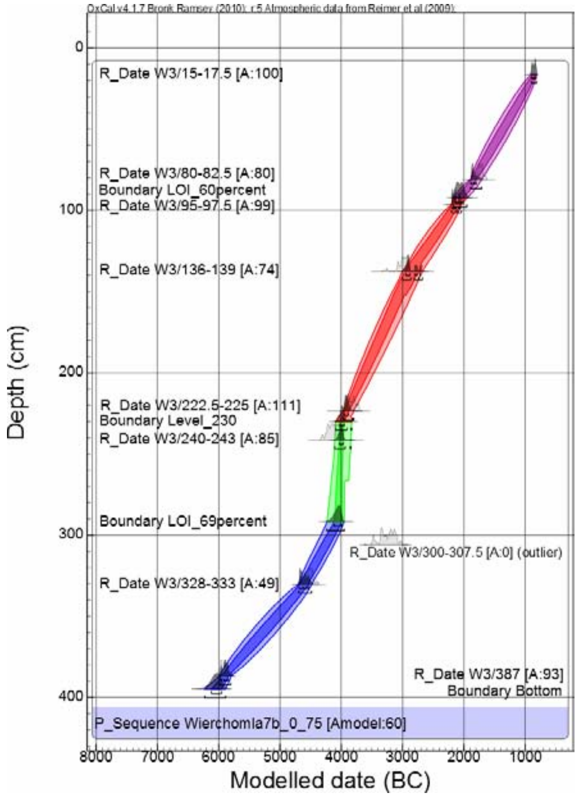

Figure 2 The age-depth relationship for Wierchomla determined using OxCal model described in text.

period 5680 ± 80 to 3990 ± 40 cal BC. Slightly later, between 4760 ± 80 and 4020 ± 50 cal BC, common ash (*Fraxinus excelsior*) spread in the external sections of the mire and its surrounding areas (Tobolski and Nalepka 2004). Together with elm (*Ulmus*), it appears to have been a very important component of woodlands growing in moist habitats.

The Atlantic/Subboreal transition and the beginning of the Subboreal chronozone brought the domination of *Picea abies* in forests (pollen percentages reached 64.5%). Since 3040 ± 90 cal BC, a stable presence of beech (*Fagus sylvatica*) pollen may point to the onset of its slow but gradual expansion. Since 2330 ± 70 cal BC, silver fir (*Abies alba*) started to occur as single trees in forest stands. Simultaneously, hornbeam (*Carpinus betulus*) spread in forests in lower altitudes, but values that have been recorded since 2420 ± 80 cal BC may point to its considerable presence in the patches of deciduous forest (Huntley and Birks 1983). A rapid expansion of *Abies alba* around 1960 ± 60 cal BC led to the gradual retreat of *Picea abies* from forests. These processes signified the initiation of the establishment of a lower mountain forest belt, which comprises mainly beech-fir forests. Presently, this is a natural type of vegetation in the Western Carpathians at altitudes between ~650 and 1250 m asl (Grodzińska and Szarek-Łukaszewska 1998). The first reliable traces of agriculture activity detected in the profile (pollen grain of *Triticum* type) were dated at 1810 ± 50 cal BC and consequent deforestations manifested thorough a drop in AP percentages. Since 1550 ± 70 cal BC a continuous rise in human impact is reflected through gradual deforestation, whereas since 1170 ± 70 cal BC cultivated fields became more widespread with dominating forests forming a mosaic in the contemporary landscape. The acceleration of deforestation was recorded at the top of the profile (uncovered by the age-depth model). Those processes drastically affected spruce stands, which were replaced by pasture lands and cultivated fields (high NAP values).

