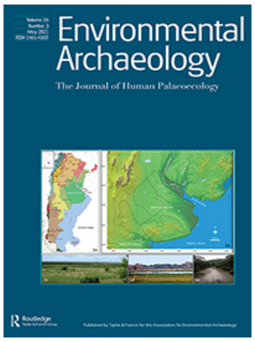

Routledge
Taylor & Francis Group

Environmental Archaeology
The Journal of Human Palaeoecology

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/yenv20

Social Context of Late Medieval and Early Modern Deforestation Periods in the Apuseni Mountains (Romania) based on an Integrated Evaluation of Historical and Paleobotanical Records

Gusztáv Jakab, Ilona Pál, Lóránd Silye, Pál Sümegi, Attila Tóth, Balázs Sümegi, József Pál Frink, Enikő Katalin Magyari, Zoltán Kern & Elek Benkő

To cite this article: Gusztáv Jakab, Ilona Pál, Lóránd Silye, Pál Sümegi, Attila Tóth, Balázs Sümegi, József Pál Frink, Enikő Katalin Magyari, Zoltán Kern & Elek Benkő (2021): Social Context of Late Medieval and Early Modern Deforestation Periods in the Apuseni Mountains (Romania) based on an Integrated Evaluation of Historical and Paleobotanical Records, Environmental Archaeology, DOI: 10.1080/14614103.2021.1942744

To link to this article: https://doi.org/10.1080/14614103.2021.1942744

Association for Environmental Archaeology
Routledge Taylor & Francis Group

Check for updates

Social Context of Late Medieval and Early Modern Deforestation Periods in the Apuseni Mountains (Romania) based on an Integrated Evaluation of Historical and Paleobotanical Records

Gusztáv Jakab [a], Ilona Pál[b], Lóránd Silye[c], Pál Sümegi[d], Attila Tóth[e], Balázs Sümegi[d], József Pál Frink[f], Enikő Katalin Magyari[b,g], Zoltán Kern[h] and Elek Benkő[i]

[a]Institute of Environmental Sciences, Hungarian University of Agriculture and Life Sciences, Gödöllő, Hungary; [b]Department of Environmental and Landscape Geography, MTA-MTM-ELTE Research Group for Paleontology, Eötvös Loránd University, Budapest, Hungary; [c]Department of Geology, Babeş-Bolyai University, Cluj-Napoca, Romania; [d]Department of Geology and Paleontology, University of Szeged, Szeged, Hungary; [e]Environmental Science Department, Sapientia Hungarian University of Transylvania, Cluj-Napoca, Romania; [f]'Marin Drăcea' National Institute for Research and Development in Forestry, Cluj-Napoca, Romania; [g]Centre for Ecological Research, GINOP Sustainable Ecosystems Group, Tihany, Hungary; [h]Institute for Geological and Geochemical Research, Research Centre for Astronomy and Earth Science, MTA Centre for Excellence, Budapest, Hungary; [i]Institute of Archaeology, Research Centre for the Humanities, Budapest, Hungary

ABSTRACT

Coeval changes in the reconstructed bog surface wetness and the pollen record of a peat sequence extracted from an ombrothropic bog (Calul de Piatră, 1630 m, Apuseni Mountains) allowed the natural and anthropogenic environmental changes over the past 1500 years to be assessed. The assessment of the social and economic context was also possible due to the exceptionally detailed documentary evidence of the investigated region. Four major deforestation periods in the past 1500 years were identified. Significant phases of deforestation coincided with particular social and political changes: (1) between AD 810 and 850, with the collapse of the Avar Khaganate and the expansion of the Bulgarian Empire in the southern areas of the Carpathian Basin; (2) between AD 1060 and 1170, with the establishment of the Kingdom of Hungary (AD 1000) and the foundation of royal, territorial administrative (county) and ecclesiastical centres of the feudal state; (3) in the sixteenth century (AD 1500–1570); and (4) after AD 1700, with population growth and economic development. Our results suggest that the observed deforestation and the consequent spread of subalpine farming were not necessarily related to the warmer or drier climatic periods, but to socioeconomic changes in nearby communities.

ARTICLE HISTORY
Received 30 September 2020
Revised 13 May 2021
Accepted 3 June 2021

KEYWORDS
Peat; pollen; plant macrofossils; shepherding; Avar period; Hungarian Kingdom

Introduction

The landscape of Europe has altered remarkably since the appearance of the first agricultural societies in the mid-Holocene (Price 2000). The most striking anthropogenic land cover change has been the clearance of forests for cropland and pasture and as a source of wood for fuel and timber (Darby 1956; Gaillard et al. 2018; Hughes and Thirgood 1982; Kaplan, Krumhardt, and Zimmermann 2009). Environmental archaeological and paleoecological records have provided extensive evidence of continuous human land use throughout the Holocene in many European regions (e.g. Brewer et al. 2008; Dearing 2006). Some regions have been through successive deforestation cycles in the past 6000 years (e.g. Berglund 2000; Cordova and Lehman 2005; Gaillard 2007; Vermoere et al. 2000). In Southeast Europe the history of deforestation has been explored in detail both in the lowlands (e.g. Feurdean et al. 2012; Magyari et al. 2012a, 2018; Salisbury, Bácsmegi, and Sümegi 2013; Willis et al. 1995, 1998) and in the mountain belt of the Carpathians (e.g. Bodnariuc et al. 2002; Carter et al. 2020; Fărcaş et al. 2007; Feurdean et al. 2011; Feurdean and Willis 2008a, 2008b; Magyari et al. 2012b; Schumacher, Schier, and Schütt 2016; Šolcová et al. 2018; Tanţău et al. 2003, 2009), but some of the details (e.g. environmental, social and economic background) are still not well defined.

Despite the destructive effects of forest clearances, valuable grassland habitats have developed on deforested areas. For example, centuries-long land use increased the extent of species-rich grassland habitats along the climatic forest boundaries in the subalpine and lowland forest steppe regions (Hájková et al. 2011; Michalcová et al. 2014; Poschlod, Baumann, and Karlik 2009; Roleček, Čornej, and Tokarjuk 2014). These grasslands play an important role in maintaining biodiversity (Coupland 1979; Habel et al. 2013; Kleijn et al. 2011; Suttie, Reynolds, and

CONTACT Gusztáv Jakab jakab.gusztav@uni-mate.hu; cembra@freemail.hu Institute of Environmental Sciences, Hungarian University of Agriculture and Life Sciences, Páter Károly utca 1, Gödöllő 2100, Hungary
Supplemental data for this article can be accessed https://doi.org/10.1080/14614103.2021.1942744.

Batello 2005) and provide significant ecosystem services, such as forage for livestock (Grigulis et al. 2013; Lemaire, Hodgson, and Chabbi 2011; Pilgrim et al. 2010). Mountain grasslands are among the most valuable ecosystems within agricultural landscapes; these habitats developed through stable agricultural management over centuries when these areas were used as hayfields and pastures. Large areas of the alpine grasslands remain very close to a natural state and exhibit high biodiversity that includes many endemic species (Coldea 2003; Coldea and Cristea 1998; Sârbu et al. 2000).

