Quaternary Science Reviews 106 (2014) 206–224

Contents lists available at ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Climate variability and associated vegetation response throughout Central and Eastern Europe (CEE) between 60 and 8 ka

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ARTICLE INFO

Article history:
Received 26 November 2013
Received in revised form
10 May 2014

ABSTRACT

Records of past climate variability and associated vegetation response exist in various regions throughout Central and Eastern Europe (CEE). To date, there has been no coherent synthesis of the existing palaeo-records. During an INTIMATE meeting (Cluj Napoca, Romania) focused on identifying CEE paleo-records, it was decided to address this gap by presenting the palaeo-community with a compilation of high-

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http://dx.doi.org/10.1016/j.quascirev.2014.06.003
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Accepted 1 June 2014
Available online 1 July 2014

Keywords:
Terrestrial records
Climate
Pollen
Vegetation response
INTIMATE
Latitudinal gradients
Glacial
Holocene

quality climatic and vegetation records for the past 60–8 ka. The compilation should also serve as a reference point for the use in the modelling community working towards the INTIMATE project goals, and in data-model inter-comparison studies. This paper is therefore a compilation of up to date, best available quantitative and semi-quantitative records of past climate and biotic response from CEE covering this period. It first presents the proxy and archive used. Speleothems and loess mainly provide the evidences available for the 60–20 ka interval, whereas pollen records provide the main source of information for the Lateglacial and Holocene. It then examines the temporal and spatial patterns of climate variability inferred from different proxies, the temporal and spatial magnitude of the vegetation responses inferred from pollen records and highlights differences and similarities between proxies and sub-regions and the possible mechanisms behind this variability. Finally, it identifies weakness in the proxies and archives and their geographical distribution. This exercise also provides an opportunity to reflect on the status of research in the area and to identify future critical areas and subjects of research.
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1. Introduction

One of the main aims of the INTIMATE group (INTegration of Ice-core, MArine, and TErrestrial records) is to reconstruct past climatic changes and their impact on the biotic and abiotic environment for the period between 60 and 8 ka. The main mechanisms used to achieve this aim are the refinement of dating methods and resulting chronologies of past changes, quantification of past climatic changes and related impacts, testing for leads and lags in the climatic system and improvement of all the above by modelling the mechanisms driving these changes (Björck et al., 1998; Walker et al., 1999; Blockley et al., 2012a,b). Initially, the main area of interest was the immediate vicinity of the North Atlantic, later expanding to Eastern Europe (Blockley et al., 2012a) and even farther afield (Petherick et al., 2013). However, discrepancies between regions in terms of data availability and quality have lead to a marked dichotomy between Western and Eastern Europe, which strongly hampers, *inter alia*, testing synchronicity of climatic events, analysis of possible lags in the transfer of climatic influences from the North Atlantic towards the east, and analysis of the response of vegetation to climate changes. Further, while records of past climate variability exist in various regions throughout Central and Eastern Europe, to date there has been no thorough review paper that synthesizes the available high-resolution climate records and data on the biotic responses to the climatic changes.

Present-day climatic differences between Eastern and Western Europe very likely translate into different climatic histories between the two regions in terms of the timing and/or amplitude of palaeoclimatic events. The proximity of Western Europe to the North Atlantic leads to a strong oceanic influence on terrestrial ecosystems, likely overwhelming other possible, distant influences. In contrast, the reduced Atlantic influence in CEE allows for a stronger input from other centres of climatic variability (*e.g.*, the Mediterranean Sea, NW Russia and the Black Sea). These influences result in the northern part (in the vicinity of the Baltic Sea) having cold winters and short, wet summers, while the southern (closer to the Mediterranean Sea) part has relatively warm, wet winters and dry, hot summers. The differences between the two regions were likely enhanced during the Last Glacial period by the strong influence of the Fennoscandian Ice Sheet and Alpine glaciers on air mass circulation (direction and intensity) and temperatures.

During an INTIMATE meeting held in Cluj-Napoca (Romania) in March 2013, it was decided to address this gap and summarize the existing high-resolution records of climate change and related impacts on vegetation in Central and Eastern Europe (CEE) for the period between 60 and 8 ka. CEE is here loosely defined as the region between the Alps and the Baltic Sea to the west, the Scandinavian Peninsula to the north, the Rhodope Mountains and Thracian Plain to the south and the Russian Plain to the east. The 60 and 8 ka interval covers the second half of the Last Glacial, the Last Glacial Maximum (LGM, ca 22–18 ka cal BP), the Lateglacial period (ca 14.7–11.7 ka cal BP), and the early Holocene (ca 11.7–8 ka cal BP). The period before the Lateglacial is divided into Marine Isotope Stage 3 (MIS 3, ca 60–28 ka) and MIS 2 (ca 28–14.7 ka cal BP). As in Moreno et al. (2014), the Greenland ice core stratigraphy has been applied as a template for CEE climate variability during the 60–8 ka time period (Blockley et al., 2012a,b). This review also serves as a reference point for high-resolution palaeodata for use in the modelling community working towards the INTIMATE project goals, and in data-model inter-comparison studies. However, this is not intended to be an exhaustive review of all palaeo-records from the CEE region. This paper should be seen as a companion to a similar compilation of Western and Central European quantitative terrestrial palaeoclimate reconstructions for the same period (Heiri et al., 2014; Moreno et al., 2014). By compiling the best available data from CEE, we aim to: i) present the palaeo-community with a concise compilation of high-quality climatic and vegetation records for the 60–8 ka period; ii) decipher the temporal and spatial patterns of climate variability inferred from different proxies and the magnitude of the vegetation responses; iii) offer a quantitative (*e.g.*, temperature or precipitation) and qualitative (*e.g.*, colder/warmer, wetter/drier) visual representation of past variability in climatic conditions, highlighting differences and similarities between proxies and regions; iv) (partly) understand the mechanisms behind these changes and variability.

2. Data compilation and selection criteria

The selection of best available records was guided, as much as possible, by the following criteria: i) the record should cover a fraction of the INTIMATE 60–8 ka time frame; ii) the record should include at least one quantitative or semi-quantitative parameter (proxy or reconstruction); iii) the records should be independently dated or tightly linked to a well-dated record age model. However, it emerged that the Lateglacial and early Holocene was the most intensively studied period in CEE and that most records include pollen data. Abiotic proxies (geomorphology, fluvial sediments, stable isotopes, geochemistry, etc) were less used, and usually with a generalized or even contradictory explanation of the mechanisms linking them to climatic parameters. Loess, on the other hand, appeared as the most complete palaeo-archive for the period beyond the Lateglacial, albeit with a lower resolution and less precise chronology.

We first identified *non-pollen records* in order to eliminate the problem of discriminating between the forcing (*i.e.*, climate change) and the response (*i.e.*, vegetation change). In the second step, we eliminated those records where it was not clear how a measured variable registered the climatic signal or what the

mechanism was by which changes in measured values were assigned to a given climate change. However, due to the extremely low number of suitable records, we have also included the pollen-based annual, summer and winter temperature reconstructions from Romania as these are among the very few quantitative climate estimates, are well dated and represent the longest quantitative records from the region. The resulting quantitative and semi-quantitative temperature reconstructions are based on two chironomid records, from Poland (Płóciennik et al., 2011) and Romania, respectively (Tóth et al., 2012); a $\delta^{18}O$ record from speleothems in Romania (Tămaş et al., 2005), a $\delta^{18}O$ record from bulk carbonates in lake sediments from Slovenia (Andrič et al., 2009), and a pollen-based quantitative reconstruction of summer, winter and mean annual temperature (MAT), as well annual precipitation from NW Romania (Feurdean et al., 2008a,b). The climate data are presented in two distinct time frames: MIS 3 (60–28 ka) and MIS 2 (28–14.7 ka), and Lateglacial to early Holocene (14.7–8 ka). Discussions follow a north to south gradient (Fig. 1).

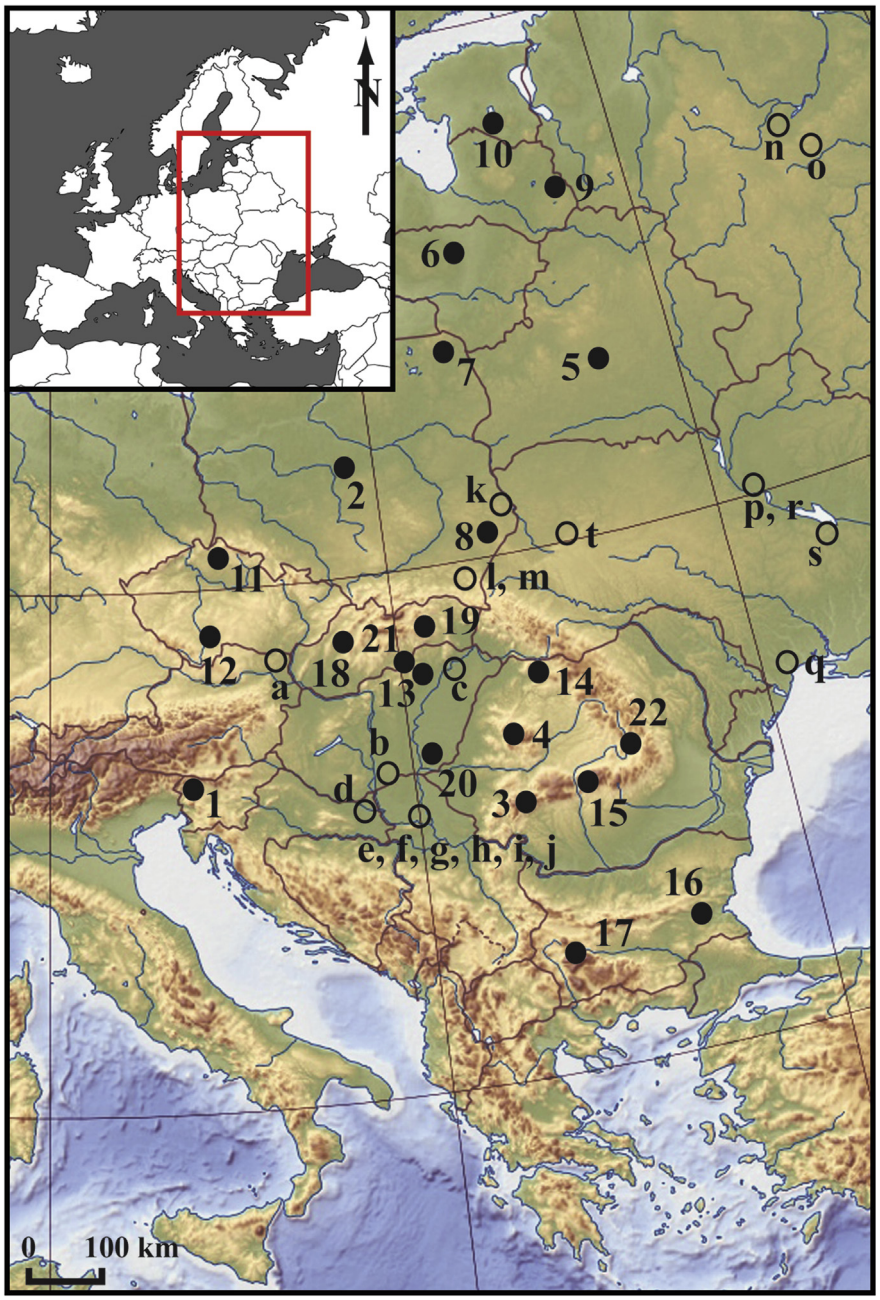

Fig. 1. Location of sites discussed in the text. Numbers refer to sites listed in Table 1: 1 – Lake Bled (SI), 2 – Żabieniec Bog (PL), 3 – Brazi Lake (RO), 4 – V11 Cave (RO), 5 – Lake Sergeyeyskoe (BY), 6 – Lake Ginkunai (LT), 7 – Jezioro Linówek (PL), 8 – Kobylnica Wołoska (PL), 9 – Lake Kurjanovas (LV), 10 – Lake Nakri (EE), 11 – Labský důl (CZ), 12 – Švarcenberk (CZ), 13 – Kis Mohos (HU), 14 – Steregoiu and Preluca Ţiganului (RO), 15 – Avrig (RO), 16 – Straldzha (BG), 17 – Trilistnika (BG), 18 – Jablůnka (SK), 19 – Šafárka (SK), 20 – Fehér Lake (HU), 21 – Nagymohos (HU), 22 – L. Sf. Ana (RO); whereas small letters refer to loess sites: a - Dolni Vestonice, Antoine et al., 2013, b – Katymar, Bokhorst et al., 2011, c – Tokaj, Schatz et al., 2011, d – Zmajevac, Banak et al. 2013, e – Petrovaradin, Marković et al., 2005, f – Irig, Marković et al., 2007, g – Mošorin, Bokhorst et al., 2011, h – Titel, Bokhorst et al., 2009, i – Surduk, Antoine et al., 2009, j – Crvenka, Stevens et al., 2011, k – Tyszowice, Jary and Ciszek, 2011, l – Dubavka, Bokhorst et al., 2011, m – Radymo, Bokhorst et al., 2011, n – Likhvin, Rutter et al., 2003, o – Korostylievo, Rutter et al., 2003, p – S. Bezradychy, Bokhorst et al., 2011, q – Sazhijka, Bokhorst et al., 2011, r – Pyrogove, Bokhorst et al., 2011, s – Stayky, Kadereit and Wagner, 2014, t – Korshov, Jary and Ciszek, 2011, Golobovo (loess site in Russia, not shown).

We have used the ages and depth-age models as provided by the authors (see Table 1 for the number of dated points and temporal resolution for each record). All data were plotted on their own depth-age model against the NGRIP stable isotope record (Rasmussen et al., 2006) and INTIMATE event stratigraphy (Blockley et al., 2012b) for the 14.7–8 ka cal BP period (Fig. 2), and subsequently used to make a semi-quantitative assessment of the climate characteristics in the region (Table 2). A complete description of the general mechanisms by which these proxies are recording the climatic variables, the methods used to date and extract the climatic signal and the associated problems are found in a companion paper by Moreno et al. (2014) on Western European climate changes between 60 and 8 ka.

To examine the vegetation response to the climate fluctuations we selected a total of 13 pollen sequences with good temporal and spatial coverage in CEE as follows: for small countries only a single pollen sequence was included, whereas for larger countries, or those with significant elevation gradients, the two most complete continuous records per country were selected. The pollen taxa in these sequences were then grouped into ecological types that largely follow the protocol for assigning pollen taxa to plant functional types and subsequently biomes (Fletcher et al., 2010; Moreno et al., 2014). The 5 main types were: coniferous, cold deciduous trees, temperate deciduous taxa, warm temperate taxa, warm/dry steppe, and other grassland and dry shrubland (Table 3). In addition, pollen and plant macrofossil maps were created for the following time slices: 17, 14.7 13.5, 12.7, 11.7, 10.5, 9.3, 8.2 ka cal BP for each record, to aid better geographical visualization of the vegetation dynamics in the CEE.

Quantitative reconstruction of climatic conditions during 60–8 ka in the CEE region poses a series of challenges, including: 1) a lack of investigated records for most of the period extending beyond the Lateglacial, or extremely fragmentary and low-temporal resolution records (the notable exceptions are loess deposits, see below); 2) imprecise age control (up to 10% dating uncertainties), which prevents accurate identification of the "short"-lived (less than 500 yrs) events; 3) difficulties in constraining the significance of the various measured variables in terms of climatic parameter or how the measured values were quantified. Insufficient temporal resolution and chronological control of the records

Table 1
List of compiled records from CEE in the INTIMATE chronological framework, specifying the dating method used, the climate variable that was reconstructed and the used proxy.