Loss on Ignition (LOI) Curve and Identification of Deposits

From the bottom of the core, a clear rise in LOI values (from 6% to 89%) reflects the continuous overgrowing of a small lake that originated within the landslide depression (Figure 3). Peat accumulation probably started around 5620 ± 90 mod cal BC, visible in the sediment changes from silty clay to decomposed sedge peat. In the peat section, decomposed woody, sedge, or sedge-moss fen peat dominates. During the period of peat accumulation, relatively constant values of LOI were detected. Only 3 slight decreases in the LOI curve were identified, i.e. around 4060 ± 70 cal BC (depth 292 cm, falling to 69%), around 3640 ± 70 cal BC (depth 202.5 cm, to 73%), and around 2060 ± 60 cal BC (depth 92.5 cm, to 60%). The topmost section of the profile reflects a rapid decline in the LOI curve (from 80% to 60%) (Figure 3).

DISCUSSION

The results of ^{14}C dating combined with palynological and LOI analyses displayed some discrepancies between the Wierchomla site and other sites from the Outer Western Carpathians. Both profiles from the Beskid Sądecki Mts., i.e. Wierchomla and Jesionowa, reflect very similar patterns of vegetation development. However, in some cases the same distinct palynological episodes (Figure 3), which could be considered benchmarks of age, were recorded non-synchronously. Our previous studies (Margielewski et al. 2010b; Michczyński 2011) showed that there was no important influence from using 2 ^{14}C dating techniques (LSC, AMS) on the coherence of the age-depth model. Due to the fact that both depth-age models for both profiles were carried out using the same technique and type of deposits, the resolution and technique of dating did not differ from each other in both cases, we have to consider more the likely scenario that major changes in vegetation were asynchronous at both sites, rather than the establishment of the chronology was erroneous.

The first distinct vegetation change registered respectively at both sites is visible in the oldest sections of the profiles, and it is manifested by a steep fall in *Corylus avellana* values. This episode is dated at 4590 ± 60 cal BC in the Jesionowa profile (Margielewski et al. 2011), whereas in the Wierchomla profile it reflected an age of 6000 ± 70 cal BC. Moreover, in both profiles the values of *C. avellana* after decreases fail to rise again and reach the previous values. Hazel decline is also clearly linked with the expansion of *Picea abies*, so there is almost no difference between both pollen episodes in terms of ecological interpretation. The optimum of hazel at both sites is always connected with the bottom section of profiles; therefore, the domination of this species might have been driven by sufficient microhabitats that existed during the early phase of the landslide niche.

An important palynological marker of the chronology in the Beskid Sądecki Mts. revealed by the Jesionowa profile seems to be the optimum of common ash, whose onset was dated at 4090 ± 70 cal BC and end was estimated at 3550 ± 90 cal BC (Figure 3; Margielewski et al. 2011). The percentages of ash exceed 30% in that section, which is unique among the palynological profiles from the Western Carpathians (Tobolski and Nalepka 2004). Moreover, in the Jesionowa profile the results of LOI analysis revealed a mineral horizon within the section containing extraordinary percentages of ash. The bottom boundary of this horizon was dated at 4315–3960 cal BC (Margielewski et al. 2011). The Wierchomla profile also reflects a distinct period of common ash expansion; however, its percentages are lower and fail to exceed 15% (but they are still extraordinary high; compare Tobolski and Nalepka 2004). Moreover, in the Wierchomla profile a slight decrease in LOI values occurs