The main causes of deforestation and pasture formation in the subalpine zone were pastoral activities, timber extraction and the collection of natural products. Seasonal pastoral activities have been practised for many centuries on accessible areas of the mountain grasslands (Isselstein, Jeangros, and Pavlu 2005; Kampmann et al. 2008; Matějková, van Diggelen, and Prach 2003; Messerli and Ives 1997). Transhumance, the seasonal migration of livestock to suitable grazing grounds, is the traditional use of mountain grasslands in Europe (Dolek and Geyer 2002; Pérez-Soba et al. 2004; Poschlod and Wallis DeVries 2002) and in the Carpathians (Baur et al. 2007). For livestock production in the Romanian Carpathians, transhumance is a common strategy for overcoming temporal and spatial shortages in fodder and forage. The loss of protected markets since the end of communism in 1989 has resulted in the decline of long-distance transhumance (Juler 2014). However, short-distance transhumance (pendulation) is still a common phenomenon because it remains a necessity for mountain households to continuously produce food for personal use. Livestock in short-distance transhumance systems spend the summer months on the grazing pastures in the mountains but are kept in barns and fed on hay during the winter (Huband, McCracken, and Mertens 2010; Juler 2014). It has been shown that grazing contributed to the lowering of the timberline in the Iezer Mountains (Mihai, Savulescu, and Sandric 2007), while the enlargement of grazing fields by slash and burn activities is documented in the Făgăraş Mountains (Nedelea and Comănescu 2009). Ecological studies on recent vegetation conclude that intensive summer alpine pasturing had a direct influence on the composition and altitude of the treeline ecotone (Coldea and Cristea 1998; Geanana 1991). Although documentary sources confirm high mountain pastoralism at least 800 years ago through tax records (1256: the first mention of the animal tax of Szeklers and Romanians; 1276: the first mention of the typical tax type of Romanian shepherds, *quinquagesima ovium*, Jakó 1997), people were very likely practicing pastoralism long before the introduction of taxes. Despite some documentary evidence spanning the thirteenth to nineteenth centuries, grazing practices in mountainous areas are generally poorly documented and there are no available documentary sources before the thirteenth century (Bărbulescu and Motcă 1983; Matley 1970; Mertens and Huband 2004). Nevertheless, we can assume that the deforestation of the high-lying areas and the use of the pastures thus formed date deep into the Middle Ages, well before the first surviving written mentions.

Paleoecological studies suggest seasonal grazing at high elevation in the Romanian Carpathians started much earlier than the written sources indicate (e.g. Fărcaş et al. 2007; Feurdean et al. 2011; Feurdean and Willis 2008a; Tanţău et al. 2003). In the South Carpathian Retezat Mountains, paleoecological proxy-based vegetation, treeline and timberline reconstructions suggested alpine grazing on naturally open meadows as early as 4200 calibrated years BP (cal yr BP), with intensive clearance of the dwarf pine zone (*Pinus mugo*) already in the Iron Age, from 2650 and 2200 cal yr BP (Vincze et al. 2017). Based on the paleoecological record, significant climate change, hence reorganisation of vegetation zones in the past 1500 years, cannot be proved. However, the climate played an increasing role through human land use, deforestation and selective logging (Wiezik et al. 2019). Nevertheless, the beginning of medieval alpine shepherding in the Romanian Carpathians overlapped with a climatic optimum in Europe (Medieval Climatic Anomaly (MCA), AD 950–1250, Mann et al. 2009). Hence it is possible that warmer climate conditions increased the duration of the potential subalpine grazing period and resulted in the modification of the vegetation (Feurdean, Willis, and Astaloş 2009; Geantă et al. 2014; Tinner et al. 2003). Feurdean et al. (2011) assumed that warmer climatic conditions led to intensification of grazing pressure by domesticated stock and forest clearance to enlarge the grazing area. In summary, previous studies emphasised the role of climate-driven land use change, but they only marginally examined the social or economic circumstances and population change effects on deforestation and grassland expansion. Therefore, archaeological and paleoecological research is particularly important to fill in some of these knowledge gaps.

Archaeological datasets can also contribute towards our understanding of the settlement history of high-elevation terrains. Although archaeological research has a centuries-old tradition in the region, research has been limited primarily to densely populated basins and valleys. The first results of mountain archaeology are already available from the Romanian Carpathians (Andronic and Niculică 2012; Bobînă 2015; Dragoman et al. 2018). However, more accurate dating of sporadic settlement remains, determination of their periodic or permanent nature and exploration of the historical dimensions of population movements (e.g. the existence or absence of shepherding in premedieval and early modern times) suggested by the finds (Bartosiewicz and Greenfield 1999; Kienlin and Valde-Nowac 2004) are necessary. In any case, it is archaeologically proven that only temporary settlements (e.g. summer huts) existed above 700 m altitude in archaeological times (Maxim 1988–1991). Unfortunately, in the absence of particular data from this elevation (e.g. the exact amount of natural products, livestock and human population, the number of temporary settlements, changes in farming and forestry methods), archaeology alone cannot move forward in this field, and this is where detailed processing of further corings and strengthening of interdisciplinary can be beneficial.

The early Middle Ages is a transitional period in history with relatively few surviving written documents, yet it is extremely important as it was the period of the formation of the state and settlement structure, and of the landscape management of modern Europe. The environmental and historical research focused so far on the Romanian Carpathians has made little effort to examine medieval deforestation from a historical point of view and has failed to link the individual phases of deforestation to historical events or economic processes. The increasing archaeological evidence and the archive resources that have become available recently, however, allow us to better pin down the parameters of the social and economic background to deforestation from the early Middle Ages. Therefore, based on a multidisciplinary investigation of the sediment core taken at Calul de Piatră peat bog and historical sources referring to its surroundings (Bistra region, Apuseni Mountains), we seek to provide answers to the following questions: (1) When did the current mountain shepherding begin in the region? (2) During which periods was the deforestation more intense? (3) Is the intensive use of mountain areas due to social and economic or environmental reasons?

Study Site

The studied area is part of the Muntele Mare Mountains located in the central-eastern part of the Apuseni Mountains in the Romanian Western Carpathians (Figure 1). Here the rocky basement consists of the Variscan (~290.9 ± 3.0 Ma) Muntele Mare biotite granodiorite pluton that intruded in the Someș metamorphic unit (Balintoni et al. 2009). The studied area has a temperate continental climate with oceanic influence (Bogdan 1983). The annual mean temperature around Bistra is 4–6°C (reference period: 1951–2000). The average temperature of the coldest month (January) is −4 to −6°C, whilst the average temperature of the warmest month (July) is ~14–15 °C. The multiannual precipitation sum is about 950 mm per year, and most of it (66–70%) is delivered between March and September (Sandu, Pescaru, and Poiană 2008).

The peat bog named *Molhașul de la Calul de Piatră* according to the local toponymy (Pop 1960) is probably the most authentic, active raised bog of the Romanian Carpathians, still intact, unaltered by human activities (Figure 1c). It is located in the central part of the Apuseni Mountains, at N46°30′17,87″; E23° 8′57,17″, 1630 m above sea level, on a high elevation and less accessible mountain plateau (Figure 1b). This ombrotrophic bog, with an elliptical shape and a total surface of *ca.* 3.5 hectares, is surrounded by a coniferous forest (Figure 1c), which has an important role in hiding and protecting it from human activities (e.g. grazing, tourism). The raised bog has a classic lens shape, with a few, small-sized polyhumic and acidic bog pools of *ca.* 2–3 m depth and many *Sphagnum* regeneration hollows (Péterfi and Momeu 1993–1994).