N°	Archive	Country	Site	Chronology			Reconstructed variable	Quantified proxy	References
				Type of dating	Number of dated points	Mean temporal resolution			
1	Lake sediments	Slovenia	Lake Bled	^{14}C, tephra	2 3	69 (isotopes) 180 (pollen)	Temperature	Bulk carbonates δ^{18}O Pollen Plant macroremains	Andrič et al., 2009, Lane et al., 2011
2		Poland	Żabieniec bog	^{14}C	5	252	Temperature	Chironomids	Plociennik et al., 2011
3		Romania	Lake Brazi	^{14}C	7	124	Temperature	Chironomids	Toth et al., 2012
4	Speleothemes	Romania	V11 Cave	U/Th	10	63	Temperature	Calcite δ^{18}O	Tămaş et al., 2005
5	Pollen in lake	Belarus	Lake Sergeyeyskoe	^{14}C	5	121	Vegetation	Pollen	Makhnach et al., 2009
6	sediments /Peat	Lithuania	Lake Ginkunai	^{14}C	8	56	Vegetation	Pollen	Stancikaite et al., 2008, 2009
7		Poland	Jezioro Linówek	^{14}C	2	200 (pollen) 40 (lant macroremains	Vegetation Lake level	Pollen Plant macroremains	Gałka et al., 2014
8			Kobylnica Wołoska	^{14}C	6	66 (pollen) 18 (plant macroremains	Vegetation	Pollen Plant macroremains	Kołaczek et al., in press.
9		Latvia	Lake Kurjanovas	^{14}C	6	66	Vegetation	Pollen Plant macroremains LOI	Heikkilä et al., 2009
10		Estonia	Lake Nakri	^{14}C	9	80 (pollen) 30 (macro)	Vegetation	Pollen Plant macroremains LOI	Amon et al., 2012; Veski et al., 2012
11		Czech	Labský důl	^{14}C	5	165	Vegetation	Pollen	Engel et al., 2010
12		Republic	Švarcenberk	^{14}C	3	60	Vegetation	Pollen	Pokorný, 2002, Pokorný et al., 2010
13		Hungary	Kiss Mohos	^{14}C	8	163	Vegetation	Pollen	Willis et al., 1997
14		Romania	Preluca Ţiganului Steregoiu	^{14}C	12 12	65 35	Vegetation Temperature Precipitation Lake level	Pollen Plant macroremains Zoological remains LOI Micro-macrocharcoal Mineral magnetic measurements	Björkman et al., 2002; Feurdean et al., 2007, 2012b; Ampel, 2004
15			Avrig	^{14}C	10	104	Vegetation	Pollen	Tanţău et al., 2006
16		Bulgaria	Atolov Straldzha	^{14}C	7	790	Vegetation Biomes	Pollen Micro-charcoal Mineral magnetic susceptibility	Connor et al., 2013
17			Trilistnika	^{14}C	6	293	Vegetation	Pollen	Tonkov et al., 2008
18		Slovakia	Jablůnka	^{14}C	2	Unknown	Vegetation	Pollen	Jankovská and Pokorný, 2008
19			Šafárka	^{14}C	10	Unknown	Vegetation	Pollen	Jankovská et al., 2002 and Jankovská and Pokorný, 2008
20		Hungary	Ferér Lake	^{14}C	6		Vegetation	Pollen	Sümegi et al., 2013
21			Nagymohos	^{14}C	4		Vegetation	Pollen	Magyari et al., 2014
22		Romania	Sf. Ana	^{14}C	7		Vegetation	Pollen	Magyari et al., 2014

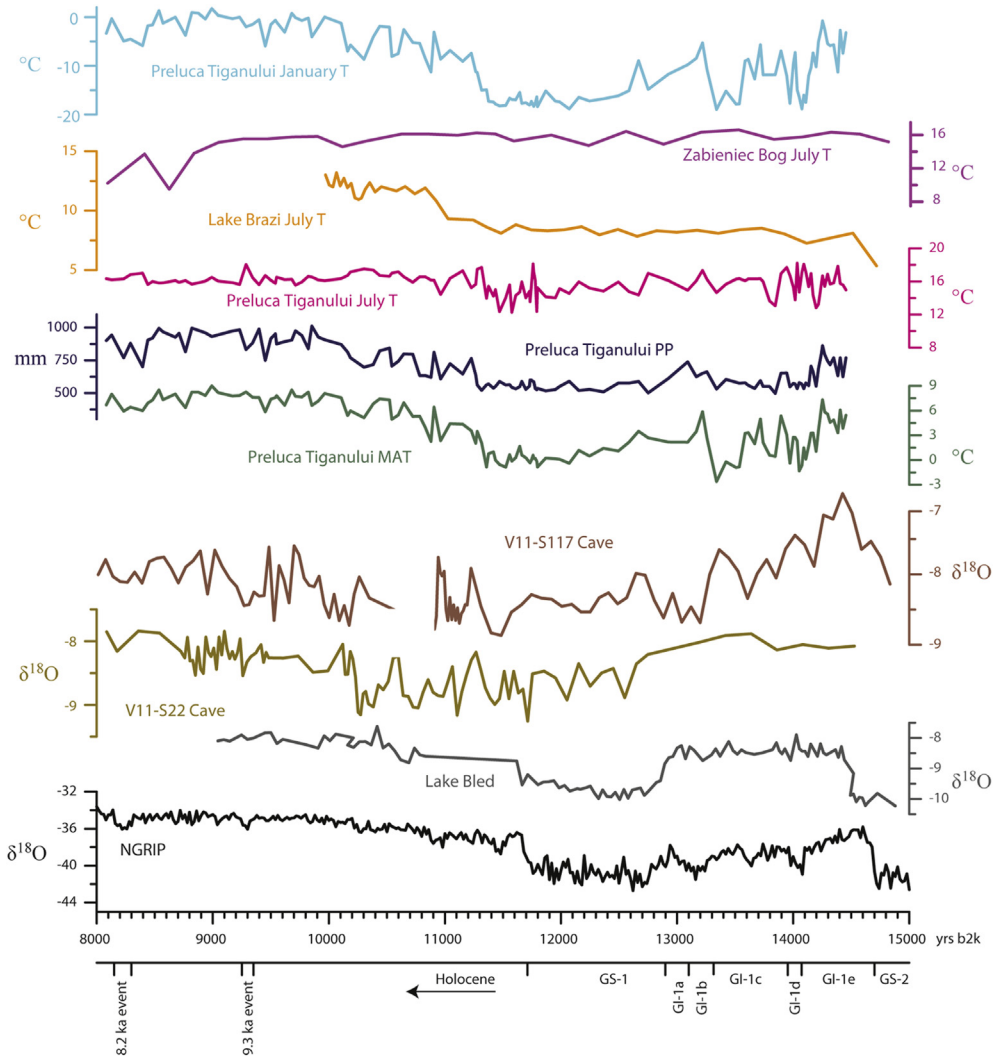

Fig. 2. Selected palaeoclimate reconstructions from CEE between 15 and 8 ka cal BP plotted against the NGRIP $\delta^{18}O$ curve (Rasmussen et al., 2006) and INTIMATE event stratigraphy of Blockley et al. (2012b).

also prevented: 1) the assignment of accurate dates for the timing of the short climatic events, and 2) a precise correlation, in terms of "synchronicity" or "lags", between the local climatic shifts and the INTIMATE event stratigraphy. However, within the dating uncertainties, possible correlations have been proposed.

3. Climate changes in CEE

Our analysis is based on stable isotope variations in lake sediments, speleothems, loess and chironomid assemblages (Fig. 2), but is restricted to loess and speleothem records for the interval between 60 and 14.7 ka.

3.1. 60–8 ka

3.1.1. Loess records

Loess covers large parts of CEE, especially in areas south of the previous maximal extent of the former Fennoscandian Ice Sheet. Its distribution widens eastward, towards the Ukrainian and Russian lowlands. The province can further be subdivided into 5 subprovinces, each experiencing contrasting palaeoclimate: 1. between the Alps and the Carpathians; 2. north of the Carpathians; 3. the middle Danube Basin; 4. the lower Danube Basin and the northern coast of the Black Sea; and 5. Ukrainian and Russian continental lowlands (Table 4). The source and transport directions of loess in these areas are diverse, with material in the N and E parts of the CEE loess belt likely a large deflation area south of former ice margins. By contrast, the central Danube Basin loess is probably initially eroded from high mountain regions and then transported and deposited in floodplains of the Danube and tributaries (Buggle et al., 2008; Újvári et al., 2013). Based on grain size investigations at three loess sections west and another five east of the Carpathian Mountains, Bokhorst et al. (2011) suggested a prevailing westerly wind over CEE during the MIS 3, and a dominant north-westerly wind during the GS-2. Generally, this interpretation corresponds well with the major wind directions previously reconstructed by Rozycki (1991) and Marković et al. (2008) based on loess landform orientation and modelling results (Rousseau et al., 2011; Sima et al., 2013).

The Eastern European loess belt provides a unique opportunity for almost continuous climatic reconstructions over this part of Europe between 60 and 14.7 ka. However each subprovince experienced quite different palaeoclimatic conditions over the time period investigated and recovering climatic information is therefore complicated due to the changing influence of specific controls on the preserved proxies. One of the earliest attempts used soil

Table 2
Summary of inferred climate changes between 14.7 and 8 ka cal BP at individual high-resolution sites from CEE.

Chronology	Age (b2k)	NW Slovenia	S Romania	W Romania	NW Romania	Central Poland	Baltic region
Event		Lake carbonates $\delta^{18}O$	Chironomids	Speleothem $\delta^{18}O$	Pollen-based	Chironomids	Pollen and macrofossil-based
8.2 ka cal BP	8300–8140	Cold			Cold		Cold
9.3 ka cal BP	9350–9240	Cold		Cold	Cold		Cold
Holocene	11,703	Warm	Warm	Warm	Warm		Moderate
GS-1	12,896–11,703	Cold and dry	Moderate	Cold and dry	Moderate, with very cold winters, dry	Mild	Cold
GI-1a	13,099–12,896	Moderate, drying tendency	Moderate	Warm	Slightly warm, wet	Warm	Moderate
GI-1b	13,311–13,099	Moderate	Moderate	Cold and wet	Moderate, cold winter	Warm	Cold
GI-1c	13,954–13,311	Moderate	Moderate	Warm	Warmest during the LG, warm winter, wet	Warm, colder than GI-1e	Moderate
GI-1d	14,075–13,954	Moderate, wetter	Cold	Cold	Cool winters, slightly warm summer	Warm	Cold
GI-1e	14,692–14,075	Warm and dry	Moderate	Very warm	Warm and dry	Warm	Cold
GS-2a		Very cold	Very cold			Very cold	Very cold

types as indicators of past climatic conditions. However, the significant palaeoenvironmental diversity over the region controls the intensity and type of pedogenesis, meaning the resultant palaeosols represent a wide variety of habitats, from tundra gley layers (Rousseau et al., 2011; Antoine et al., 2013), parklands and grasslands soils in the Middle Danube and Ukraine (Gerasimenko and Rousseau, 2008; Marković et al., 2008; Schatz et al., 2011; Kovács et al., 2012), to dry steppic soils in the Lower Danube lowland and around the Black Sea coast (Buggle et al., 2009). Furthermore, uncertainties in loess age models (see Timar-Gabor et al., 2011; Timar-Gabor and Wintle, 2013 for the Romanian loess) prevent confident correlation of palaeopedological horizons in the CEE with individual NW European interstadials such as: Denekamp, Hengelo, Moershoofd or Glinde, or to specific Greenland interstadials. Refining these correlations represents a significant avenue of future research.

Despite this, attempts have been made to correlate multiple episodes of abrupt climatic fluctuations recorded in loess grain-size from Moravian Czech Republic and Central Ukrainian deposits, with cooling in the North Atlantic, partly associated with Heinrich events as well as with cold phases of Dansgaard–Oeschger cycles recorded in Greenland ice (Antoine et al., 2009, 2013; Rousseau et al., 2011). However, investigations in N Serbia using a similar chronological framework and level of uncertainty suggest that it is only possible to establish relationships between grain-size peaks in loess and some Heinrich Events, rather than Greenland stadial events, which require greater precision in age-dating (Stevens et al., 2011) and depending on their magnitude may not show a grain-size response. In any case, Hatte et al. (2013) suggest that these coarse-grain depositional phases are usually associated with the appearance of dry and probably cold climatic events. More frequent periods of coarser grain deposition occurred during the MIS 3 under dominant westerly air circulation (Bokhorst et al., 2011). This greater deposition of coarser material during the relatively cold early Last Glacial (loosely 74–50 ka) compared to during the period around the Last Glacial maximum is likely to be a consequence of reorganization of atmospheric circulation due to initial ice sheet growth and sediment mobilization, as well as changes in depositional regime of the Danube fluvial system. By contrast, during the MIS 2 although ice sheet growth was significantly greater (Wohlfarth, 2010), maximal extension of northern European ice may have partially blocked penetration of the Atlantic air masses to the east (Dodonov and Baiguzina, 1995). Model results of Van Huissteden and Pollard (2003) indicate a strong anticyclonal circulation over the Fennoscandian Ice Sheet around the Last Glacial Maximum. At the same time, the Alpine ice cap played an important role in the hydrological regime of the Danube River through controlling the considerable melt-water driven flow of the system, as well as in the production and transport of source material for later aeolian deposition (Marković et al., 2008). The shift to finer depositional modes is also likely to have been associated with changes to more dense vegetation cover during MIS 2 in Serbia (Marković et al., 2005; Zech et al., 2009, 2013).

Table 3
Major vegetation types (megabiomes) in CEE Europe. Each pollen type was assigned to one of these megabiomes.

Megabiomes	Characteristic pollen taxa
Coniferous trees	*Picea*, *Pinus*, *Abies*, *Larix*, *Juniperus*
Cold deciduous trees	*Alnus*, *Betula*, *Salix*, *Populus*
Temperate deciduous trees	*Ulmus*, *Quercus* (deciduous-type), *Tilia*, *Corylus*, *Acer*, *Fraxinus*, *Acer*, *Carpinus*, *Hedera*, *Ilex*, *Fagus*, *Viscum*, *Sambucus*, *Viburnum*, *Cornus*, *Frangula*, *Myrica*, *Prunus*, *Sorbus*
Warm temperate taxa	*Quercus* (evergreen-type), *Olea*, *Carpinus orientalis/Ostrya*, *Loranthus*, *Fraxinus ornus-type*, *Rhamnus/Paliurus*, *Euonymus*, *Jasminum*, *Colutea*, *Cotinus*
Grass and shrubs	Ericaceae, *Calluna*, *Hippophae*, Poaceae, Cyperaceae, other NAP
Xerophytic herbs	*Artemisia* and Chenopodiaceae/Amaranthaceae

The relatively sparse quantitative climatic reconstructions from loess subprovinces north of the Carpathians and in the middle Danube Basin generally suggest that the Carpathians significantly modified Last Glacial climatic gradients. Based on the spatial distribution of ice wedge casts recorded in Last Glacial loess, Jary (2009) suggested that in the central and E parts of Poland and W Ukraine, permafrost developed twice; in the latest part of early Last Glacial (potentially equivalent to Heinrich Event (HE) 6) and the late Last Glacial (approximately from HE2 to YD). Mean annual air temperature (MAAT) has been estimated as between −2 and −6 °C during the older phase (Vandenberghe et al., 1998; Renssen and Vandenberghe, 2003; Vandenberghe et al., 2004), while the common occurrence and large size of the younger phase of cryogenic structures indicates continuous areas of permafrost existed in the central and E parts of Poland and W Ukraine. Assuming this interpretation is correct, the MAAT of the coldest phase of the late Last Glacial was most likely 10–15 °C lower than present. Similar environmental conditions are suggested from loess in the N parts of the Ukrainian and Russian lowlands (Little et al., 2002). However, significantly drier and warmer conditions are indicated by the general absence of cryo features (Marković et al., 2008) and the

Table 4
Temporal and spatial environmental dynamics over the Eastern European loess belt. Abbreviations: CP-continuous permafrost; DP-discontinuous permafrost; T-tundra; TA-taiga; DF-forest; FS-forest steppe; PL-mosaic parkland; MS-modern steppe; CLS-cold loess steppe; WLS-warm loess steppe; DWLS-dry warm loess steppe.