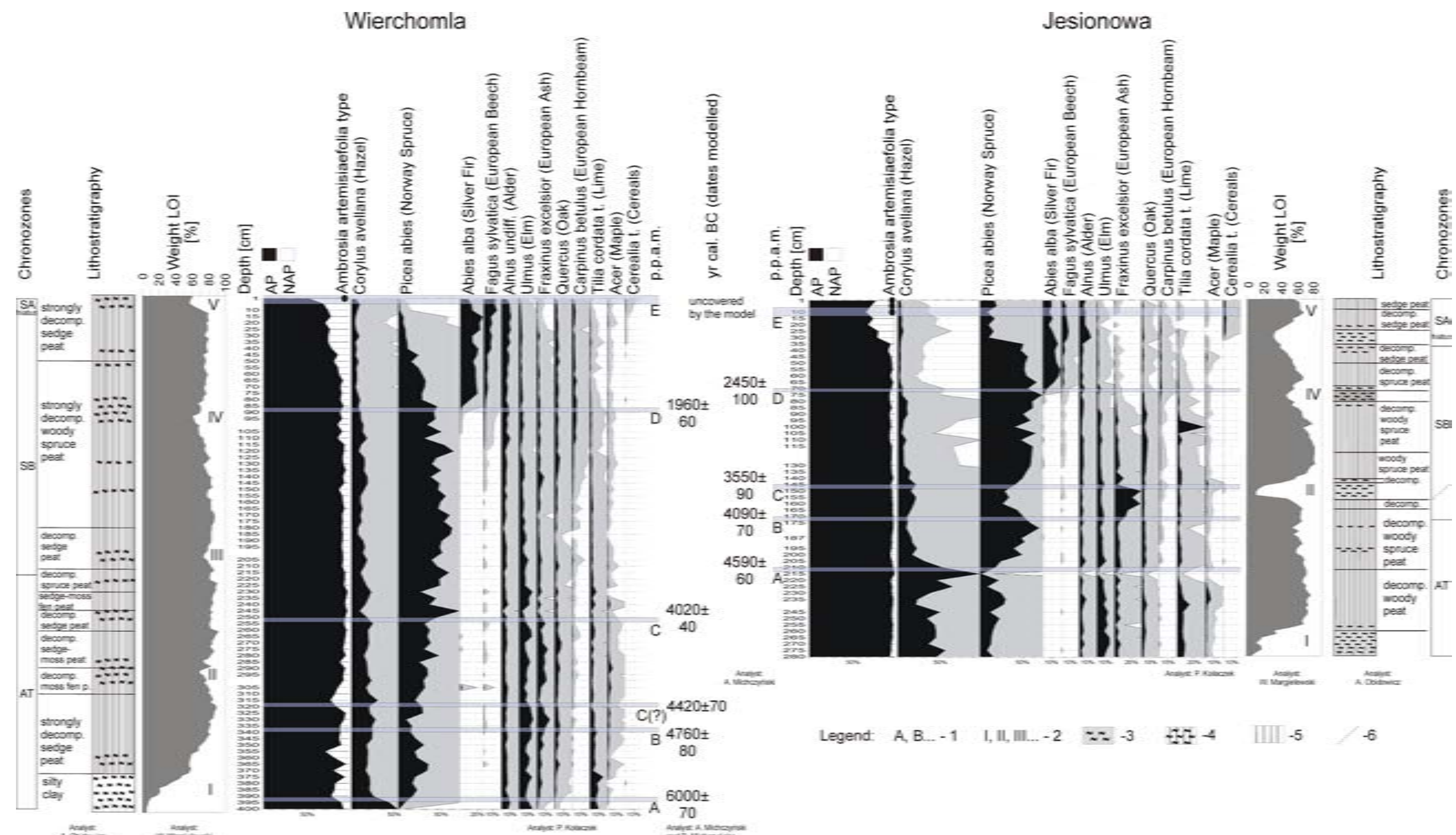

Figure 3 Comparison of deposits, loss on ignition (LOI), main palynological trends between the Wierchomla and Jesionowa profiles (Margielewski et al. 2011; supplemented by new pollen data). Legend: 1–potential palynological age markers (p.p.a.m): A–steep fall in *Corylus avellana* percentages; B–distinct rise in *Fraxinus excelsior* before its optimum; C–fall in *F. excesior* percentages after its optimum; D–strong increase in *Abies alba* values; E–beginning of stable values of *Ambrosia artemiasiaefolia* type; 2–potential simultaneous episodes of heavier input of inorganic matter to the mires; 3–peat; 4–peat with silt admixture; 5–minerogenic sediments; 6–the boundary between the Atlantic and Subboreal chronozones determined according to the age-depth model (not shown in Margielewski et al. 2011)