Although Calul de Piatră peat bog has been known for a long time, only scattered floristic data have been reported (Péterfi and Momeu 1993–1994; Pop 1939, 1960) and comprehensive flora and vegetation as well as palynological studies have not yet been performed. Based on our field observations and vegetation transects carried out in 2013–2015, the dominant bryophytes are *Sphagnum capillifolium* and *S. magellanicum*. Other moss species such as *S. cuspidatum*, *S. fuscum*, *S. rubellum*, *Polytrichum commune* and *Cladopodiella fluitans* are also frequent. In some of the central hollows, there are populations of *Carex limosa, C. pauciflora* and of the rare *Drosera intermedia.* The other sundew species, *D. rotundifolia*, is more common, and grows on the higher microrelief forms. Nano-phanerophytes such as *Andromeda polifolia, Empetrum nigrum, Vaccinium microcarpum, V. myrtillus* and *V. vitis-idaea* can be found on the compact moss layer. The wetter parts of the bog are covered with *Sphagnum capillifolium* mats, while the drier parts are characterised by mats of *Sphagnum magellanicum* with *Eriophorum vaginatum, Polytrichum strictum* and *Empetrum nigrum*, which represent a typical plant assemblage in the region's peat bogs (Pop 1960). The woody vegetation is represented by scattered stunted individuals of Norway spruce (*Picea abies*) in the marginal area of the bog (Figure 1c).

The forest belt surrounding the bog and the woody vegetation of the entire upland area are made up of spruce-dominated forest communities belonging to the following plant associations: *Sphagno–Piceetum* around the bog areas and fens; *Soldanello majoris–Piceetum* and *Hieracio rotundati–Piceetum* on the plateau and the mountain slopes over 1300–1400 m elevation (Stoica 2011). On lower areas, down to the valleys, mixed forest communities with Norway spruce, European silver fir (*Abies alba*) and European beech (*Fagus sylvatica*) are presented; these belong to the *Pulmonario rubrae–Fagetum* association (Stoica

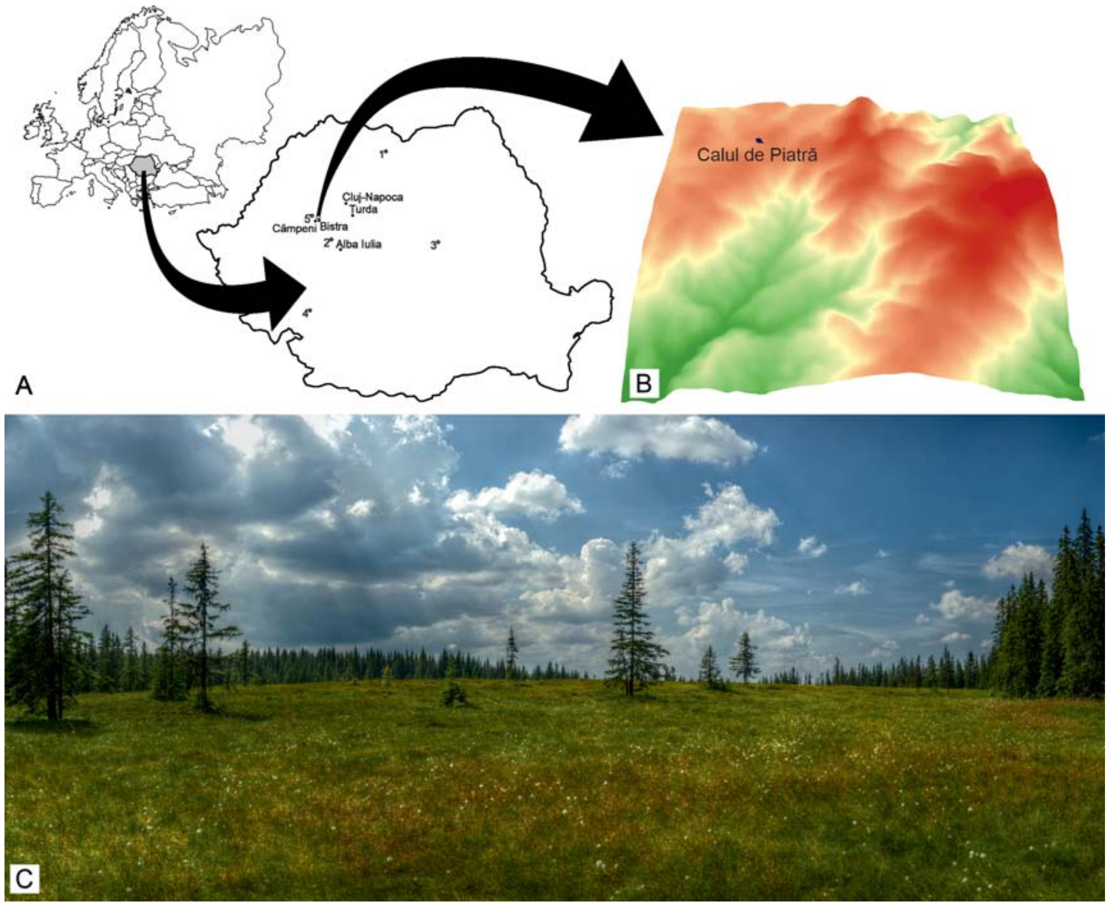

Figure 1. Digital elevation model and map showing the position of the study site (Bistra), and a panoramic view of the peat bog. Locations of the mentioned paleoclimate records: 1, Rodna Mountains; 2, Lake Ighiel; 3, Lake St Anne and Mohoş peat bog; 4, Cloşani Cave; 5, Scărişoara Ice Cave.

2011). Grasslands appear patchily in the forest and are very heterogeneous depending on the ecological features of the habitat. Mesic phytocoenoses of the *Festuco rubrae–Agrostietum capillaris* community are typical, as is the oligotrophic, acidophilous community of *Violo declinatae–Nardetum strictae* (Stoica 2011). In moist parts of the micro-depressions, these plant associations are substituted by the phytocoenoses of the *Agrostio–Deschampsietum caespitosae* community (Frink 2009, 2010).

Currently, the human influence in the Apuseni Mountains is mostly reduced to forestry and grazing (Supplementary data Figure 1), and the human settlements are small or mid-sized dispersed villages (Pop 2006).

Materials and Methods

Field Methods

A 5.6 m long peat core was recovered from the central plateau of the peat bog using a modified 1 m long Russian corer with steel bars (Sümegi 2001) and overlapping core technique (De Vleeschouwer, Chambers, and Swindles 2010). The two-borehole technique involves taking alternate, overlapping samples from two parallel boreholes. The two parallel cores had 10 cm overlaps, but only 5 cm from the overlapping sequences of each core could be preserved.