Period/Loess subprovinces	Early Last Glacial	Middle Last Glacial	Late Last Glacial	Early Holocene
Between the Alps and the Carpathians	CLS	FS-PL-WLS	CLS-T	DF-FS-TA
N of the Carpathian Mts.	DP	FS-T-TA	CD-T-CLS-TA	DF-FS-TA
Middle Danube	PL-CLS-DWLS	PL-WLS-DWLS	CLS-PL	FS-PL-MS
Lower Danube and Northern coast of the Black Sea	DWLS-CLS	PL-WLS-DWLS	DWLS-CLS	FS-PL-MS
Ukrainian and Russian lowlands	DP-CLS	FS-WLS-T	DP-T-CLS	DF-FS-TA-MS

relatively high July palaeotemperatures reconstructed from malacofauna (Sümegi and Krolopp, 2002; Marković et al., 2007; Molnár et al., 2010) in the Danubian loess south of the Carpathian Basin, reinforcing the suggestion of diverse climates found in this region. Cold spells related to Heinrich Events, the LGM and YD were inferred from a biomarker record from the NW Black Sea region (40–9 ka), but the amplitude of these cold phases was smaller than lake temperature records in the region or other records from central Europe would suggest (Sanchi et al., 2014). Dansgaard–Oeschger variability was not detected in this record.

3.1.2. Speleothem records

The deposition of speleothems in caves of CEE during this time span is discontinuous, showing intervals (with variable length) of enhanced and decreased (or even ceased) growth. Such periods are traditionally associated with either warm or cold intervals, respectively. The cumulative growth frequency record of 62 U/Th-dated speleothems from different karst regions in NW Romania situated between 450 and 1150 m asl, show more continuous growth during the past 60 ka (Onac, 1996, 2001; Onac and Lauritzen, 1996; Lauritzen and Onac, 1999) compared to those at higher latitudes, although the Scandinavian Ice Sheet was only 500 km away (Ehlers et al., 2011). This confirms that NW Romania was neither covered by alpine glaciers nor experienced enough severe permafrost conditions to suppress water percolation into the caves and hence speleothem growth. Further, the growth of a stalagmite in NW Romania between 59 and 46 ka indicates a warm/wet period (Tămaş and Causse, 2001). In contrast, the palaeoclimate records from alpine caves in Central and Western Europe are sparse over this time period (Spotl et al., 2006) because the presence of ice caps caused a significant temperature drop, prompting permafrost development, thus preventing the continuous growth of speleothems.

An almost continuous isotope record covering the period between 60 and 8 ka was documented by Constantin et al. (2007) from a cave in SW Romania (stalagmite PP10 in Poleva Cave). Its $\delta^{18}O$ isotopic values show an increase from 60 to 57 ka when they reach a maximum of −7.7‰. This interval was interpreted as representing warming at the onset of Marine Isotope Stage 3 (MIS 3). After this event, the oxygen isotopic profile suggests an overall cooling trend emphasized by the gradual $\delta^{18}O$ decrease to −9.0‰ at ~42 ka when the stalagmite ceased to grow for a short period of time. Beyond this hiatus, the $\delta^{18}O$ values decrease abruptly to −10.5‰ indicating an extreme cold phase between 38 and 35 ka. The gradual increase of $\delta^{18}O$ values by ca 2‰ after 38 ka and until 25 ka points toward a moderate warming, which was followed by rapid cooling at the beginning of the Last Glacial Maximum when the speleothem ceased to grow until the end of the Younger Dryas (Constantin et al., 2007). The cold interval recorded in the PP10 stalagmite between 38 and 35 ka was also documented from central Romania, where archaeological findings in Gura Cheii – Râşnov Cave suggest a cold phase prior to 40 and until at least 34 ka cal BP (Cârciumaru et al., 2012).

A new study by Drăguşin et al. (2014) demonstrates that $\delta^{18}O$ record does not show significant variations (−9.2 ± 0.3‰) across the 8.2 ka event in the POM2 stalagmite (Ascunsă Cave, SW Romania). The low isotopic variability during the 8.2 ka event apparently reflect only temperature variations, but hydrologic conditions such as relatively more summer vs. winter rainfall cannot be ruled out. One clear indication that environmental conditions changed is the growth rate, which increased 8 times during this event compared to the rest of the Holocene.

3.2. GI-1e

The beginning of GI-1 in the Greenland Ice Core record is centred at 14,692 b2k and shows a temperature amplitude increase of 10 °C over just a few years (Blockley et al., 2012b). A warming trend was noticed throughout CEE about the same time (Table 2); however, the timing and magnitude of this warming can only be roughly estimated (Fig. 2). For example in Slovenia, the $\delta^{18}O$ on bulk carbonates from lake sediments indicates a sharp increase in summer temperatures at 14.8 ka cal BP, followed by relatively stable conditions (Andrič et al., 2009). Similarly, a rapid warming phase initiated at ~14.8 ka cal BP is revealed by the $\delta^{18}O$ values of a speleothem from NW Romania (Tămaş et al., 2005) and was also inferred from the growth intervals of another speleothem in Scărişoara Ice Cave (Onac, 2001). For the same region, Feurdean et al. (2008a) used pollen to document a 2 °C increase (from 2 to 4 °C) in annual temperatures that correlate well with the timing of the GS-2/GI-1e transition in Greenland, increase generated by winter temperatures only (summer temperatures remained unchanged). A chironomid-based reconstruction of summer temperatures in the S Romanian Carpathians indicates an increase of ~2.8 °C in summer air temperature during the same transition, reaching a maximum of ~8.1 °C (Tóth et al., 2012). Further to the NE during the same period, July temperatures fluctuated between 12 and 16 °C in central Poland (Ralska-Jasiewiczowa et al., 1998; pollen data), 13–16.5 °C at Żabieniec bog, central Poland (Płóciennik et al., 2011; chironomid assemblages) and 15.5–16.5 °C at Lake Okunin, in NW Ukraine (Dobrowolski et al., 2001; ostracod assemblages). In the eastern Baltic area, July temperatures below 12 °C (Kirilova et al., 2011 – chironomid data; Veski et al., 2012; pollen data) were characteristic during the early phase of the Lateglacial (roughly overlapping with GI-1e in Greenland).

3.3. G1-1d through GI-1a

The climatic conditions during this time interval are seen as relatively stable in most of the records, with only two small-leaved decline in annual temperatures, that could be tentatively correlated with GI-1d and GI-1b in Greenland (Fig. 2). Based on the $\delta^{18}O$ record, Tămaş et al. (2005) report a decline (~1‰ in the $\delta^{18}O$ values)

in mean annual temperatures, punctuated by rapid and strongly expressed cooling events that could correlate with GI-1d and GI-1b. Chironomid-based July temperatures in S Romania (Tóth et al., 2012) and central Poland (Płóciennik et al., 2011) were relatively stable with values slightly lower than those during GI-1e (*e.g.*, a weak increase to 8.1–8.6 °C between 13,700 and 11,480 cal BP in Romania). Instead, pollen-based quantitative reconstructions from NW Romania (Feurdean et al., 2008a) indicate that between 13,800 and 12,700 cal BP (*i.e.*, during GI-1a-c in Greenland), summer temperatures rose close to modern values (13–17 °C), whereas winter (ca −6 to −12 °C) and annual temperatures (0.5–6 °C) as well as precipitation (550–700 mm) were still lower (Fig. 2), indicating stronger inter-seasonal variability and enhanced continental conditions compared to the present-day climate. The $\delta^{18}O$ based climate reconstruction at Lake Bled (Slovenia) shows warmer conditions after 13,8 ka cal BP (Andrič et al., 2009; Lane et al., 2011), whereas the chironomid assemblages indicate a lowering of the lake level connected to warmer and drier environment (Andrič et al., 2009). Another line of evidence for warmer summer temperatures comes from fire activity, which increased between 13,8 and 12,7 ka cal BP in the Carpathian Mountains and lowlands of Hungary and Slovenia (Willis et al., 1997; Andrič et al., 2009; Feurdean et al., 2012a).

3.4. GS-1

A decline in average temperatures occurred throughout the region after 12,800 cal BP, correlating, within dating uncertainties, with the onset of GS-1 in Greenland. July temperatures registered a decline of 1 °C in Poland and S Romania (chironomids-based; Płóciennik et al., 2011; Tóth et al., 2012), and 2 °C in NW Romania (pollen estimate; Feurdean et al., 2008a). However, pollen-based estimated winter temperatures drop ~9 °C (Feurdean et al., 2008a), whereas precipitation declines by ca 250 mm (Fig. 2). Similarly, diatom inferred winter ice cover in the southern Carpathians suggests that cooling associated to the GS-1 was mainly expressed during winter (Buczkó et al., 2012). Drier and cooler conditions for the stadial are indicated by $\delta^{13}C$ and $\delta^{18}O$ in speleothems from Romania (Tămaş et al., 2005; Romania); $\delta^{13}O$ (Lane et al., 2011), chironomid assemblages and lake level in a lacustrine sequence from Slovenia (Andrič et al., 2009), and ostracod assemblages from Poland (Dobrowolski et al., 2001). A drop in precipitation at the onset of GS-1 is also shown by the decreased fluvial activity from Poland (Starkel et al., 2013). Although the GS-1 was generally dry, the record from Northern Poland shows that the onset of lacustrine sedimentation occurred during this period, but was most intensive during the first half of the GS-1 (Michczyńska et al., 2013). Further, Goslar et al. (1995) have ascribed rapid fluctuations in $\delta^{18}O$ of authigenic carbonates in Lake Gościąż (central Poland) to changes in air temperature, synchronous (within dating uncertainty) with those seen in the Greenland ice cores. The rapid (within 170 years) cooling at the onset of the Younger Dryas was followed by an even rapid warming (at 11,44 ka cal BP), seen as a 2‰ increase in $\delta^{18}O$ values within ~70 years.

Summarizing the records above, it appears that the decline in temperatures between 12,8 and 11,7 ka cal BP (corresponding to GS-1) in CEE was more pronounced for winter than for summer, which, along with evidence for a marked drop in precipitation, indicates a progression transition towards more continental, arid or seasonally variable climatic conditions (Table 2).

3.5. Early Holocene

Independent palaeoclimatological evidence from CEE suggests that transition to markedly warmer and drier conditions (summers) occurred at 40–50 °N approximately between 11.7 and 8 ka cal BP. In the northern part of Central Europe (above 47 °N), the temperature increase was significantly slower and with smaller magnitudes compared to more southern locations (Table 2). Higher (by 1–1.5 °C) than today summer temperatures have been both reconstructed (Seppä and Poska, 2004; Feurdean et al., 2008b; Seppä et al., 2009) and modelled (Renssen et al., 2009) for the region during the Early Holocene. Higher summer temperature and lower moisture availability is also demonstrated by the increase in fire activity over large areas and elevations of CEE (Andrič et al., 2008, 2009; Magyari et al., 2010; Feurdean et al., 2012a, 2013; Connor et al., 2013; Hájková et al., 2013). Climate simulation of the early Holocene for the lowlands of NW Romania (Transylvania) shows, higher summer temperatures (by about 4 °C) and lower precipitation values (by about ~33%) but only moderately higher annual temperatures compared to present-day values (Feurdean et al., 2013). In the southern part of the region (Poleva Cave in SW Romania), the steady increase of the $\delta^{18}O$ values (up to 2 ‰) in speleothems PP 9 and 10 indicates a gradual warming trend from ~11.5 ka, continuing well into the Holocene (Constantin et al., 2007), with similar warming trends seen west (Slovenia, Andrič et al., 2009) and north (Romania, Tămaş et al., 2005) of this site, while more northern regions experienced a less pronounced warming. There is also evidence for a decrease in peat surface moisture and lake levels in NW and E Romania at the beginning of the Holocene (Magyari et al., 2009; Buczkó et al., 2012; Feurdean et al., 2013) and in northeastern Polish lakes (Gałka and Sznel, 2013; Gałka and Tobolski, 2013; Gałka et al., 2014), while rivers in NW Romania changed their behaviour from braided to meandering, indicating lower discharge and related lower amounts of precipitation (Perşoiu, 2010). Simultaneously, kettle hole peatland in N Poland reveals a fen-bog transition, suggesting a decrease in the ground water table, likely related to the complete disappearance of permafrost (Lamentowicz et al., 2008; Słowiński, 2010). The Lake Gościąż record, a lacustrine sequence with the highest temporal resolution in the region (1–4 yr/cm), shows an overall warming and drying trend at the Lateglacial/Holocene transition, but with three sub-phases: a phase of dry winter conditions (11.55–11.52 ka cal BP); a second phase with warm, moist summer conditions (11.52–11.46 ka cal BP) and a third phase with dry summers (11.46–11.39 ka cal BP), which caused a lowering of the lake level. In central Poland, only a small (if any) summer temperature increase is observed in chironomid assemblages during the Early Holocene, compared to the late GS-1 (Płóciennik et al., 2011).

4. Biotic response

4.1. Vegetation response to climatic oscillations from 60 to 20 ka

Unlike in S Europe (Fletcher et al., 2010), continuous Last Glacial lake or mire sediments are very rare and the chronology uncertain in CEE (Šercelj, 1966). Nonetheless, several shorter middle Last Glacial (60–27 ka) loess and solifluction clay sediments have been studied for pollen and plant macrofossils in this region. This, together with the numerous macrocharcoal studies from archaeological sites (Środoń, 1968; Willis and van Andel, 2004; Jankovská and Pokorný, 2008; Komar et al., 2009; Nádor et al., 2011), allow us a general characterization of the MIS 3 and 2 vegetation in CEE, and a preliminary interpretation of region-wide vegetation responses to rapid climate change events.

In the western Carpathians, pollen and plant macrofossil analyses on peat deposits of MIS 3 provide evidence for a dense taiga forest cover until the onset of the Last Glacial Maximum (Jankovská et al., 2002; Jankovská and Pokorný, 2008; Kuneš et al., 2008). The record of Šafárka (Fig. 3) starts at ~52 ka, ends at around 16 ka cal BP and shows a forest succession from *Larix decidua* to dense *Picea*

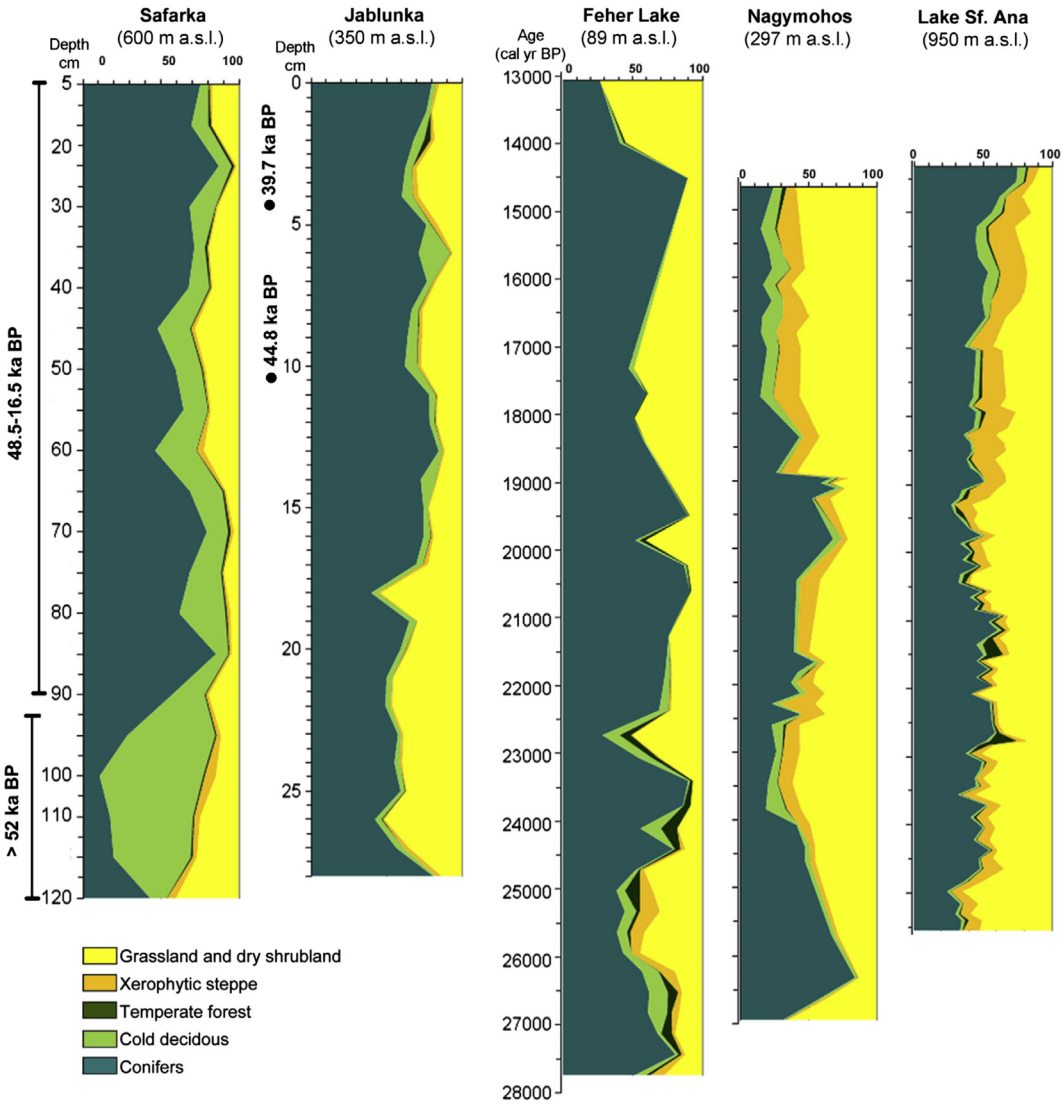

Fig. 3. Vegetation changes during mid to late Last Glacial (MIS 3, 2) in selected terrestrial pollen records from CEE. The taxa are grouped into a summary percentage diagram where each pollen type was assigned to a major vegetation type following a simple biome scheme.

abies taiga. Both *P. abies* and *L. decidua* macrofossils were abundant at the site and Jankovská et al. (2002) inferred the local presence of several other mainly boreal trees like *Betula*, *Alnus*, *Pinus cembra* and *Pinus sylvestris*. Pollen of temperate deciduous trees (*Corylus*, *Ulmus*, *Quercus*, *Tilia*, *Fagus* and *Carpinus*) was also recorded and the regional presence of these tree taxa was inferred in the Western Carpathians.