simultaneously with the second peak of the optimum of *F. excelsior* pollen (Figure 3). These findings may appear to lead to the conclusion that the optima of ash in both profiles resulted from similar and simultaneous processes. However, these palynological assumptions go against the results of ^{14}C modeling, which showed that these processes took place earlier at the Wierchomla site than at the Jesionowa site. The age of the beginning of ash expansion at the Wierchomla site was dated at 4760 ± 80 cal BC, whereas its retreat occurred at 4420 ± 70 or 4020 ± 40 cal BC (depending on which decline of the curve is considered; Figure 3). In both profiles dates from the section of *F. excelsior* optimum introduced to the models came from wood or in minority from peat (only in the case of the onset of ash expansion in the Jesionowa profile). These were also mainly conventional (liquid scintillation counting, LSC; Table 1) dates with the exception of the ^{14}C date 5675 ± 45 BP (the onset of ash expansion) from the Wierchomla profile, which was dated using AMS. Therefore, these results are rather comparable in terms of material and dating method. Even though the pattern of postglacial history of ash is unique to the Beskid Sądecki Mts., in comparison with the whole Polish Carpathians (Kołaczek, personal communication), it is unfortunately unsuitable for the validation of ^{14}C chronologies as well.

Another possible palynological benchmark for absolute chronologies might be the beginning of a dramatic increase in *Abies alba* percentages after the Holocene Climatic Optimum. This phenomenon is visible in several profiles from the Polish Western Carpathians (e.g. Szczepanek 2001; Obidowicz 2003; Margielewski 2006, 2010a,b; Margielewski et al. 2011). Among several profiles from that area the earliest expansion of fir was dated at 3891–3136 cal BC (95.4%) at the Bogdanówka-Beło mire in the Beskid Makowski Mts. (Margielewski 2006), and at 3790–3522 cal BC at Mt. Pilsko site (1270 m asl) in the Beskid Żywiecki Mts. (Obidowicz 2003). The later expansion of fir revealed the Pcim-Sucha site (Beskid Makowski Mts.) and the Mt. Kamiennik site in the Beskid Wyspowy Mts. The former is located at 480 m asl and fir expansion was dated there at 2850–2470 cal BC (95.4%), whereas the latter is located at 587 m asl and this episode was dated at 2500–1750 cal BC (95.4%, Margielewski et al. 2010a,b). In the Wierchomla profile, the expansion of fir was dated to 1960 ± 60 cal BC, whereas in the Jesionowa profile it occurs 2450 ± 100 cal BC (Figure 3; Margielewski et al. 2011), which is relatively late for the Polish Western Carpathians. Therefore, assuming the differences outlined above, using the episode of rapid increase in *Abies* pollen values as a benchmark for validation ^{14}C dating is inadvisable, despite its distinctness. Similarly to the Beskid Sądecki Mts., a nonsynchronous expansion of *A. alba* was revealed by 2 palynological sites from the Maramureş Mountains (the Eastern Carpathians, northern Romania), in which at similar altitudes the onset of continuous presence of *Abies* pollen varies in age about 700 calendar yr (Fărkaş et al. 2013). The distance between both sites is <3 km (Fărkaş et al. 2013), i.e. less than the distance between Wierchomla and Jesionowa.

Thus, if one of the profiles, Wierchomla or Jesionowa, lacked ^{14}C dates or contained only a few, there would be seriously misleading results when constructing the chronology of this profile through comparison of similar events. The discrepancies in the times of the pollen episodes' appearances in both profiles might be explained by differences between microhabitats within the sites, which might have retarded or accelerated major shifts in vegetation in the mire surroundings. Moreover, the dimensions of both mires discussed in the paper, extorted domination of local pollen component among fen deposits (Jacobson and Bradshaw 1981), i.e. pollen was provided by vegetation overgrowing the aforementioned microhabitats. The phenomenon of diachronic pollen events may also occur in profiles collected from the same peat bogs as at Engbertsdijksveen, a vast peatland in the eastern Netherlands (Blaauw and Mauquoy 2012). In that case, the lack of synchronicity between the same palynological patterns was explained by the effect of various microhabitats surrounding the coring spots as well (Blaauw and Mauquoy 2012). The difficulties connected with coincidence (or its lack) of the same pollen events resulting from ^{14}C dating were also detected in the course of studies conducted on a larger scale, e.g. during the reconstruction of the vegetation history of the British Isles (Smith and Pilcher 1973) and when analyzing the mid-Holocene decline of *Tsuga canadensis* in eastern North America (Bennett and Fuller 2002).