Radiocarbon Dating, Chronology

Radiocarbon dating (^{14}C analysis) was performed on nine *Sphagnum* fragments (Table 1). Following the recommended protocol, samples were meticulously checked for contaminants such as rootlets, fungal remains or foreign materials that might have entered the sample during extraction or preparation (e.g. dust, hair or textile), and if observed these were then removed using forceps (Piotrowska et al. 2011). Such pre-cleaned peat samples provide excellent material for ^{14}C dating (Piotrowska et al. 2011). AMS ^{14}C dating was performed by the DirectAMS Lab at Seattle (USA) (Zoppi et al. 2007). The IntCal13 dataset (Reimer et al. 2013) was used to convert the conventional radiocarbon ages to calendar timescale and the age–depth model was obtained using BACON (Blaauw and Christen 2011). The inverse autoregressive model (AR) was constrained by prior information: accumulation (acc.) shape = 2 and acc.mean = 5 for the gamma distribution, and memory (mem.)-mean = 0.45 and mem.strength = 15 for the beta

Table 1. Results of ^{14}C AMS dating of the studied core (Sphagnum fragments).

Lab code	Depth (cm)	^{14}C age (years BP ± 1σ)	cal AD (95% ranges)
D-AMS 020199	43	108 ± 38	1678–1764AD (31.8%) 1800–1940AD (63.7%)
D-AMS 020200	83	146 ± 27	1668–1709AD (16.2%) 1717–1782AD (30.5%) 1796–1889AD (32.0%) 1910–1948AD (16.8%)
D-AMS 017154	100	97 ± 26	1686–1731AD (26.3%) 1808–1927AD (69.1%)
D-AMS 020201	151	284 ± 32	1492–1602AD (60.0%) 1615–1665AD (34.0%) 1785–1794AD (1.4%)
D-AMS 020202	171	825 ± 29	1164–1262AD (95.4%)
D-AMS 020203	201	1056 ± 32	896–926AD (13.6%) 942–1025AD (81.9%)
D-AMS 023736	231	1300 ± 34	658–770AD (95.4%)
D-AMS 023737	247	1140 ± 25	777–792AD (4.5%) 804–843AD (7.6%) 859– 979AD (83.4%)
D-AMS 023738	300	1646 ± 31	265–272AD (0.7%) 331–434AD (80.7%) 452–470AD (2.2%) 486–534AD (11.9%)

distribution describing the memory effects (or autocorrelation) of inverse AR. Radiocarbon ages suggest abrupt change at 165 cm depth corresponding to a layer indicating temporal desiccation (see Section 2.3.). Therefore, a supposed hiatus was considered in the age–depth modelling. The top of the core (0 cm) was assigned to AD 2016 and was used to constrain the age–depth model. The deposition time (DT) was calculated by the age–depth model and expressed as yr cm^{-1} (Bennett 1994).

Sediment Analysis

The lithostratigraphic description of the profiles followed the system of Troels-Smith (1955). A marked hiatus was observed at 165 cm, where the sediment was strongly humified indicating temporary desiccation. The uppermost 9 cm consisted of living *Sphagnum* mosses, which were excluded from the analysis. Sedimentological and palaeobotanical data were plotted using Psimpoll (Bennett 1996, 2007).

Plant Macrofossil Remains

The core was analysed for macrofossils at 2 cm intervals. The studied subsamples were 1 cm thick. Sample volume was measured by water displacement. The samples were disaggregated if necessary and wet-sieved with a 250 µm mesh prior to analysis of the fossil content. Remains were systematically picked out from the residues under a stereomicroscope, identified using reference collections and identification keys, and counted (Birks 2001; Bojnanský and Fargašová 2007; Jakab and Sümegi 2011b; Katz, Katz, and Kipiani 1965). The quantitative description of the macrofossil community was carried out using a modified version of the QLCMA (semi-quantitative quadrate and leaf-count macrofossil analysis) technique (Barber et al. 1994; Jakab, Sümegi, and Magyari 2004). In the diagrams, the total number of seeds relates to 10 cm^3 of sediment, while other macrofossil components are expressed as concentrations (piece cm^{-3}). In evaluating the results, we considered the ecological indication of the species (e.g. Daniels and Eddy 1985 for *Sphagnum*) and also their role in the local vegetation (Pop 1960; Popescu and Sanda 1998). Unidentifiable macrofossils also have important indication values, since high values of wood fragments and unidentified organic material (UOM) always indicate dry bog surfaces (Jakab and Sümegi 2011a).

Pollen

The entire sediment core was subsampled at 2 cm intervals for pollen analysis. Each cm^3 subsample was prepared for pollen analysis in the laboratory using standard methods but excluding the use of hydrofluoric acid to dissolve the silicate particles (Bennett and Willis 2001). We added *Lycopodium* tablets to calculate the pollen concentrations of the samples (Stockmarr 1971). Pollen, spores and stomata were counted and identified under an Olympus CX41 light microscope at 400× and 1000× magnification. At least 500 terrestrial pollen grains were counted in each slide. For pollen identification, the pollen atlases of Reille (1992, 1995, 1998) and the pollen identification key of Moore, Webb, and Collinson (1991) and Beug (1982) were used. Local pollen assemblage zones were determined using optimal splitting by information content on the terrestrial pollen taxa. The statistical significance of the pollen assemblage zone boundaries was tested by comparison with the broken stick model (Bennett 1996). Principal component analysis (PCA) was implemented with Psimpoll 4.27 (Bennett 2007) using data on those terrestrial pollen taxa which attained at least 5% relative abundance in at least one sample.

We distinguished three stomata types on the pollen slides: *Picea abies*, *Pinus* haploxylon and *Pinus* diploxylon types using the keys of Sweeney (2004), Finsinger and Tinner (2019) and Magyari et al. (2012b). Stomata abundance was expressed as percentages relative to the terrestrial pollen sum.

Historical Aspects and Data

Relatively rich documentary sources were available in the study area due to the proximity of famous gold mines located along the road from the town of Turda (Torda) to Baia de Arieş (Aranyosbánya/Offenbánya), Câmpeni (Topánfalva) and Abrud (Abrudbánya). On the outskirts of Bistra (Bisztra), suspected traces of Roman gold panning have survived, and Roman artefacts and coins have also been unearthed (Moga and Ciugudean 1995). Gold mining continued in the Middle Ages in the area to the east of Bistra at Baia de Arieş, where a royal gold mine first mentioned in AD 1325 (Csánki 1913) had operated since the fourteenth century. All these findings are significant, because in some archaeological periods human activity in the vicinity of gold deposits of international importance may have exceeded the intensity of other mountain areas. In the course of our research we aimed to reconstruct the historical antecedents of current land use. Therefore, we decided to collect medieval and early modern archival data, as relatively rich archival material on the subject concerning the wider area of Bistra is available compared with other Transylvanian areas. We examined documents of a fundamentally economic nature (inventories, tax registers, etc.) which have so far been rarely used in environmental history research, although their data are of paramount importance in this respect; however, the old Hungarian and Latin texts published in difficult-to-access publications can only be used with special knowledge.