Solifluction clay deposits in the northern piedmont zone of the Carpathians (*e.g.*, Dobra, Sowliny) indicate that members of herb communities, typical alpine grasslands (*Callianthemum coriandrifolium*, *Dianthus speciosus*, *Helianthemum alpestre*, *Leontodon pseudotaraxaci*, *Linum extraaxillare*, *Minuartia sedoides*, *Minuartia verna*, *Polygonum viviparum*, *Potentilla aurea*, *Selaginella selaginoides*, *Soldanella carpathica*), snowbed and scree communities (*Arabis alpina*, *Doronicum stiriacum*, *Cerastium lapponicum*, *Ranunculus montanus*) were found at altitudes of 300–640 m between 40 and 29 ka (MIS 3). Lowland steppe plants were also present (*e.g.*, *Alyssum*, *Artemisia*, *Aster alpinus*, *Potentilla heptaphylla*, Chenopodiaceae, *Festuca*, *Filipendula*, *Helianthemum*). Macrofossil evidence shows that these were accompanied by cold temperate and boreal trees and tundra dwarf shrubs: *Alnus incana*, *Betula nana*, *Betula pubescens*, *Larix*, *Picea excelsa*, *P. cembra*, *P. sylvestris*, *Populus* and *Salix*, altogether forming a non-analogue steppe-tundra vegetation in association with boreal forest communities. The woody component of these communities was very similar to the Šafárka flora suggesting both, open and closed boreal forests in the Western Carpathians. Loess pollen studies in S Poland and S Ukraine furthermore demonstrate that lowland areas north and east of the Carpathian Mountains hosted a vegetation mosaic of steppe tundra and boreal parkland forests, dominated by *P. sylvestris*, *P. cembra*, *Betula*, *Larix*, *P. abies*, *Abies alba* and various shrubs (Komar et al., 2009). Open woodlands reached well into middle Poland during the MIS 3 (Mamakowa and Latałowa, 2003; Szczepanek et al., 2007).

Vegetation in the lowland and hill zone W, E and S of the Carpathian Mountains over the same period is mainly recorded by macrocharcoal and pollen studies of archaeological sites or loess exposures (*e.g.*, Urban, 1984; Svoboda and Svobodová, 1985; Opravil, 1994; Culiberg and Šercelj, 1995; Haesaerts et al., 1996, 2010; Damblon, 1997; Damblon and Haesaerts, 1997; Willis et al., 2000; Rudner and Sümegi, 2001; Musil, 2003). These studies demonstrate that during the MIS 3 a wide spectrum of tree species *e.g.*, *A. alba*, *Alnus*, *B. nana*, *B. pubescens*, *Betula pendula*, *Carpinus betulus*, *Corylus*, *Fagus sylvatica*, *Fraxinus*, *Juniperus communis*, *Larix*,

P. sylvestris, *Pinus mugo*, *P. cembra*, *P. abies*, *P. excelsa*, *Populus*, *Quercus*, *Salix*, *Sorbus aucuparia*, *Ulmus* were present in the lowland and hill zones of E Austria, the Czech Republic (Moravia, Bohemia), Slovakia, Hungary, Romania and Slovenia. The most diverse woody assemblages were dated to between 35 and 30 ka cal BP (Willis and van Andel, 2004), these also include the oceanic *Taxus baccata* that likely grew in association with *F. sylvatica* in Moravia (Mason et al., 1994). Notable is that Moravia in the Czech Republic showed exceptional tree diversity with several temperate deciduous tree taxa. In comparison, the lowlands of the Carpathian Basin were dominated by boreal trees such as *P. abies*, *Larix*, *Betula* and *P. sylvestris* (Rudner and Sümegi, 2001), whereas temperate deciduous tree macrocharcoal fragments (*C. betulus*) are rare in these sequences, suggesting their scarcity in the loess accumulation zone. A greater extent of forest cover (*Pinus*-dominated) during the early part of MIS 3 (55–38 ka) compared to the period after 38 ka was very recently identified in a pollen record from lowlands of Transylvania (Feurdean et al., sub). This difference in the two areas may potentially be explained by the more varied topography of the Czech Republic and its less continental climate. The response of vegetation to climate change during the MIS 3 has been studied in the eastern Hungarian Plain by Nádor et al. (2011), who found *Pinus*, *Picea* and *Ulmus* dominance between 40 and 30 ka, along with sporadic regional occurrence of *Tilia*, *C. betulus*, *F. sylvatica*, *Quercus*, and *Corylus avellana*, but no increases in arboreal pollen between 40 and 30 ka. This pollen record complements the macrocharcoal record in that it suggests the dominance of mixed deciduous-coniferous forests.

Moving to the southeast, a mid to late Last Glacial (MIS 3) vegetation record from Straldzha Mire in the Thracian Plain, Bulgaria shows the dominance of cold steppe vegetation with herbs until MIS 2 (*Artemisia*, Poaceae, *Polygonum aviculare* type, Chenopodiaceae) (Connor et al., 2013). Notably, the pollen record shows no sign of millennial-scale vegetation fluctuation. On the basis of the pollen data, Connor et al. (2013) inferred the small-scale presence of xeric woodland with *Quercus*, *Juniperus* and Rosaceae trees/shrubs in the *Artemisia*-steppe dominated landscape during the period. Comparable vegetation likely prevailed in the southeasternmost part of the Carpathian region, in Serbia (Marković et al., 2007, 2008; Zech et al., 2013). In Slovenia, the middle Last Glacial-associated pollen spectra from Ljubljana Moor show fluctuations between mixed coniferous-deciduous woodland comprising *Abies*, *Betula*, *Alnus*, *Corylus*, *Quercus*, *Tilia*, *Ulmus*, *Acer*, *Salix* and *Juglans* and periods of predominantly steppe-dominated landscape with *Pinus* and *Picea* (Šercelj, 1966).

The MIS 3–2 transitional sections of the pollen records of the Carpathians and lowlands in E Hungary show: i) a predominance of needle-leaved and cold temperate tree vegetation in the W Carpathians (at Jablunka and Safarka); ii) increased representation of steppe herbs in the more continental E Carpathians (Lake S f.An; Magyari et al., 2014) and lowlands of W Romania (Lake Ştiucii); and iii) recurring fluctuations in AP values in the Carpathians Basin (Fehér Lake, Nagymohos; Rudner and Sümegi, 2001; Sümegi et al., 2013, Fig. 3). The Last Glacial Maximum part of these pollen records suggests that some woody cover was maintained in these regions during the maximum northern hemisphere ice extent (between 26.5 and 19 ka cal BP). This picture is similar to the Thracian Plain (42° N) vegetation response in that it shows no large amplitude vegetation change during the Last Glacial Maximum, although cold steppe dominates at this more southerly latitude, pointing to increased continentality towards the south (Connor et al., 2013). Temperate deciduous tree pollen is recorded in the Carpathian area, but macrofossils or charcoal of these taxa have not been reported from the Last Glacial Maximum.

4.2. Spatial vegetation response to the climate conditions at the end of LGM (20–14.7 ka cal BP)

A few of the selected high-resolution pollen records in CEE stretch back to the end of GS-2 (20–14.7 ka cal BP). Arranged on a S to N transect, these pollen records reveal three features of the vegetation during this period: i) that the vegetation assemblages were marked by a high proportion of non-arboreal pollen, principally *Artemisia*, Chenopodiaceae and Poaceae; ii) there is an increase in steppe and grasslands along a north (20 %) to south (90 %) transect, with sites located south of 45 °N (Rila Mountains and the Thracian Plain in Bulgaria) showing the strongest continental conditions; iii) the persistence of open woodlands/parkland forest in CEE (Figs. 4 and 5). There is some spatial distinctiveness in the tree species composition and proportion in CEE: i) regions north of 55 °N and east of 20 °E (Latvia, Lithuania, Belarus) contain more abundant pioneer species of the tundra and boreal zone (*B. nana*, *Betula*, *Pinus*); ii) in the Carpathian region (46–55 °N and 15–25 °E Czech Republic, Slovakia, Hungary, Romania), *Pinus* was abundant with a comparatively lower proportion of cold deciduous taxa (*Betula*, *Alnus*, *Salix*); iii) in Slovenia (46 °N) *Pinus* dominated the record entirely; iv) in the Balkans there is also a high proportion of needle-leaved taxa (Figs. 4 and 5). Pollen of temperate deciduous taxa (*Quercus*, *Ulmus*, *Tilia*, *Carpinus* and *Fagus*) was also recorded in Hungary, Romania and Slovenia (Figs. 4 and 5; Fărcaş and Tanţău, 2012). Plant macrofossil remains of trees are virtually absent in all these sequences. However, woody plant macrofossils of conifers dated to the end of GS-2 are known from loess deposits (see Willis and van Andel, 2004), and from fluvial sediments in the lowlands of Transylvania (Lascu, 2003). Pollen records covering the end part of GS-2 reinforce the idea that most of the CEE landscapes supported open forest principally needle-leaved and cold deciduous trees, and a small population of temperate deciduous trees during the late GS-2, whereas more compact temperate deciduous populations were confined to latitudes south of 46 °N. Although pollen of long-distance transported or reworked origin could have increased the proportion of arboreal taxa during the glacial period, the prevalence of harsh climatic conditions for growth and reproduction could have reduced pollen production.

4.3. Spatial vegetation response during GI-1e

Fossil pollen and plant macrofossil sequences from the continental records of CEE indicate that there was a large-scale reduction in dry steppe vegetation and a northern latitudinal expansion of boreal forest vegetation around 14.7 ka cal BP, that correlate approximately to the onset of GI-1e in Greenland. However, the CEE pollen records also show that the magnitude of vegetational response was not uniform; i) regions from Baltic area (north of 55 °N and 25 °E), previously covered or closer to the ice sheets and permafrost (Estonia, Latvia, Lithuania) show abundant pollen of pioneer taxa such as *B. nana* (Amon and Saarse, 2010; Amon et al., 2012; Veski et al., 2012), while more eastern records from Belarus (south of 54 °N and east of 24 °E) contain a higher proportion of pollen of *Pinus* (up to 90% Zernitskaya et al., 2005; Makhnach et al., 2009). In addition, plant macrofossil records from the Baltic region suggest that a tundra biome (*B. nana*) with patchy occurrences of tree birch including *Betula* sect. *Albae* (Stančikaitė et al., 2008) occupied the newly deglaciated areas, while boreal tree taxa (*Betula* and *Pinus*) expanded from 13.4 ka cal BP in Estonia (Amon et al., 2012), at ca 14.4 ka cal BP in Latvia and Estonia (Heikkilä et al., 2009; Veski et al., 2012), and at ~14 ka cal BP in south-eastern Lithuania (Stančikaitė et al., 2008) and the northern part of Poland (Gałka and Sznel, 2013).

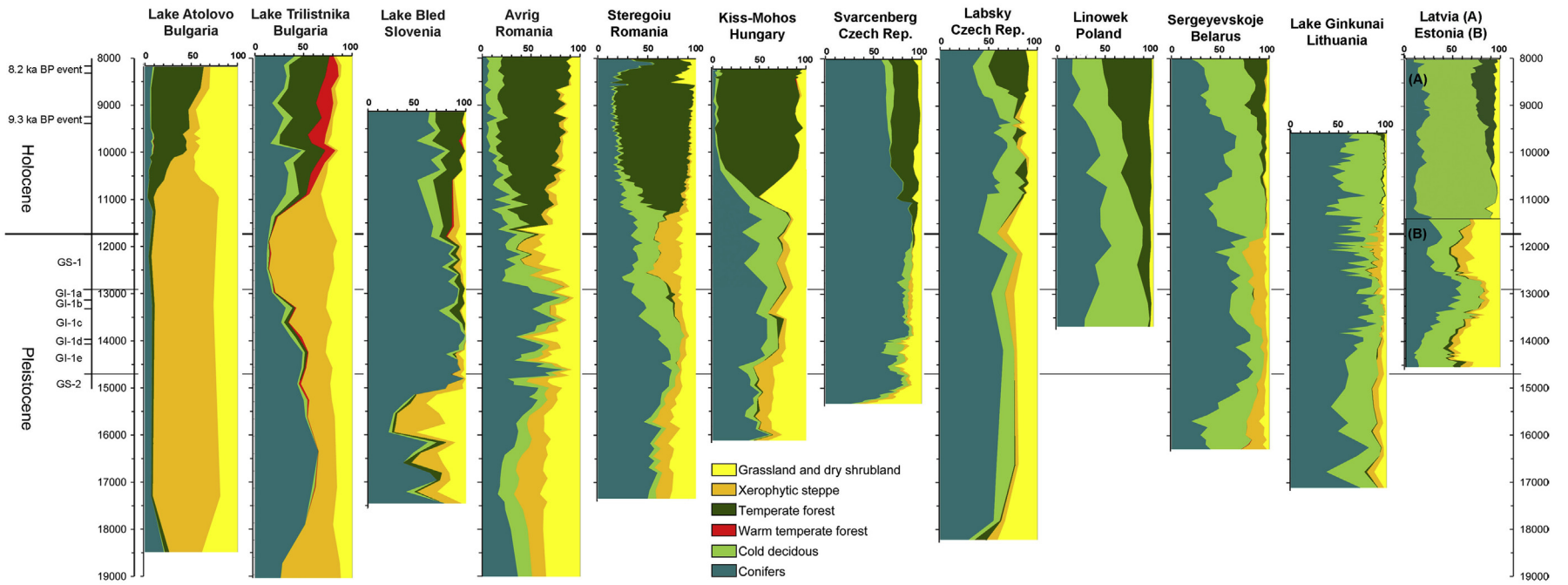

Fig. 4. Vegetation changes between 14.7 and 8 ka cal BP in selected high-resolution terrestrial pollen records from CEE. The taxa are grouped into a summary percentage diagram where each pollen type was assigned to a major vegetation type following a simple biome scheme. All records are plotted using the best available chronology for each individual site.