The second potential source of event asynchronicity in the present studies might have been the resolution of sampling for pollen analysis and the subsequent incorrect assessment of the exact position of the same event in both profiles (Liu et al. 2012). For example, the age of the episode of rapid rise in *A. alba* percentages might have been erroneously assessed in the range of 5 cm (distance between palynological samples) i.e. a range of 100 ± 60 yr for the Wierchomla profile and 230 ± 110 yr for the Jesionowa one. So taking into consideration both ranges, the dates of the event from both profiles may overlap each other, which leads to the suggestion that the rapid rise in fir values might have been synchronous at both sites. Nonetheless, manipulation of events within chronological uncertainties may cause effects known as "sucking in" and "smearing," i.e. respectively, misleading recognition of asynchronous events as synchronous ones and vice versa (Blaauw 2012).

The last distinct potential age marker in pollen profiles from the Western Carpathians could be the constant presence of pollen of *Ambrosia artemisiaefolia* in the topmost deposits. This pollen type is mostly ascribed to American species of this genus (Punt and Hoen 2009), which started to expand in southern and central Europe in the second half of the 19th century (Makra et al. 2005). However, the acceleration of this process took place during and after World War I in that part of Europe (Makra et al. 2005; Csontos et al. 2010). The occurrences of *Ambrosia* pollen in the topmost section of the Wierchomla profile enable them to be dated to the 19th–20th century. Therefore, a very thin topmost Subatlantic layer (~16 cm) in the Wierchomla profile suggests the presence of a sedimentary gap in this section and erosional removal of part of the sediments affecting the sedimentary basin opening (see Margielewski 2006). Up until now, pollen grains of *A. artemisiaefolia* type were identified in few palynological profiles from the Polish Western Carpathians and their foreland (Kłapyta and Kołaczek 2010; Kołaczek 2010; Kołaczek et al. 2010, 2013; Margielewski et al. 2011). Hence, these could be an important marker for age verification in those layers.

CONCLUSIONS

A prevailing number of palynological profiles from the Polish Western Carpathians has been collected from small lakes or mires that reflect mainly the patterns of local vegetation. Even relatively closely situated sites with similar location parameters, e.g. the same range, altitude, and exposure, may reflect different trends of forest succession. Comparison between the pollen profiles from the Wierchomla Mała and Jesionowa sites shows that episodes that appear identical at the first sight may in fact have different ages (e.g. Blaauw and Mauquoy 2012). The examples of the decline of *Corylus avellana* during the Atlantic chronozone, the expansion and decline of *Fraxinus excelsior* in the Atlantic and Subboreal chronozones, and a rapid increase of *Abies alba* during the Subboreal chronozone in both profiles reveal that within an area of diameter of <7 km the same biogeographical phenomena might have had a time lag even longer than 1000 yr (for comparable studies on larger spatial scales, see Smith and Pilcher 1973). The diversity of habitats in mountainous areas contributes to the variety of scenarios of vegetation development. This fact makes it risky to establish chronologies by aligning palynological profiles to well-dated ones (Blaauw 2012). Therefore, each Holocene palynological profile from this mountainous area should be supported by absolute chronologies of the highest possible resolution. In mountain areas, only pollen profiles supported by absolute age-depth models are reliable for reconstructing postglacial plant migrations and responses of vegetation to climate change.

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