Results and Interpretation

Lithology and Sediment Accumulation Rates

The radiocarbon data suggest that the upper ∼250 cm long section of the undisturbed sequence in the Calul de Piatră peat bog at Bistra formed during the last 1500 years. The investigated sediment consists of *Sphagnum* and *Eriophorum* remains. The only visible difference is the level of humification and the relative proportion of *Sphagnum* and *Eriophorum*. In two definite layers (241–233 cm and 169–165 cm) the level of humification was pronounced (Table 2). In the upper 25 cm the abundance of *Sphagnum* decreased, while *Polytrichum* and *Empetrum* increased (Supplementary data Figure 2). The accumulation rate of the peat varied between 2.9 mm/yr in the less humified layers and 2.4–1.5 mm/yr in the more humified layers (Figure 2). Age–depth modelling estimated the duration of the hiatus in peat accumulation as ∼140 years in the late thirteenth and early fourteenth centuries.

The Plant Macrofossil Record

The core was divided into six different zones based on macrofossil assemblages (Figure 3). There were no large-scale changes in the upper 250 cm, with only the proportion of the different components changing with depth, which seems to reflect the degree of humification of the peat (Supplementary data Figure 2). The dominant components of the peat were the branches and leaves of *Sphagnum* and the rhizomes of *Eriophorum vaginatum*. The amounts of *Sphagnum* and *Eriophorum* showed an inverse relation. The amount of *Empetrum* and *Polytrichum strictum* remains showed similar changes to *Eriophorum*, indicating drier bog surfaces and the lack of prolonged waterlogging (Bell and Tallis 1973; Pop 1960). Three different types of *Sphagnum* could be identified from the peat: *Sphagnum magellanicum* and two other types which were identified only at section level. Such changes are quite common in the European and Romanian peat sequences, when *Eriophorum* and *Sphagnum* remains are interpreted as intervals indicating drier and wetter bog surfaces, respectively (e.g. Diaconu et al. 2020; Feurdean et al. 2015; Gałka et al. 2013, 2014, 2016, 2017; Lavoie et al. 2005; Silvan

Table 2. Sediment types and stratigraphy from the undisturbed core sequence of Calul de Piatră peat bog

Depth (cm)	Troels-Smith symbol	Sediment description
25–0	Tb3Tl1	Light brown *Polytrichum*-peat with *Sphagnum* and *Empetrum*.
33–25	Tb4	Light brown *Sphagnum*-peat with a few *Polytrichum* and *Eriophorum* remains.
40–33	Tb3Th1	Light brown *Sphagnum*-peat with *Eriophorum* and *Polytrichum*.
127–40	Tb3Th1	Light brown *Sphagnum*-peat with *Eriophorum*. A few woody particles of *Vaccinium* and *Betula*.
133–127	Tb2Th2	Light brown *Sphagnum*-peat with *Eriophorum*. A few woody particles of *Picea*.
165–133	Tb3Th1	Light brown *Sphagnum*-peat with *Eriophorum*. A few woody particles of *Vaccinium*.
169–165	Th2Sh2	Dark brown, humified *Eriophorum*-peat with *Sphagnum*.
171–169	Th3Tb1	Light brown *Eriophorum*-peat with *Sphagnum*.
233–171	Tb3Th1	Light brown *Sphagnum*-peat with *Eriophorum*.
241–233	Tb2Th1Sh1	Dark brown, humified *Sphagnum*-peat with *Eriophorum*. A few woody particles of *Picea*.
250–241	Tb3Th1	Light brown *Sphagnum*-peat with *Eriophorum*.

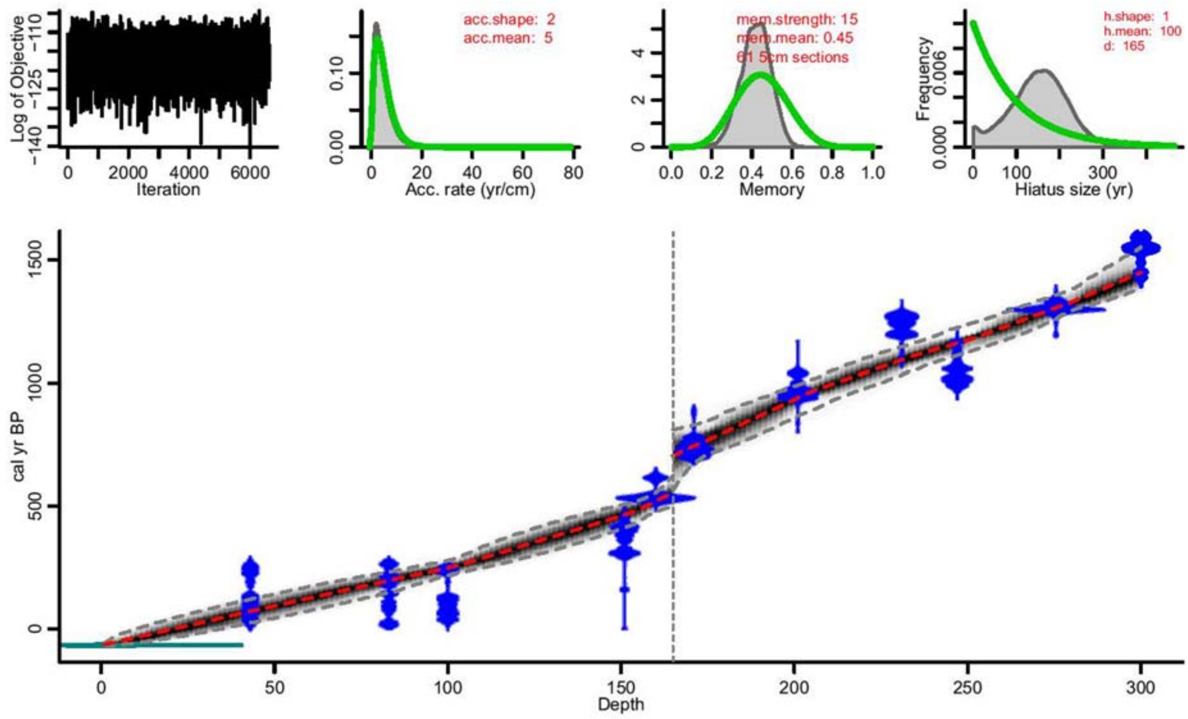

Figure 2. Age–depth model of the Calul de Piatră peat bog sequence.

et al. 2004). *Sphagnum magellanicum* plays a subordinate role in the profile, but its appearance indicates lower water levels (Daniels and Eddy 1985).

BM-1 macrofossil zone (250–241 cm, AD 780–810) represents a wetter period where the amount of *Sphagnum* remains high (Figure 3). The remains of *Sphagnum magellanicum* and *Betula* in the last sample of the zone suggest a transition to a more arid period.

BM-2 macrofossil zone (241–233 cm, AD 810–850) represents a significant period of aridity identified by a pronounced reduction in *Sphagnum.* The decomposition of peat is shown by the high concentrations of UOM. Dry conditions prevailing at the bog surfaces are indicated by the emergence of *Picea* macro remains (Figure 3). This is the first pronounced dry period in the investigated sequence.

BM-3 macrofossil zone (233–183 cm, AD 850–1130) represents a wetter period with aridity pulses. Although the concentrations of *Sphagnum* remains are high in this zone, the high proportion of UOM and *Eriophorum* and the emergence of *Polytrichum strictum* remains (Figure 3) indicate some short arid periods, e.g. ~AD 950s, 1020s, 1070s.