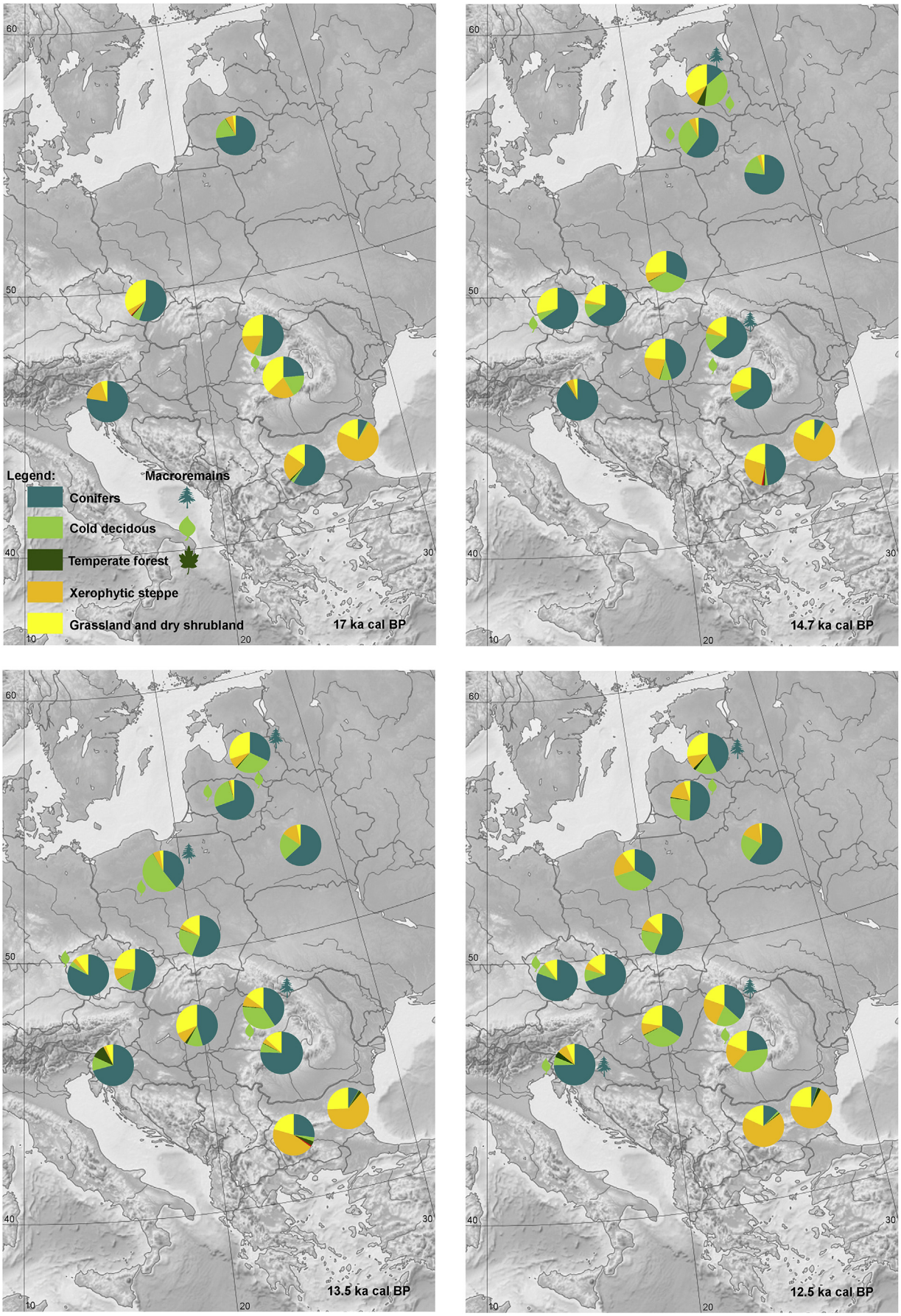

Fig. 5. Vegetation changes at selected time slices between 17 and 8 ka cal BP. The time slices were selected to match significant climatic shifts during the investigated time period. The taxa are grouped following the same scheme as in Fig. 4 and 5.

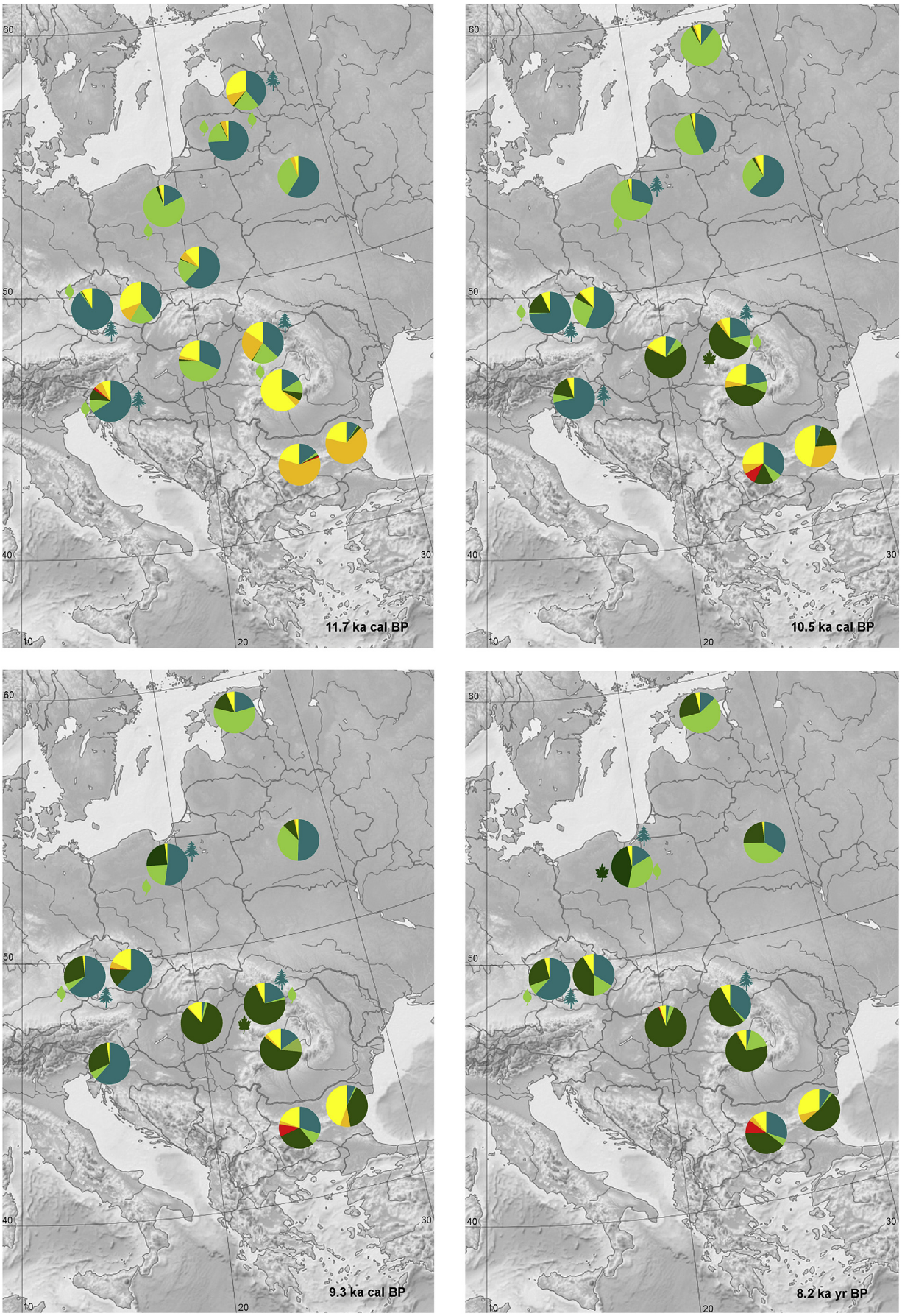

Fig. 5. (*continued*).

In the central part of CEE, including the Carpathians region (46–50 °N; 15–22 °E), there was a considerable increase in biomass and an expansion of boreal forests around 14.7 ka cal BP (Figs. 4 and 5). Nevertheless, significant elevational distinctiveness in the vegetation existed in this region. For example, pollen records from sites in the lowlands (Kis Mohos in Hungary, Avrig in Romania) indicate the presence of more fragmented or more open forests of needle-leaved (*Larix*, *Pinus*), and cold deciduous taxa (*Betula*, *Alnus* and *Salix*); whilst sites in the uplands (Steregoiu, Romania, Lapysky, Slovakia) contained more extensive boreal forests (Figs. 4 and 5; Willis et al., 1997; Wohlfarth et al., 2001; Björkman et al., 2002; Pokorný, 2002; Tanţău et al., 2006, 2014; Feurdean et al., 2007, 2012b; Kuneš et al., 2008; Pokorný et al., 2010). Plant macrofossil records from this area support the inference of the local abundance of *P. sylvestris*, *P. cembra*, *P. mugo*, *Betula* and *Salix* in Romania already at 14,5 ka cal BP (Wohlfarth et al., 2001; Feurdean et al., 2012b) and around 13.2 ka cal BP in the Czech Republic (Jankovská, 1984). Further south (south of 46 °N) in Slovenia and Bulgaria, this time interval is marked by a greater diversity of tree taxa that include needle-leaved taxa such as *L. decidua* (only dominant in Slovenia), *Pinus diploxylon-type*, *Pinus peuce*, *Juniperus*), xerophytic shrubs (*Ephedra distachya*, *Ephedra fragilis-type*), cold deciduous (*Betula*, *Salix*, *Alnus*), as well as temperate deciduous taxa (*Quercus*, *Corylus*, *Acer*) (Tonkov et al., 2006; Andrič et al., 2009; Connor et al., 2013). The latter group is also locally documented by sub-fossil wood remains of *Quercus*, *Ulmus* and Rosaceae (Magyari et al., 2008). The lowlands of SE Bulgaria, close to the Black Sea, however, remained predominantly covered by steppe vegetation (Magyari et al., 2008; Connor et al., 2013).

Summarizing our pollen and plant macrofossil data-sets for the onset of the Lateglacial, there is evidence: i) for a northward expansion of boreal forest into CEE; ii) that extensive boreal forests (needle-leaved) as well as small areas of temperate deciduous forests developed in latitudes stretching between 45 and 55 °N; iii) that regions south of 45 °N also included fragmented temperate deciduous forests.

4.4. Spatial vegetation response during GI 1a-c

High-resolution pollen and plant macrofossil records from CEE indicate a further northerly development of boreal forests containing *Betula* sect. *Albae*, *Betula humilis*, *P. sylvestris*, *Populus tremula*, *P. abies*, *J. communis* and *Alnus* into the Baltic region between 13.8 and 12.7 ka cal BP, which may correspond to the GI-1a-c warming in Greenland (čikaitė et al., 2008, 2009; Heikkilä et al., 2009; Amon and Saarse, 2010, 2012; Gaidamavičius et al., 2011; Veski et al., 2012), whereas the expansion of *P. abies* in Belarus the was dated ca 13.2 ka cal BP (Zernitskaya et al., 2005; Makhnach et al., 2009). The northern treeline became located in central Estonia at ~58.5 °N (Figs. 4 and 5). In the Carpathian region (45–50 °N), forest assemblages changed from those dominated by *Pinus* (*Pinus* spp., *P. sylvestris*, *P. cembra*, *P. mugo*) and *Betula* to mixed *Pinus*, *P. abies* and *Betula* (*B. pubescens*, *B. pendula*). Generally, there is an increased proportion and diversity of cold deciduous taxa (*Salix*, *Sambucus*, *Alnus*, *P. tremula*, *Prunus padus*) but also of temperate tree species such as *Ulmus*, *Quercus*, *Tilia*, *Fraxinus excelsior* and *C. avellana* at most sites in this region (Figs. 4 and 5). The plant macro-remains support the inference of more extensive, dense, and diverse forest cover during this time interval (Wohlfarth et al., 2001; Pokorný, 2002; Ampel, 2004; Latalowa and van der Knaap, 2006; Kuneš et al., 2008; Magyari et al., 2012; Feurdean et al., 2012b).

Sites located south of 46 °N (Slovenia) contained almost pure needle-leaved forests (90 %), with only minor contributions of cold deciduous (*Alnus*, *Betula*, *Salix*) and warm temperate deciduous taxa (*Quercus*, *Tilia*, *F. excelsior*, *Acer*, *C. avellana*) (Figs. 4 and 5). Sites from Bulgaria (Rila Mountains; Tonkov et al., 2008, 2011), on the other hand, witnessed only modest forest expansion, composed of a mixture of needle-leaved, cold deciduous (primarily at higher elevations) and most notably of warm temperate deciduous taxa (mid-low elevations), whereas no forest expansion is visible in the Thracian Plain (Figs. 4 and 5).

The response of vegetation to the warming associated to GI-1a-c can be summarized as exhibiting: i) the greatest spatial expansion of forest cover, forest density, and diversity during the Lateglacial; ii) a more consistent spread of warmth-demanding temperate tree taxa; iii) the expansion of more moisture-demanding trees (*P. abies*) in the Carpathians Mountains; iv) limited forest development in lowlands of SE Balkans (Figs. 4 and 5).

4.5. Spatial vegetation response during GS-1

Significant, region-wide changes in terrestrial vegetation composition occurred in CEE around 12,7 cal yr BP, which may correlate with the onset of cold GS-1 event in Greenland. These largely included i) a decrease in plant biomass; ii) fragmentation of the boreal forest and a more southerly displacement of temperate forest; and iii) a re-expansion of steppe and grassland vegetation (Figs. 4 and 5). Superimposed on this large-scale pattern of vegetation changes during GS-1 there is considerable north to south distinctiveness in the vegetation composition. In the north-eastern Baltic area (N of 55° N and 25°E) there was a stronger re-expansion of tundra communities (*B. nana*, *Salix polaris*), whereas trees disappeared (Amon et al., 2012); ii) in the southern Baltic regions (Latvia, Lithuania, N Poland), small populations of boreal tree species (*Pinus*, *Betula*, *Picea*) survived the cold GS-1 (Stančikaitė et al., 2008, 2009; Gaidamavičius et al., 2011; Veski et al., 2012), iii) in Belarus, a tundra-forest (*Picea*) landscape developed N of 54 °N and E of 24 °E, and boreal forest S of 54 °N (Zernitskaya, 2008; Makhnach et al., 2009). Sites in the Carpathian region (45–50 °N) show fragmentation of the boreal forests and reduced diversity, but also a replacement of large tracts of dry-adapted needle-leaved taxa (*Pinus* and *Larix*) and *Betula* by *P. abies*, *Alnus*, *Ulmus*, *Quercus* (Fărcaş et al., 1999; Tanţău et al., 2006; Feurdean et al., 2007). In Slovenia, a smaller-scale contraction in the forest cover occurred with needle-leaved taxa (*Pinus* and *Larix*) remaining the dominant vegetation type but also preserving temperate deciduous forest composed of *Quercus*, *Corylus*, *Tilia*, *Ulmus* (Andrič et al., 2009, Figs. 4 and 5). Pollen sequences at sites further south in the Balkans show either a contraction of forest cover (in the Rila Mountains) that consisted of *Pinus*, *Betula* and *Quercus* and a corresponding marked expansion of xeric herb communities, grasses and other cold-resistant heliophilous herbs (Tonkov et al., 2013), or the persistence (in the lowlands) of xeric steppe, semi-desert vegetation, in the area near Black Sea (Connor et al., 2013).

Overall, apart of the general trend of contraction of the forest cover over the CEE during GS-1, there is also an increase in the steppe communities and therefore enhanced continentality along a N to S latitudinal transect in this region.

4.6. Other short-term fluctuations

High-resolution pollen records from CEE also document smaller vegetation changes occurring around 13.9 ka cal BP (GI1-d), 13.6 ka cal BP (GI-c2) and 13.2 ka cal BP (GI-1b) (Fig. 5). This indicates that short-lived climate fluctuations have also produced some response in the vegetation composition in continental areas (Tanţău et al., 2006, 2014; Feurdean et al., 2007, 2012a,b; Stančikaitė et al., 2008; Amon et al., 2012; Magyari et al., 2012; Veski et al., 2012).

4.7. Onset of the Holocene and early Holocene (11.7–8 ka cal BP)

Pollen and plant macrofossil records indicate that, from about 11.7 ka cal BP, there was a significant increase in biomass production, a retraction of cold- and dry-adapted taxa and a general northward advance of many tree species into areas that were covered by permafrost during the preceding cold GS-1 (Figs. 4 and 5). The species range shift was not uniform over the whole CEE. In the Baltic region (northern Poland, Lithuania, Belarus, Latvia and Estonia), both pollen and plant macrofossil data suggest the establishment of *Pinus–Betula* forest, enriched by *Picea* at ca 11.7 ka cal BP (Zernitskaya et al., 2005; Heikkilä et al., 2009; Veski et al., 2012), but temperate deciduous forests (*Ulmus*, *Quercus*, *Fraxinus*) were largely absent from this region until about 10.5–10 ka cal BP (Stančikaitė et al., 2008, 2009; Gaidamavičius et al., 2011; Gryguc et al., 2014, Figs. 4 and 5). At low and middle elevations in the Carpathian region (including Hungary, Czech Republic, Slovakia), there was an initial increase in open woodlands of cold deciduous temperate taxa (*Alnus*, *Betula*, *Salix*) at around 11.7 ka cal BP. This was then followed rapidly (11.3 ka cal BP) by a large-scale increase in temperate forests dominated by *Ulmus*, *Quercus*, *Tilia*, *Acer*, *F. excelsior*, *C. avellana*, though the forests preserved a more open character in lowlands (Willis et al., 1997; Tanţău et al., 2006, 2009; Magyari et al., 2010; Feurdean et al., 2012b, 2013). This forest composition was preserved at least until 8 ka and represented a larger extension of temperate forest than today. Plant macrofossil analysis at these sites also indicates that *Larix* was a significant component of the very early Holocene forests likely as a response to continental conditions (Feurdean et al., 2007; Magyari et al., 2012b). A rapid expansion of *Pinus* and temperate deciduous taxa was documented in Slovenia (Andrič et al., 2008, 2009). In the Balkans (Rila Mts., Bulgaria) the rapid climate warming initiated a widespread of pioneer *Betula* forests with *P. sylvestris*/*mugo*, *P. peuce* for the time interval 11.6–9.8 ka cal BP at mid-higher elevations altitudes, which shaped the tree-line for nearly 4000 years after the onset of the Holocene. The fossil pollen record also revealed the beginning of a wide distribution of mixed *Quercus* forests with *Tilia*, *Ulmus*, *F. excelsior*, *Acer* below the birch zone. These forests reached their maximal distribution ca 10–9.8 ka cal BP (Tonkov et al., 2013). Lowlands in SE Bulgaria recorded a delayed forest expansion due to the prevalence of drier climatic conditions (Connor et al., 2013).

5. Key findings

i) Analysis of loess deposits suggests more pronounced phases of coarse-grain deposition, associated with drier and probably colder climate, during the MIS 3 than during the Last Glacial Maximum. This is likely to be a consequence of changes in general atmospheric circulation due to initial ice sheet growth, as well as changes in depositional regime of the Danube fluvial system. During the MIS 2, enlarged northern European ice masses may have partially blocked penetration of the Atlantic air to the east, with strong anticyclonal circulation over the Fennoscandian Ice Sheet during the peak of the Last Glacial phase. The inference of warmer condition during MIS 3 is also supported by a more continuous growth of Romanian speleothems through this period.

ii) Loess-covered lowland areas in Serbia, SE Hungary, Romania and Bulgaria that are characterized by warm/dry macroclimate today were dominated during the MIS 3 by warm steppe vegetation, often with *Artemisia*. By contrast, similar loess covered areas but with more humid climatic conditions supported predominant parkland boreal forests accompanied by some temperate deciduous trees (*P. abies*, *P. sylvestris*, *P. cembra*, *L. decidua*, *Ulmus*, *Salix* and *Alnus*). Despite the high-resolution studies of dry loess steppe areas south of 45 °N, millennial-scale vegetation fluctuations have not been recognized. This suggests that temperature and precipitation fluctuations during the MIS-3 were of relatively low magnitude, failing to trigger major shifts in biomes or that the changes were of significant magnitude but did not cross critical thresholds for biome shift. On the other hand, a few available records from lowlands and mountain areas between 45 and 48 °N suggest recurring fluctuations between boreal forest-steppe and steppe vegetation. This suggests that millennial-scale climatic oscillations drove a stronger vegetation response in these more humid macroclimate areas, and interstadials were characterized by boreal and temperate tree advances lasting for 200–300 years.

iii) Most records from the continental CEE cover the period 14.7 and 8 ka cal BP and show that this region experienced climate changes more or less synchronous (within centennial-scale age errors) with those around the North Atlantic region. However, the magnitude of these climatic shifts appears to be less dramatic in the continental part of Europe than in more oceanic Western Europe. Thus, whereas the onset of GI-1e in Greenland was marked by a 10 °C increase in annual temperature, the corresponding warming in CEE is only of about 2.8–3 °C. Similarly, the cooling associated with the onset of GS-1 in Greenland was of about 1–2 °C for MAT. The climate records from CEE show that temperature changes were more pronounced in winter than in summer during both cold and warm periods of the Lateglacial indicating enhanced seasonality. Precipitation dropped markedly at the onset of cold periods, suggesting increased continentality. In contrast, early Holocene seasonality was driven by high summer insolation and therefore increased summer temperature.

iv) The consequence of lower amplitude cooling in CEE compared to Western Europe implies that vegetation was less drastically impacted and allowed for the persistence of open boreal forests at latitudes below 55 °N even during the coldest intervals of the Last Glacial. However, higher resolution pollen records covering the Lateglacial clearly indicate that vegetation responded sensitively to these climate shifts, with the most pronounced changes visible at 14.7 (GI-1e), 13.8 (GI-1c-a), 12.7 (GS-1), and at 11.7 ka cal BP (GS-1/Holocene transition). This further underscores the impact of climate change on vegetation across a broad region (Giesecke et al., 2011).

v) Differences exist in the temporal response of vegetation to the climate shifts compared to the actual climate shifts in the Greenland ice core record. Thus, while vegetation responded to GI-1e warming, the magnitude of this vegetation response was smaller compared to the magnitude of temperature increase suggested by the Greenland oxygen isotope record at 14.7 ka cal BP. Conversely, a strong vegetation shift is visible in most pollen records during G1c-a, at a time when the NGRIP record indicates a more modest temperature increase.

vi) On a spatial scale, the records from CEE show that the magnitude of the vegetational response follows a S–N latitudinal and elevation trend. Vegetation at more northern locations appears more strongly impacted by climate changes between 60 and 8 ka, whereas the more southern locations appear more stable. There is also a marked N to S increase in steppe communities, suggesting an increase in continentality following a N–S latitudinal transect. From the these pollen records it is apparent that besides the influences of the North Atlantic, other centres of climatic variability (the

Mediterranean Sea, NW Russia and the Black Sea) have created a complex climatic region and vegetation pattern.

6. Suggestions for the future

The key points above not only highlight the main findings, but also the major gaps and problems in palaeoclimatic data from CEE for the period covering 60–8 ka, as well as a selection of future directions for improvement. Numerous records have poor chronological control, mainly because of too few dates and use of bulk sediment. There is also a subjective tendency towards wiggle-matching and tuning of time scales, often falsely synchronizing the forcing (climate) and response (vegetation). Searching for (crypto) tephra layers such as the Campanian Ignimbrite (39,280 ± 110 cal yr BP), Vedde Ash (12,007–12,235 cal yr BP), and Laacher See tephra (12,880 ± 40 cal yr BP), and working on varved lake sediments (Brauer et al., 1999) would better constrain chronologies and allow for correct identification of lags in the response of regional climate systems and vegetation to both external and internal forcings. In this respect, an important step has been achieved by the identification of the Laacher See Tephra in the Trzechowskie palaeolake (Wulf et al., 2013) and Węgliny (Housley et al., 2013). These advances have allowed a precise correlation between pollen and lithological records in Western and Eastern Europe, showing that the abrupt environmental changes and associated impacts on vegetation were synchronous in these regions at the B-A/YD transition. In addition, the use of statistically-secure age-models could improve chronologies.

Quantitative climate reconstructions in the CEE are extremely rare. Therefore, a major future research direction is the construction of local calibration sets and transfer functions to improve the existing, insufficiently quantified biotically-derived paleoclimate reconstructions. The different present-day climate to that of Western and Northern Europe, where most of the calibration sets used for CEE originate, adds a strong bias to the quantitative reconstructions. Except for pollen, there is no single proxy that is investigated in a similar manner in the whole area making proxy inter-comparison difficult. This calls for a coordinated effort to identify sites from various climatic settings that need to be investigated in order to obtain a coherent picture of patterns in past climate changes.

While the application of new proxies or methods could provide a much clearer image of the region's past climate, we believe that a systematic use of the well established, classical proxies (i.e., accurately dated and quantified) could also result in an improved understanding of the past climate and environmental changes in the area.

Acknowledgements

A.F. and A.P. conceived the paper, collected the data sets and drafted chapters of the manuscript. I.T., T.S., E.K.M., B.P.O and S.M. drafted individual chapters and figures. M.A., S.C., S.F., M.G., T.G., W.H., P.K., P.K., M.L., E.M., D.J.M., I.P., M.P., M.S., M.S., P.S., A.S., T.T., A.T., S.T., M.T., S.V., K.J.W., V.Z. participated to the workshop and/or contributed to data and revised the final drafts of the paper. A.F., led to overall wrapping up of the manuscript. This study is a contribution to the INTIMATE project, funded as a EU COST ES 0907 Action. A.F., acknowledges support from the German Research Foundation (grant FE-1096/2-1), and PN-II-RU-TE-2011-3-0145 and A.P. acknowledges projects PN-II-RU-TE-2011-3-0235 and PN-II-ID-PCE-2011-3-0057, financed by CNCS for writing up this manuscript. We thank to all contributors to the European Pollen Database.

References

Ampel, L., 2004. Lacustrine and Terrestrial Response to a Rapid Temperature Rise – a Case Study based on Sediments Record from Northwestern Romania. Masters thesis in Quaternary Geology. Stockholm University, 29 pp.

Amon, L., Saarse, L., 2010. Postglacial palaeoenvironmental changes in the area surrounding Lake Udriku in North Estonia. Geol. Q. 54, 85–94.

Amon, L., Veski, S., Heinsalu, A., Saarse, L., 2012. Timing of Lateglacial vegetation dynamics and respective palaeoenvironmental conditions in southern Estonia: evidence from the sediment record of Lake Nakri. J. Quat. Sci. 27, 169–180.

Andrič, M., Kroflič, B., Toman, M.J., Ogrinc, N., Dolenec, T., Dobnikar, M., Čermelj, B., 2008. Late quaternary vegetation and hydrological change at Ljubljansko barje (Slovenia). Palaeogeogr. Palaeoclimatol. Palaeoecol. 270, 150–165.

Andrič, M., Massaferro, J., Eicher, U., Ammann, B., Leuenberger, M.C., Martinčič, A., Marinova, E., Brancelj, A., 2009. A multi-proxy Late-glacial palaeoenvironmental record from Lake Bled, Slovenia. Hydrobiologia 631, 121–141.

Antoine, P., Rousseau, D.D., Fuchs, M., Hatté, C., Gautier, C., Marković, S.B., Jovanović, M., Gaudeenyi, T., Moine, O., Rossignol, J., 2009. High resolution record of the last climatic cycle in the Southern Carpathian basin (Surduk, Vojvodina, Serbia). Quat. Int. 198, 19–36.

Antoine, P., Rousseau, D.D., Degeai, J.P., Moine, O., Lagroix, F., Kreutzer, S., Fuchs, M., Hatté, C., Gauthier, C., Svoboda, J., Lisá, L., 2013. High-resolution record of the environmental response to climatic variations during the Last Interglacial–Glacial cycle in Central Europe: the loess-palaeosol sequence of Dolní Věstonice (Czech Republic). Quat. Sci. Rev. 67, 17–38.

Björck, S., Walker, M.J.C., Cwynar, L., Johnsen, S.J., Knudsen, K.-L., Lowe, J.J., Wohlfarth, B., INTIMATE Members, 1998. An event stratigraphy for the last termination in the North Atlantic region based on the Greenland Ice Core record: a proposal by the INTIMATE group. J. Quat. Sci. 13, 283–292.

Björkman, L., Feurdean, A., Cinthio, K., Wohlfarth, B., Possnert, G., 2002. Lateglacial and early Holocene vegetation development in the Gutaiului Mountains, northwestern Romania. Quat. Sci. Rev. 21, 1039–1059.

Blockley, S.P.E., Lane, C.S., Turney, C.S.M., Ramsey, C.B., 2012a. The INTegration of Ice core, MArine and TErrestrial records of the last termination (INTIMATE) 60,000 to 8000 BP. Quat. Sci. Rev. 36, 1.

Blockley, S.P.E., Lane, C.S., Hardiman, M., Rasmussen, S.O., Seierstad, I.K., Steffensen, J.P., Svensson, A., Lotter, A.F., Turney, C.S.M., Ramsey, C.B., 2012b. Synchronisation of palaeoenvironmental records over the last 60,000 years, and an extended INTIMATE event stratigraphy to 48,000 b2k. Quat. Sci. Rev. 36, 2–10.

Banak, A., Pavelić, D., Kovačić, M., Mandic, O., 2013. Sedimentary characteristics and source of loess in Baranja (Eastern Croatia). Aeolian Res. 11, 129–139.

Bokhorst, M.P., Beets, C.J., Marković, S.B., Gerasimenko, N.P., Matviishina, Z.N., Frechen, M., 2009. Pedo-chemical climate proxies in Late Pleistocene Serbian-Ukrainian loess sequences. Quat. Int. 198, 123–133.

Bokhorst, M.P., Vandenberghe, J., Sümegi, P., Łanczont, M., Gerasimenko, N.P., Matviishina, Z.N., Beets, C.J., Marković, S.B., Frechen, M., 2011. Atmospheric circulation patterns in central and eastern Europe during the Weichselian Pleniglacial inferred from loess grain size records. Quat. Int. 234, 62–74.

Brauer, A., Endres, C., Gunter, C., Litt, T., Stebich, M., Negendank, J.F.W., 1999. High resolution sediment and vegetation responses to Younger Dryas climate change in varved lake sediments from Meerfelder Maar, Germany. Quat. Sci. Rev. 18, 321–329.

Buczkó, K., Magyari, E., Hübener, T., Braun, M., Bálint, M., Tóth, M., Lotter, A.F., 2012. Responses of diatoms to the Younger Dryas climatic reversal in a South Carpathian mountain lake (Romania). J. Paleolimnol. 48, 417–431.

Buggle, B., Glaser, B., Zöller, L., Hambach, U., Markovic, S., Glaser, I., Gerasimenko, N., 2008. Geochemical characterization and origin of Southeastern and Eastern European loesses (Serbia, Romania, Ukraine). Quat. Sci. Rev. 27, 1058–1075.

Buggle, B., Hambach, U., Glaser, B., Gerasimenko, N., Marković, S.B., Glaser, I., Zöller, L., 2009. Magnetic susceptibility stratigraphy and spatial and temporal paleoclimatic trends in East European loess paleosol sequences. Quat. Int. 196, 86–106.

Cârciumaru, M., Ion, R.-M., Nițu, E.-C., Ştefănescu, R., 2012. New evidence of adhesive as hafting material on Middle and Upper Palaeolithic artefacts from Gura Cheii-Râșnov Cave (Romania). J. Archaeol. Sci. 39, 1942–1950.

Connor, S.E., Ross, S.A., Sobotkova, A., Herries, A.I.R., Mooney, S.D., Longford, C., Iliev, I., 2013. Environmental conditions in the SE Balkans since the Last Glacial Maximum and their influence on the spread of agriculture into Europe. Quat. Sci. Rev. 68, 200–215.

Constantin, S., Bojar, A.-V., Lauritzen, S.-E., Lundberg, J., 2007. Holocene and Late Pleistocene climate in the sub-Mediterranean continental environment: a speleothem record from Poleva Cave (Southern Carpathians, Romania). Palaeogeogr. Palaeoclimatol. Palaeoecol. 243, 322–338.

Culiberg, M., Šercelj, A., 1995. Anthracotomical and palynological research in the Palaeolithic site Šandalja II (Istria, Croatia)/Antrakotomske in palinološke raziskave v paleolitski postaji Šandalja II (Istra, Hrvaška). In: Razprave IV. razreda SAZU 36(3). SAZU, Ljubljana, pp. 49–57.

Damblon, F., 1997. Palaeobotanical study of representative Upper Palaeolithic sites in the central European Plain: a contribution to the SC-004 project. Préhistoire Eur. 11, 245–253.

Damblon, F., Haesaerts, P., 1997. Radiocarbon chronology of representative Upper Palaeolithic sites in the central European Plain: a contribution to the SC-004 project. Préhistoire Eur. 11, 255–276.