BM-4 macrofossil zone (183–163 cm, AD 1130–1400) represents a significant period of aridity identified by a significant retreat in *Sphagnum.* The concentration of UOM increased and *Eriophorum* remains were common exclusively at the beginning of the zone (see Supplementary data Figure 3). This dry spell started in the first part of the twelfth century and peaked at the end of the fourteenth century. By this time the surface of the peat bog had dried completely and *Sphagnum* had almost disappeared from the sequence. Dwarf shrubs (*Empetrum*, *Vaccinum)* and spruce (*Picea abies*) colonised on the bog surface at the coring point. At 168 cm a *Typha latifolia* seed appeared in the sediment (Figure 3), which may indicate a warmer event. The retreat of *Sphagnum* in the central parts of the bog is surprising at this elevation and suggests a regional drought which also affected the broader subalpine ecosystem.

BM-5 macrofossil zone (163–31 cm, AD 1400–1920) represents a wetter period from the late Middle Ages to the early twentieth century when the amount of *Sphagnum* remains high (Figure 3). However, after the middle part of the nineteenth century the increasing presence of *Polytrichum strictum* remains suggests a gradual decrease in the water table in the surroundings of the peat bog. Some short dry spells could be suspected at 130 cm (AD 1570) and 90 cm (AD 1730). One of the most characteristic phenomena of the sequence is the lack of macrocharcoal, except in this zone. Some large macrocharcoal pieces appeared at 144 cm (AD 1520) and some minor pieces at 134 cm (AD 1560). The macrocharcoal remains likely indicate some human impact (burning) in the close vicinity of Calul de Piatră peat bog.

BM-6 macrofossil zone (31–8 cm, AD 1920–2016) represents a significant period of aridity identified by a pronounced reduction in *Sphagnum*. In this zone, which roughly corresponds to the last century, the amount of *Polytrichum strictum* and *Empetrum nigrum* increased, indicating intensifying peat surface aridity (Supplementary data Figure 3).

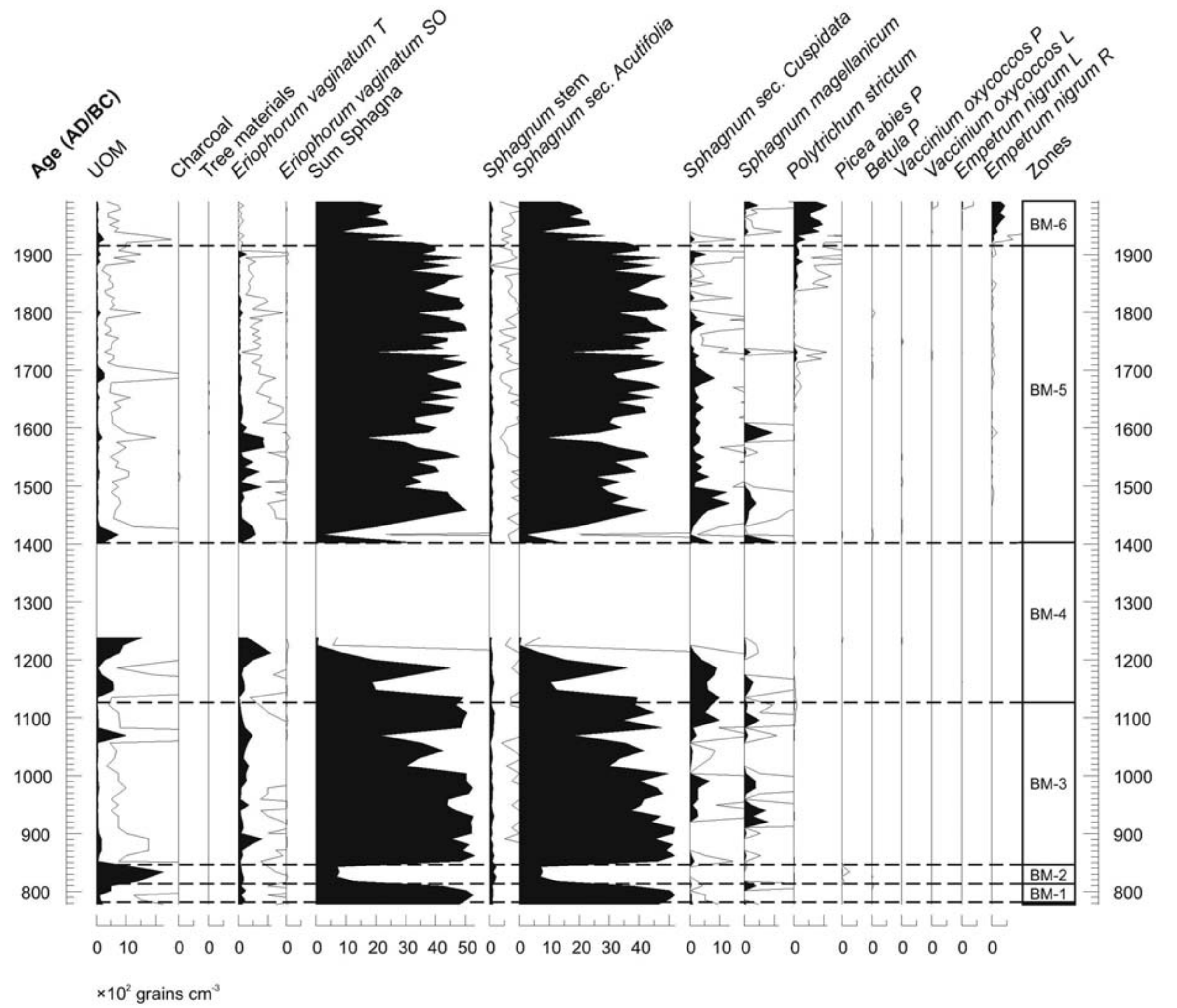

Figure 3. Macrofossil diagram (unidentified organic material, UOM; tissue, T; sclerenchyma, SO; periderm, P; leaf, L; rhizome, R) of the Calul de Piatră peat bog sequence.

Pollen Zones

Six local pollen zones were identified (Figure 4 and Supplementary data Figure 4), based on optimal splitting by information content on the terrestrial pollen taxa (Figure 5). The pollen diagram is characterised by episodic changes in the relative frequencies of spruce (*Picea abies*) which reflect changes in the surrounding of the examined site (the pollen percentage values of spruce is higher than 40%) and beech (*Fagus*) which reflect changes in the lower elevation. The upper part of the core is characterised by the increase of tree pollen. It is visible in the notable increase in the relative frequencies of spruce (*Picea abies*) and hornbeam (*Carpinus betulus*). At these depths, the relative frequencies of anthropogenic indicator taxa (Moore, Webb, and Collinson 1991) such as grasses (Poaceae), pigweeds (Chenopodiaceae), ribgrasses (*Plantago lanceolata, P. major/media*), sorrel (*Rumex acetosa/acetosella*), cow-wheat (*Melampyrum*) and nettle (*Urtica*), and also the secondary successional woody taxa such as hazel (*Corylus*), increase inferring partial reforestation and secondary succession after partial abandonment of grazing pastures.