Dobrowolski, R., Bałaga, K., Bogucki, A., Federowicz, S., Melke, J., Pazdur, A., Zubovič, S., 2001. Chronostratigraphy of the Okunin and Czerepacha lake-mire geosystems(Volhynia Polesiye, NW Ukraine) during the late glacial and Holocene. Geochronometria 20, 107–115.
Dodonov, A.E., Baiguzina, L.L., 1995. Loess stratigraphy of Central Asia: paleoclimatic and paleoenvironmental aspects. Quat. Sci. Rev. 14, 707–720.
Drăgușin, V., Staubwasser, M., Hoffmann, D.L., Ersek, V., Onac, B.P., Veres, D., 2014. Constraining Holocene hydrological changes in the Carpathian-Balkan region using speleothem ^{18}O and pollen-based temperature reconstructions. Clim. Past Discuss. 10, 381–427. http://dx.doi.org/10.5194/cpd-10-381-2014.
Ehlers, J., Gibbard, P.L., Hughens, P.D., 2011. Quaternary Glaciations – Extent and Chronology. A Closer Look. Elsevier, Amsterdam, 1108 p.
Engel, Z., Nývlt, D., Křížek, M., Treml, V., Jankovská, V., Lisá, L., 2010. Sedimentary evidence of landscape and climate history since the end of MIS 3 in the Krkonoše Mountains, Czech Republic. Quaternary Science Reviews 29, 913–927.
Fărcaş, S., de Beaulieu, J.L., Reille, M., Coldea, G., Diaconeasa, B., Goeury, C., Goslar, T., Jull, T., 1999. First 14C datings of late Glacial and Holocene pollen sequences from Romanian Carpathes. C. R. Acad. Sci. Paris 322, 799–807.
Fărcaş, S., Tanţău, I., 2012. Poiana Ruscă mountains (Romania). Peşteana peat bog. Grana 51, 249–251.
Feurdean, A., Wohlfarth, B., Björkman, L., Tanţău, I., Bennike, O., Willis, K.J., Fărcaş, S., Robertsson, A.M., 2007. The influence of refugial population on Lateglacial and early Holocene vegetational changes in Romania. Rev. Palaeobot. Palynol. 145, 305–320.
Feurdean, A., Klotz, S., Brewer, S., Mosbrugger, V., Tămaş, T., Wohlfarth, B., 2008a. Lateglacial climate development in NW Romania – comparative results from three quantitative pollen based methods. Palaeogeogr. Palaeoclimatol. Palaeoecol. 265, 121–133.
Feurdean, A., Klotz, S., Mosbrugger, V., Wohlfarth, B., 2008b. Pollen-based quantitative reconstruction of Holocene climate variability in NW Romania. Palaeogeogr. Palaeoclimatol. Palaeoecol. 260, 494–504.
Feurdean, A., Spessa, A., Magyari, E.K., Willis, K.J., Veres, D., Hickler, T., 2012a. Trends in biomass burning in the Carpathian region over the last 15,000 years. Quat. Sci. Rev. 45, 111–125.
Feurdean, A., Tămaş, T., Tanţău, I., Fărcaş, S., 2012b. Elevational variation in regional vegetation responses to late-glacial climate changes in the Carpathians. J. Biogeogr. 39, 258–271.
Feurdean, A., Liakka, J., Vanniere, B., Marinova, E., Mossbruger, V., Hickler, T., 2013. Holocene fire regime drivers in the lowlands of Transylvania (Central-Eastern Europe): a data-model approach. Quat. Sci. Rev. 81, 48–61.
Fletcher, W.J., Sánchez Goñi, M.F., Allen, J.R.M., Cheddadi, R., Coumbourieu-Nebout, N., Huntley, B., Lawson, I.T., Londeix, L., Magri, D., Margari, V., Müller, U.C., Naughton, F., Novenko, E., Roucoux, K.H., Tzedakis, P.C., 2010. Millennial-scale variability during the last glacial in vegetation records from Europe. Quat. Sci. Rev. 29, 2839–2864.
Gaidamavičius, A., Stančikaitė, M., Kisielienė, D., Mažeika, J., Gryguc, G., 2011. Postglacial vegetation and environment of the Labanoras region, East Lithuania: implications for regional history. Geol. Q. 55 (3), 269–284.
Gałka, M., Sznel, M., 2013. Late glacial and Early Holocene development of lakes in northeastern Poland in view of plant macrofossil analyses. Quat. Int. 292, 124–135.
Gałka, M., Tobolski, K., 2013. Macrofossil evidence of the early Holocene presence of Picea abies (Norway spruce) in NE Poland. Ann. Bot. Fenn. 50, 129–141.
Gałka, M., Tobolski, K., Zawisza, E., Goslar, T., 2014. History of vegetation, human activity, and changes in lake level during the Postglacial period in region under the influence of a transitional climate (NE Poland). Veg. Hist. Archaeobot. 23, 123–152.
Gerasimenko, N., Rousseau, D.-D., 2008. Stratigraphy and paleoenviroments of the last pleniglacial in the Kyiv Loess Region (Ukraine). Quaternaire 19 (4), 293–307.
Giesecke, T., Bennett, K.D., Birks, H.J.B., Bjune, A.E., Bozilova, E., Feurdean, A., Finsinger, W., Froyd, C., Pokorny, P., Rösch, M., Seppä, H., Tonkov, S., Valsecchi, V., Wolters, S., 2011. The pace of Holocene vegetation change – testing for synchronous developments. Quat. Sci. Rev. 30, 2805–2814.
Goslar, T., Arnold, M., Bard, E., Kuc, T., Pazdur, M., Ralskajasiewiczowa, M., Rozanski, K., Tisnerat, N., Walanus, A., Wicik, B., Wieckowski, K., 1995. High-concentration of atmospheric C-14 during the Younger Dryas cold episode. Nature 377 (6548), 414–417.
Gryguc, G., Kisielienė, D., Stančikaitė, M., Šeirienė, V., Skuratovič, Ž., Vaitkevičius, V., Gaidamavičius, A., 2014. Holocene sediment record from Briaunis palaeolake, Eastern Lithuania: history of sedimentary environment and vegetation dynamics. Baltica 26 (2). http://dx.doi.org/10.5200/baltica.2013.26.13.
Haesaerts, P., Borziac, I., Chekha, V.P., Chirica, V., Drozdov, N.I., Koulakovska, L., Orlova, L.A., van der Plicht, J., Damblon, F., 2010. Charcoal and wood remains for radiocarbon dating Upper Pleistocene loess sequences in Eastern Europe and Central Siberia. Palaeogeogr. Palaeoclimatol. Palaeoecol. 291 (1–2), 106–127.
Haesaerts, P., Damblon, F., Bachner, M., Trnka, G., 1996. Revised stratigraphy and chronology of the Willendorf II sequence, Lower Austria. Archaeol. Austriaca 80, 25–42.
Heiri, O., Koinig, K.A., Spötl, C., Barrett, S., Brauer, A., Drescher-Schneider, R., Gaar, D., Ivy-Ochs, S., Kerschner, H., Luetscher, M., Moran, A., Nicolussi, K., Preusser, F., Schmidt, R., Schoeneich, P., Schwörer, C., Sprafke, T., Terhorst, B., Tinner, W., 2014. Palaeoclimate records 60–8 ka in 1 the Austrian and Swiss Alps and their forelands. Quat. Sci. Rev. http://dx.doi.org/10.1016/j.quascirev.2014.05.021.
Hatte, C., Gauthier, C., Rousseau, D.D., Antoine, P., Fuchs, M., Lagroix, F., Markovich, S.B., Moine, O., Sima, A., 2013. Excursions to C4 vegetation recorded in the Upper Pleistocene loess of Surduk (Northern Serbia): an organic isotope geochemistry study. Clim. Past 9, 1001–1014.
Hájková, P., Jamrichová, E., Horsák, M., Hájek, M., 2013. Holocene history of a Cladium mariscus-dominated calcareous fen in Slovakia: vegetation stability and landscape development. Preslia 85, 289–315.
Heikkilä, M., Fontana, S.L., Seppä, H., 2009. Rapid Lateglacial tree population dynamics and ecosystem changes in the eastern Baltic region. J. Quat. Sci. 24, 802–815.
Housley, R.A., MacLeod, A., Nalepka, D., Jurochnik, A., Masojć, M., Davies, L., Lincoln, P.C., Ramsey, C.B., Gamble, C.S., Lowe, J.J., 2013. Tephrostratigraphy of a Lateglacial lake sediment sequence at Węgliny, southwest Poland. Quat. Sci. Rev. 77 (1), 4–18.
Jankovská, V., 1984. Late glacial finds of Pinus cembra L. in the Lubovnianská kotlina Basin. Folia Geobot. Phytotax 19, 323–325.
Jankovská, V., Chromý, P., Nižnianská, M., 2002. Šafárka – first palaeobotanical data on vegetation and landscape character of Upper Pleistocene in West Carpathians (North East Slovakia). Acta Palaeobot 42, 29–52.
Jankovská, V., Pokorný, P., 2008. Forest vegetation of the las full-glacial period in the Western Carpathians (Slovakia and Czech Republic). Preslia 80, 307–324.
Jary, Z., 2009. Periglacial markers within the Late Pleistocene loess-palaeosol sequences in Poland and Western Ukraine. Quat. Int. 198 (1–2), 124–135.
Jary, Z., Ciszek, D., 2011. Late Pleistocene loess-palaeosol sequences in Poland and western Ukraine. Quat. Int. 296, 37–50.
Kadereit, A., Wagner, G.A., 2014. Geochronological reconsideration of the eastern European key loess section at Stayky in Ukraine. Clim. Past 10, 783–796.
Kirilova, E., Heiri, O., Veski, S., Lotter, A.F., 2011. Summer temperature shifts during the Late Glacial in Northeastern Europe. In: EGU General Assembly, Vienna (Austria). Abstr. Geophys. Res. Abstr., vol. 13, p. 6000.
Komar, M., Łanczont, M., Madeyska, T., 2009. Spatial vegetation patterns based on palynological records in the loess area between the Dnieper and Odra Rivers during the last interglacial–glacial cycle. Quat. Int. 198 (1–2), 152–172.
Kovács, J., Moravcová, M., Újvári, G., Pinter, A.G., 2012. Reconstructing the paleoenvironment of East Central Europe in the Late Pleistocene using the oxygen and carbon isotopic signal of tooth in large mammal remains. Quat. Int. 276–277, 145–154.
Kuneš, P., Pelánková, B., Chytrý, M., Jankovská, V., Pokorný, P., Petr, L., 2008. Interpretation of the last-glacial vegetation of eastern-central Europe using modern analogues from southern Siberia. J. Biogeogr. 35, 2223–2236.
Lamentowicz, M., Obremska, M., Mitchell, E.A.D., 2008. Autogenic succession, land-use change, and climatic influences on the Holocene development of a kettle hole mire in Northern Poland. Rev. Palaeobot. Palynol. 151, 21–40.
Lane, C., Andrič, M., Cullen, V.L., Blockley, S.P.E., 2011. The occurrence of distal Icelandic and Italian tephra in the Lateglacial of Lake Bled, Slovenia. Quat. Sci. Rev. 30, 1013–1018.
Lascu, I., 2003. Studiul Tardiglaciarului de la Sieu-Magherus (jud. Bistrita-Nasaud) (Bachelor thesis). Babes-Bolyai University, Cluj Napoca.
Latalowa, M., van der Knaap, W.O., 2006. Late Quaternary expansion of Norway spruce (L.) Karst. in Europe according to pollen data. Quat. Sci. Rev. 25, 2780–2805.
Lauritzen, S.E., Onac, B.P., 1999. Isotopic stratigraphy of a last interglacial stalagmite from northwestern Romania: correlation with the deep-sea record and northern-latitude speleothem. J. Cave Karst Stud. 61 (1), 22–30.
Little, E.C., Lian, O.B., Velichko, A.A., Morozova, T.D., Nechaev, V.P., Dlussky, K.G., Rutter, N.W., 2002. Quaternary stratigraphy and optical dating of loess from the east European Plain (Russia). Quat. Sci. Rev. 21, 1745–1762.
Magyari, E.K., Chapman, J.C., Gaydarska, B., Marinova, E., Deli, T., Huntley, J.P., Allen, J.R.M., Huntley, B., 2008. The 'oriental' component of the Balkan flora: evidence of presence on the Thracian Plain during the Weichselian Lateglacial. J. Biogeogr. 35, 865–883.
Magyari, E.K., Chapman, J.C., Passmore, D.G., Allen, J.R.M., Huntley, J.P., Huntley, B., 2010. Holocene persistence of wooded steppe on the Great Hungarian Plain. J. Biogeogr. 37, 915–935.
Magyari, E.K., Buczkó, K., Jakab, G., Braun, M., Pál, Z., Karátson, D., Papp, P., 2009. Palaeolimnology of the last crater lake in the Eastern Carpathian Mountains – a multiproxy study of Holocene hydrological changes. Hydrobiologia 631, 29–63.
Magyari, E.K., Jakab, G., Bálint, M., Kern, Z., Buczkó, K., Braun, M., 2012. Rapid vegetation response to Lateglacial and early Holocene climatic fluctuation in the South Carpathian Mountains (Romania). Quat. Sci. Rev. 35, 116–130.
Magyari, E.K., Kunes, P., Jakab, G., Sumegi, P., Pelánková, B., Schäbitz, F., Braun, M., Chytry, M., 2014. Late Pleniglacial vegetation in eastern-central Europe: are there modern analogues in Siberia. Quat. Sci. Rev. 95, 60–79.
Makhnach, N., Zernitskaya, V., Kolosov, I., 2009. Stable carbon and oxygen isotopes and spore-pollen spectra in Late Glacial – holocene carbonate sediments from lake Sergeyevskoye, Belarus. Lithosphere 1 (30), 103–114 (in Russian).
Mamakowa, K., Latałowa, M., 2003. Quaternary. In: Dybova-Jachowicz, S., Sadowska, A. (Eds.), Palinology, Wydawnictwa Instytutu Botaniki PAN, pp. 224–273 (in Polish).
Marković, S.B., McCoy, W.D., Oches, E.A., Savić, S., Gaudenyi, T., Jovanović, M., Stevens, T., Walther, R., Ivanišević, P., Galić, Z., 2005. Paleoclimate record in the Late Pleistocene loess-paleosol sequence at Petrovaradin Brickyard (Vojvodina, Serbia). Geol. Carpathica 56, 483–491.
Marković, S.B., Oches, E.A., Mc Coy, W.D., Frechen, M., Gaudenyi, T., 2007. Malacological and sedimentological evidence for "warm'' glacial climate from the Irig loess sequence, Vojvodina, Serbia. Geochem. Geophys. Geosyst. 8 (9), 1–12.
Marković, S.B., Bokhorst, M., Vandenberghe, J., Oches, E.A., Zöller, L., McCoy, W.D., Gaudenyi, T., Jovanović, M., Hambach, U., Machalett, B., 2008. Late Pleistocene loess-paleosol sequences in the Vojvodina region, North Serbia. J. Quat. Sci. 23, 73–84.

Michczyńska, D.J., Starkel, L., Nalepka, D., Pazdur, A., 2013. Hydrological changes after the last ice retreat in northern Poland using radiocarbon dating. Radiocarbon 55 (2–3), 1712–1723.
Molnár, D., Hupuczi, J., Galović, L., Sümegi, P., 2010. Preliminary malacological investigation on the loess profile at Zmajevac, Croatia. Cent. Eur. J. Geosci. 2 (1), 52–56.
Moreno, A., Svensson, A., Brooks, S.J., Connors, S., Engels, S., Fletcher, W., Genty, D., Heiri, O., Labuhn, I., Persiou, A., Peyron, O., Sadori, L., Valero-Garcés, B., Wulf, S., Zanchetta, G., data contributors, 2014. A compilation of Western European terrestrial records 60–8 ka BP: towards an understanding of latitudinal climatic gradients. Quat. Sci. Rev. 106, 167–185.
Musil, R., 2003. The Middle and Upper Palaeolithic game suite in central and southeastern Europe. In: van Andel, T.H., Davies, S.W. (Eds.), Neanderthals and Modern Humans in the European Landscape during the Last Glaciation. McDonald Institute for Archaeological Research, Cambridge, pp. 167–190.
Nádor, A., Sinha, A., Magyari, Á., Tandon, S.K., Medzihradszky, Zs, Babinszki, E., Thamó-Bozsó, E., Unger, Z., Singh, A., 2011. Late Quaternary (Weichselian) alluvial history and neotectonic control on fluvial landscape development in the southern Körös plain, Hungary. Palaeogeogr. Palaeoclimatol. Palaeoecol. 299, 1–14.
Onac, B.P., 1996. Mineralogy of speleothems from caves in Padurea Craiului Mountains (Romania), and their palaeoclimatic significance. Cave Karst Sci. 24, 109–124.
Onac, B.P., Lauritzen, S.E., 1996. The climate of the last 150,000 years recorded in speleothems: preliminary results from north-western Romania. Theor. Appl. Karstol. 9, 9–21.
Onac, B.P., 2001. Mineralogical studies and Uranium-series dating of speleothems from Scarisoara Glacier Cave (Bihor Mountains, Romania). Theor. Appl. Karstol. 13–14, 33–38.
Opravil, E., 1994. Vegetation. In: Svoboda, J. (Ed.), Pavlov I—Excavation 1952-1983, Ch. V., ERAUL 66. The Dolní Věstonice Studies 2, Liége, pp. 177–180. Liége.
Persoiu, I., 2010. Reconstruction of Holocene Geomorphological Evolution of Somesu Mic Valley (Unpublished PhD thesis). "A. I. Cuza" University, Iasi, Romania (in Romanian).
Petherick, L., Bostock, H., Cohen, T.J., Fitzsimmons, K., Tibby, J., Fletcher, M.-S., Moss, P., Reeves, J., Mooney, S., Barrows, T., Kemp, J., Jansen, J., Nanson, G., Dosseto, A., 2013. Climatic records over the past 30 ka from temperate Australia – a synthesis from the Oz-INTIMATE workgroup. Quat. Sci. Rev. 74, 58–77.
Płóciennik, M., Self, A., Birks, H.J.B., Brooks, S.J., 2011. Chironomidae (Insecta: Diptera) succession in Żabieniec bog and its palaeo-lake (Central Poland) through the Late Weichselian and Holocene. Palaeogeogr. Palaeoclimatol. Palaeoecol. 307, 150–167.
Pokorný, P., 2002. A high-resolution record of Late-Glacial and Early-Holocene climatic and environmental change in the Czech Republic. Quat. Int. 91, 101–122.
Pokorný, P., Šída, P., Chvojka, O., Žáčková, P., Kuneš, P., Světlík, I., Veselý, J., 2010. Palaeoenvironmental research of the Schwarzenberg Lake, southern Bohemia, and exploratory excavations of this key Mesolithic archaeological area. Památky Archeol. 101, 5–38.
Ralska-Jasiewiczowa, M., Goslar, T., Madeyska, T., Starkel, L., 1998. Lake Gościąż, Central Poland, a Monographic Study. Part 1. W. Szafer Institute of Botany, PAS Kraków, Poland, 340 pp.
Rasmussen, S.O., Andersen, K.K., Svensson, A.M., Steffensen, J.P., Vinther, B.M., Clausen, H.B., Siggaard-Andersen, M.-L., Johnsen, S.J., Larsen, L.B., Dahl-Jensen, D., Bigler, M., Röthlisberger, R., Fischer, H., Goto-Azuma, K., Hansson, M.E., Ruth, U., 2006. A new Greenland ice core chronology for the last glacial termination. J. Geophys. Res. 111, D6.
Renssen, H., Vandenberghe, J., 2003. Investigation of the relationship between permafrost distribution in NW Europe and extensive winter sea-ice cover in the North Atlantic Ocean during the cold phases of the Last Glaciation. Quat. Sci. Rev. 22 (2–4), 209–223.
Renssen, H., Seppä, H., Heiri, O., Roche, D.M., Goosse, H., Fichefet, T., 2009. The spatial and temporal complexity of the Holocene thermal maximum. Nat. Geosci. 2 (6), 411–414.
Rousseau, D.D., Antoine, P., Gerasimenko, N., Sima, A., Fuchs, M., Hatte, C., Moine, O., Zoeller, L., 2011. North Atlantic abrupt climatic events of the last glacial period recorded in Ukrainian loess deposits. Clim. Past 7, 221–234.
Rozycki, S.Z., 1991. Loess and Loesss like Deposit. PAN, Wroclaw, 187 pp.
Rutter, N., Rokosh, D., Evans, M.E., Little, E.C., Chlachula, J., Velichko, A., 2003. Correlation and interpretation of paleosols and loess across European Russia and Asia over the last interglacial–glacial cycle. Quat. Sci. Rev. 60, 101–109.
Rudner, Z.E., Sümegi, P., 2001. Recurring taiga forest-steppe habitats in the Carpathian Basin in the Upper Weichselian. Quat. Int. 76/77, 177–189.
Sanchi, L., Ménot, G., Bard, E., 2014. Insights into continental temperatures in the northwestern Black Seaarea during the Last Glacial period using branched tetraether lipids. Quat. Sci. Rev. 84, 98–108.
Schatz, A.K., Zech, M., Buggle, B., Gulyás, S., Hambach, U., Marković, S.B., Sümegi, P., Scholten, T., 2011. The late Quaternary loess record of Tokaj, Hungary: reconstructing palaeoenvironment, vegetation and climate using stable C and N isotopes and biomarkers. Quat. Int. 240, 52–61.
Seppä, H., Poska, A., 2004. Holocene annual mean temperature changes in Estonia and their relationship to solar insolation and atmospheric circulation patterns. Quat. Res. 61 (1), 22–31.
Seppä, H., Bjune, A.E., Telford, R.J., Birks, H.J.B., Veski, S., 2009. Last nine-thousand years of temperature variability in Northern Europe. Clim. Past 5, 523–535.
Šercelj, A., 1966. Pelodne analize pleistocenskih in holocenskih sedimentov Ljubljanskega barja/Pollenanalytische Untersuchungen der Pleistozänen und Holozänen Ablagerungen von Ljubljansko barje. In: Razprave IV. razreda SAZU 9. SAZU, Ljubljana, pp. 431–469.
Sima, A., Kageyama, M., Rousseau, D.D., Ramstein, P., Balkanski, Y., Antoine, P., Hatté, C., 2013. Modeling dust emission response to North Atlantic millennial-scale climate variations from the perspective of East European MIS 3 loess deposits. Clim. Past 9, 1385–1402.
Słowiński, M., 2010. Macrofossil reconstruction of preboreal wetland formed on dead ice block a case study of the Borzechowo mire in East Pomerania, Poland. Stud. Quat. 27, 3–10.
Spötl, C., Mangini, A., Richards, D.A., 2006. Chronology and paleoenvironment of Marine Isotope Stage 3 from two high-elevation speleothems, Austrian Alps. Quat. Sci. Rev. 25, 1127–1136.
Środoń, A., 1968. O roślinności interstadiału Paudorf w Karpatach Zachodnich (summary: On the vegetation of the Paudorf Interstadial in the Western Carpathians). Acta Palaeobot. 9 (1), 3–28.
Stančikaitė, M., Kisielienė, D., Moe, D., Vaikutienė, G., 2009. Lateglacial and early Holocene environmental changes in northeastern Lithuania. Quat. Int. 207 (1–2), 80–92.
Stančikaitė, M., Šinkūnas, P., Šeirienė, V., Kisielienė, D., 2008. Patterns and chronology of the Lateglacial environmental development at Pamerkiai and Kašučiai, Lithuania. Quat. Sci. Rev. 27 (1–2), 127–147.
Starkel, L., Michczyńska, D.J., Krąpiec, M., Margielewski, W., Nalepka, D., Pazdur, A., 2013. Progress in the Holocene chrono-climatostratigraphy of Polish territory. Geochronometria 40 (1), 1–21.
Stevens, T., Marković, S.B., Zech, M., Hambach, U., Sümegi, P., 2011. Dust deposition and climate in the Carpathian Basin over an independently dated last glacial-interglacial cycle. Quat. Sci. Rev. 30, 662–681.
Sümegi and Krolopp, 2002. Quatermalacological analysis for modeling the upper Weichselian palaeoenvironmental changes in the Carpathian Basin. Quat. Int. 91, 53–63.
Sümegi, P., Magyari, E., Dániel, P., Molnár, M., Törőcsik, T., 2013. Responses of terrestrial ecosystems to Dansgaard-Oeshger cycles and Heinrich-events: a 28,000-year record of environmental changes from SE Hungary. Quat. Int. 293, 34–50.
Svoboda, J., Svobodová, H., 1985. Les industries de type Bohunice dansleur cadre stratigraphique et écologique. L'Anthropologie 89, 505–514.
Szczepanek, K., Kalinowicz, N., Gebica, P., 2007. Alluvial deposits and vegetation of the Interpleniglacial period of the Vistulian Glaciation in the Wisłok River valley between Rzeszów and Łańcut (Sub-Carpathian Trough). Prz. Geol. 55, 595–600.
Tanţău, I., Reille, M., de Beaulieu, J.L., Fărcaş, S., 2006. Late Glacial and Holocene vegetation history in the southern part of Transylvania (Romania): pollen analysis of two sequences from Avrig. J. Quat. Sci. 21, 49–61.
Tanţău, I., Reille, M., de Beaulieu, J.L., Fărcaş, S., Brewer, S., 2009. Holocene vegetation history in Romanian Subcarpathians. Quat. Res. 72, 164–173.
Tanţău, I., Feurdean, A., de Beaulieu, J.L., Reille, M., Fărcaş, S., 2014. Vegetation sensitivity to climate changes and human impact in the Harghita Mountains (Eastern Romanian Carpathians) over the past 15,000 years. J. Quat. Sci. 29, 141–152.
Tămaş, T., Causse, C., 2001. U-Th TIMS chronology of two stalagmites from V11 Cave (Bihor Mountains, Romania). Theor. Appl. Karstol. 13–14, 25–32.
Tămaş, T., Onac, B.P., Bojar, A.V., 2005. Lateglacial-Middle Holocene stable isotope records in two coeval stalagmites from the Bihor Mountains, NW Romania. Geol. Q. 49 (2), 185–194.
Timar-Gabor, A., Vandenberghe, D.A.G., Vasiliniuc, S., Panaoitu, C.E., Panaiotu, C.G., Dimofte, D., Cosma, C., 2011. Optical dating of Romanian Loess a comparison between silt-sized and sand-sized quartz. Quat. Int. 240, 62–70.
Timar-Gabor, A., Wintle, A.G., 2013. On natural and laboratory generated dose response curves for quartz of different grain sizes from Romanian loess. Quat. Geochronol. 18, 34–40.
Tonkov, S., Possnert, G., Bozilova, E., 2006. Lateglacial vegetation and radiocarbon dating of Lake Trilistnika, Rila Mountain (Bulgaria). Veg. Hist. Archaeobot. 16 (1), 15–22.
Tonkov, S., Bozilova, E., Possnert, G., Velcev, A., 2008. A contribution to the postglacial vegetation history of the Rila Mountains, Bulgaria: the pollen record of Lake Trilistnika. Quat. Int. 190, 58–70.
Tonkov, S., Possnert, G., Bozilova, E., 2011. The Lateglacial in the Rila Mountains (Bulgaria) re-visited: the pollen record of Lake Ribno (2184 m). Rev. Palaeobot. Palynol. 166 (1–2), 1–11.
Tonkov, S., Bozilova, E., Possnert, G., 2013. Postglacial vegetation history as recorded from the subalpine Lake Ribno (NW Rila Mts.), Bulgaria. Central Eur. J. Biol. 8 (1), 64–77.
Tóth, M., Magyari, E.K., Brooks, S.J., Braun, M., Buczkó, K., Bálint, M., Heiri, O., 2012. A chironomid-based reconstruction of late glacial summer temperatures in the southern Carpathians (Romania). Quat. Res. 77, 122–131.
Újvári, G., Klötzli, U., Kiraly, F., Ntaflos, T., 2013. Towards identifying the origin of metamorphic components in Austrian loess: insights from detrital rutile chemistry, thermometry and U-Pb geochronology. Quat. Sci. Rev. 75, 132–142.
Urban, B., 1984. Palynology of Central European loess–soil sequences. In: Pécsi, M. (Ed.), Lithology and Stratigraphy of Loess and Paleosols. Geographical Research Institute, Hungarian Academy of Sciences, Budapest, pp. 229–248.
Van Huissteden, K., Pollard, D., 2003. Oxygen isotope stage 3 fluvial and eolian successions in Europe compared with climate model results. Quat. Res. 59, 223–233.
Vandenberghe, J., Hujizer, B., Mucher, H., Laan, W., 1998. Short climatic oscillations in a western European loess sequence (Kesselt, Belgium). J. Quat. Sci. 13, 35–38.

Vandenberghe, J., Lowe, J., Coope, R., Litt, T., Zoller, L., 2004. Climatic and environmental variability in the midlatitude Europe sector during the last interglacial-glacial cycle. In: Battarbee, R.W., Gasse, F., Stickley, C.E. (Eds.), Past Climate Variability throughout Europe and Africa. Springer, Dordrecht, Netherlands, pp. 393–416.
Veski, S., Amon, L., Heinsalu, A., Reitalu, T., Saarse, L., Stivriņš, N., Vassiljev, J., 2012. Late-Glacial vegetation dynamics in the eastern Baltic region, a complete record since the Bølling (GI-1e). Quat. Sci. Rev. 40, 39–53.
Walker, M.J.C., Björck, S., Lowe, J.J., Cwynar, L., Johnsen, S., Knudsen, K.-L., Wohlfarth, B., INTIMATE group, 1999. Isotopic 'events' in the GRIP ice core: a stratotype for the Late Pleistocene. Quat. Sci. Rev. 18, 1143–1150.
Wohlfarth, B., 2010. Ice free conditions in Sweden during Marine Oxygen Isotope Stage 3. Boreas 39, 377–398.
Willis, K.J., Braun, M., Sumegy, P., Toth, A., 1997. Does soil change cause vegetation change or vice verse? A temporal sequence from Hungary. Ecology 78, 740–750.
Willis, K.J., Rudner, E., Sumegi, P., 2000. The full-glacial forests of central and southeastern Europe. Quat. Res. 53, 203–213.
Willis, K.J., van Andel, T.H., 2004. Trees or no trees? the environments of central and eastern Europe during the Last Glaciation. Quat. Sci. Rev. 23, 2369–2387.
Wohlfarth, B., Hannon, G., Feurdean, A., Ghergari, L., Onac, B.P., Possnert, G., 2001. Reconstruction of climatic and environmental changes in NW Romania during the early part of the last deglaciation (15,000-13,600 cal years BP). Quat. Sci. Rev. 20, 1897–1914.
Wulf, S., Ott, F., Slowinski, M., Noryskiewicz, A.M., Drager, N., Martin-Puertas, C., Czymzik, M., Neugebauer, I., Dulski, P., Bourne, A.J., Blaszkiewicz, M., Brauer, A., 2013. Tracing the Laacher See Tephra in the varved sediment record of the Trzechowskie palaeolake in central Northern Poland. Quat. Sci. Rev. 76, 129–139.
Zech, M., Buggle, B., Leiber, K., Marković, S., Glaser, B., Hambach, U., Huwe, B., Stevens, T., Sümegi, P., Wiesenberg, G., Zöller, L., 2009. Reconstructing Quaternary vegetation history in the Carpathian Basin, SE Europe, using n-alkane biomarkers as molecular fossils: problems and possible solutions, potential and limitationsEiszeitalter und Gegenwart. Quat. Sci. J. 58, 148–155.
Zech, R., Zech, M., Marković, S., Hambach, U., Huang, Y., 2013. Humid glacials, arid interglacials? Critical thoughts on pedogenesis and paleoclimate based on multi-proxy analyses of the loess–paleosol sequence Crvenka, Northern Serbia. Palaeogeogr. Palaeoclimatol. Palaeoecol. 387, 165–175.
Zernitskaya, V.P., Matveyev, A.V., Makhnach, N.A., Mihailov, N.D., 2005. Stratigraphic scheme of the Late Glacial and Holocene deposets of the Belarus. Lithosphere 1 (22), 157–165 (in Russian).
Zernitskaya, V.P., 2008. Late Glacial – Holocene history of Belarusian boreal forests. In: Abstract. International Conference "Man and Environment in Boreal Forest Zone: Past, Present and Future". Moscow. July 24-30, pp. 29–30.