BP-1 zone (250–232 cm, AD 780–850): this zone is characterised by high pollen frequencies of spruce (*Picea abies*), silver fir (*Abies alba*) and beech (*Fagus*). Deciduous tree taxa, such us oak (*Quercus*) and hornbeam (*Carpinus betulus*), are also present in this zone in addition to herbs, especially grasses (Poaceae) and wormwood (*Artemisia*). At the end of this zone (around AD 810) spruce started to increase at the expense of beech and silver fir. Cow-wheat (*Melampyrum*) pollen appeared with relatively high frequency throughout this zone, especially between AD 820 and 850, which can be connected to increasing human impact (pastoral farming activity, deforestation and grazed forests) (Behre 1981; Deza-Araujo et al. 2020; Kuneš, Pokorný, and Šída 2008; van der Linden et al. 2008).

BP-2 zone (232–190 cm, AD 850–1080): this zone is characterised by high frequencies of conifers such as spruce (*Picea abies*) and silver fir (*A. alba*), and also deciduous tree taxa, especially beech (*Fagus*), oak (*Quercus*) and hornbeam (*C. betulus*).

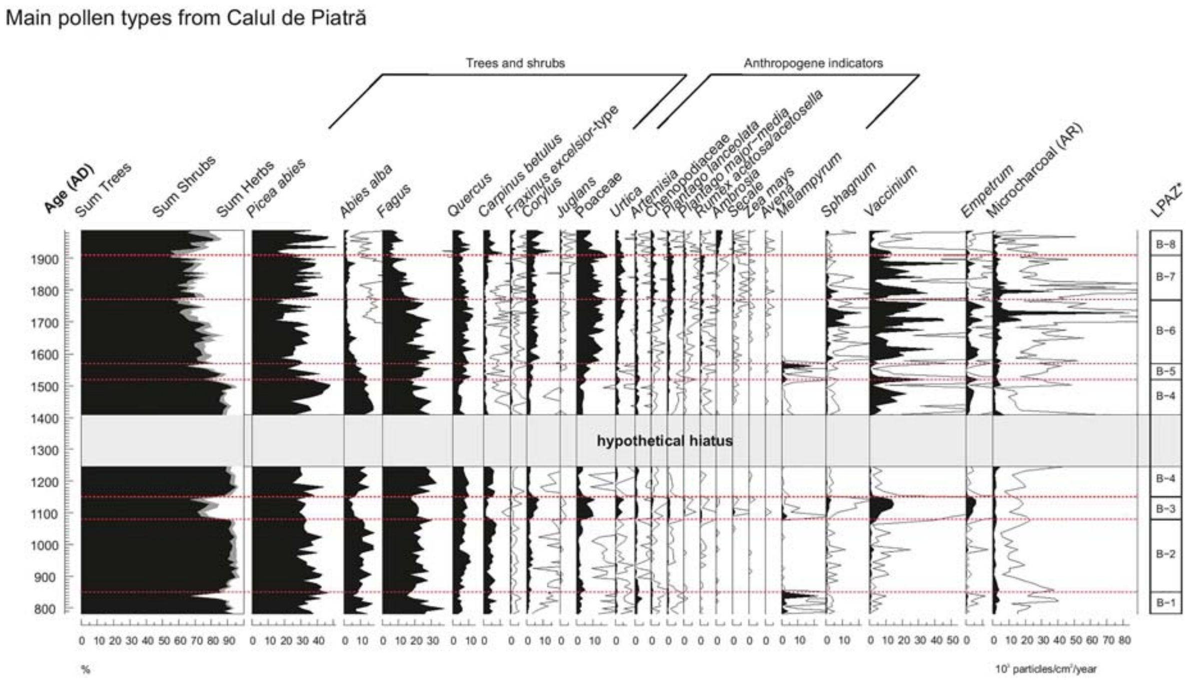

Figure 4. Pollen diagram of the Calul de Piatră peat bog sequence (main pollen types) (LPAZ: local pollen assemblage zone).

Cow-wheat (*Melampyrum*) pollen is exceptionally rare in this pollen zone. Cereals appear sporadically in this zone.

BP-3 zone (190–180 cm, AD 1080–1150): the relative frequency of hazel (*Corylus*) as a secondary successional taxon started to increase significantly at the expense of silver fir (*A. alba*) and hornbeam (*C. betulus*). Herbs displayed a temporary increase in this time interval, which is visible especially in the pollen percentages of grasses (Poaceae), ribgrasses (*Plantago lanceolata, P. major/media*), pigweeds (Chenopodiaceae), sorrel (*Rumex acetosa/acetosella*) cow-wheat (*Melampyrum*) and nettle (*Urtica*). These changes in the herbaceous taxa can be connected to the temporary increase in human impact (deforestation and pastoral farming activity) together with the decrease in arboreal pollen.

BP-4 zone (180–144 cm, AD 1150–1520): from the start of this zone, the frequencies of oak (*Quercus*) and hornbeam (*C. betulus*) started to increase and

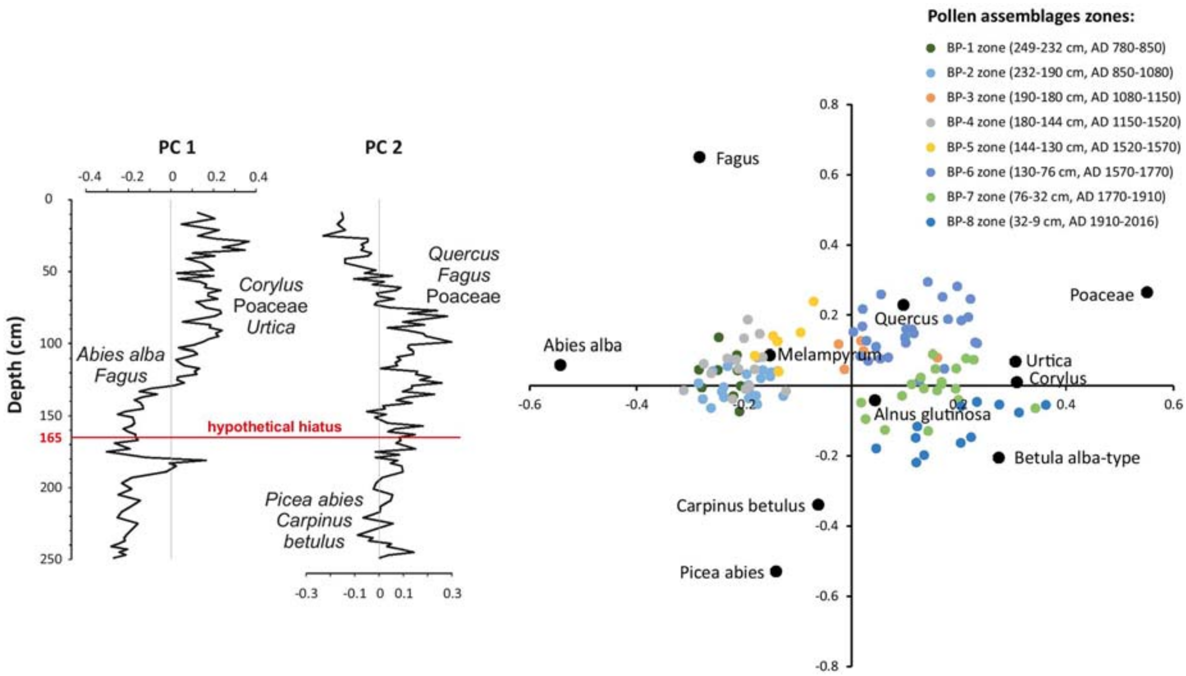

Figure 5. Pollen PCA score of the Calul de Piatră peat bog sequence. The first principal component (PC1) represents 51.09% of the variance, while the second principal component (PC2) represents only 15.69% of the variance.

remained constant until AD 1230. The decrease in hazel (*Corlyus*) is characteristic for the entire zone. The frequencies of silver fir (*A. alba*) and beech (*Fagus*) increased until AD 1430 and thereafter started to decrease together with oak and hornbeam. Norway spruce (*Picea abies*) became dominant after this time. There are no significant changes in the pollen percentages of herbs in this time interval.

BP-5 zone (144–130 cm, AD 1520–1570): this interval is characterised by the last significant increase of cow-wheat (*Melampyrum*) pollen, which is connected to the decrease in the pollen frequencies of conifer species of spruce (*Picea abies*) and silver fir (*A. alba*). The pollen percentage of beech (*Fagus*) increased, while oak (*Quercus*) pollen frequencies remained at a constant level during this time interval. As previously mentioned, the significant increase in the pollen percentage value of cow-wheat together with the decrease of some tree taxa (especially spruce, silver fir, beech and hornbeam) can be connected to deforestation in the fir–spruce zone. Together with the significant increase in grass (Poaceae) pollen, this indicates the start of the opening up of the mountain tops for pastural activities (summer mountain grazing). Cereals start to become prominent in this zone after AD 1500 and remain constant in the sediment. It is important to mention that the surrounding mountains are not suitable for cereal production, hence cereal pollen may come from regional sources and so they represent regional changes. Thus there can be no close correlation between deforestation and changes in the amount of cereal pollen in this case.

BP-6 zone (130–76 cm, AD 1570–1770): this zone is characterised by the continual decrease in silver fir (*A. alba*). Antagonistic changes between spruce (*Picea abies*) and beech (*Fagus*) are notable in this zone. Other deciduous species are also present, such as oak (*Quercus*), hazel (*Corylus*), birch (*Betula alba*-type) and common alder (*Alnus glutinosa*). The relative frequency of herbs is high, especially grasses (Poaceae) and nettle (*Urtica*), but the pollen percentages of ribgrasses (*Plantago lanceolata, P. major/media*) and sorrel (*Rumex acetosa/acetosella*) are also prominent. Cereals are continuously prominent in this zone, especially rye (*Secale*), while corn (*Zea*) and oat (*Avena*) pollen are rare. The microcharcoal accumulation rate showed a remarkable increase between 105 and 89 cm (AD 1680–1730) suggesting that regional forest fires were significant during this time interval.

BP-7 zone (76–32 cm, AD 1770–1910): this zone is characterised by the spread of hornbeam (*C. betulus*) and the constant presence of spruce (*Picea abies*), oak (*Quercus*), hazel (*Corylus*) and birch (*B. alba*-type). The relative frequency of beech (*Fagus*) pollen decreased continuously. From AD 1770, willow (*Salix*) and walnut (*Juglans*) pollen are present in the sediment. High pollen percentages of herbs are characteristic in this zone – e.g. grasses (Poaceae), pigweeds (Chenopodiaceae), ribgrasses (*Plantago lanceolata, P. major/media*), sorrel (*Rumex acetosa/acetosella*), nettle (*Urtica*), yarrow (*Achillea*) and cuckoo flower (*Cardamine*). Rye (*Secale*) is the main cereal in this zone. The microcharcoal accumulation rate showed high values between 76 and 60 cm (AD 1770–1820), pointing to significant regional forest fires.

BP-8 zone (32–9 cm, AD 1910–2016): this zone is characterised by the significant increase in spruce (*Picea abies*), birch (*B. alba*-type), ash (*Fraxinus excelsior*-type), European hornbeam (*C. betulus*) and common alder (*Alnus glutinosa*). Viburnum (*Viburnum*) appeared for the first time at the end of this zone. Ragweed (*Ambrosia*) and Liguliflorae increased in this zone among the herbs. Rye (*Secale*) was also dominant in this zone among the cereals. These changes point to secondary successional processes and gradual expansion of the deciduous forests and also a small-scale increase in spruce cover.

Statistical Analysis of the Pollen Data

The relative frequencies of silver fir (*A. alba*) and beech (*Fagus*) showed a negative correlation, while the percentages of hazel (*Corylus*), grasses (Poaceae) and nettle (*Urtica*) showed a positive correlation with the leading mode of variability (PC1) of the pollen data (Figure 5). The pollen diagram and PCA results suggest that increases in the component scores along PC1 might represent the intensification of human impact. Negative values of the component scores characterised the lower part of the sediment, where the relative frequencies of silver fir (*A. alba*) and beech (*Fagus*) were high, reflecting the regional dominance of these taxa. The first significant change along PC1 occurred between AD 1500 and 1570 (147–130 cm), when the relative frequencies of silver fir (*A. alba*) and beech (*Fagus*) decreased – i.e. the extent of the forested area significantly and steadily decreased, likely due to human impact (deforestation). The relative frequencies of hazel (*Corylus*), nettle (*Urtica*) and grasses (Poaceae) started to increase during this interval. Following modest afforestation, the deforestation intensified again, suggested by a repeated decrease in the relative frequencies of silver fir (*A. alba*) and beech (*Fagus*). Pollen of cereals – mainly oat (*Avena*), rye (*Secale*) and corn (*Zea*) – is present in this second phase of deforestation. In the upper part of the sediment, between AD 1890 and 1920 (40–30 cm), relative frequencies of silver fir (*A. alba*), spruce (*Picea abies*) and beech (*Fagus*) showed significant decreases, suggesting intensive human impact (deforestation). The spread of the secondary successional taxa, such as hazel (*Corylus*), ash (*F. excelsior*-type) and hornbeam (*C. betulus*), also reflects significant changes in the vegetation composition.

Discussion

Deforestation Periods as Consequences of Historical Change

Based on pollen records, major deforestation periods in the surroundings of Calul de Piatră peat bog are assumed to have occurred in the periods AD 810–850, AD 1060–1170, AD 1500–1570 and from AD 1700. From AD 1700 the continuous decline in the pollen of the arboreal taxa suggests a pervasive decline in forest cover, particularly in AD 1730 and lastly between AD 1890 and 1920 (Figure 6). These periods are characterised by the decrease in the relative abundance of silver fir (*A. alba*), beech (*Fagus*) and sometimes spruce (*Picea abies*). The secondary successional taxa, such as hazel (*Corylus*), ash (*F. excelsior*-type) and hornbeam (*C. betulus*), started to increase following the opening up of these forests, as did other anthropogenic indicator herbs, such as grasses (Poaceae), pigweeds (Chenopodiaceae), ribgrasses (*Plantago lanceolata, P. major/media*), sorrel (*Rumex acetosa/acetosella*), cow-wheat (*Melampyrum*) and nettle (*Urtica*). Most of these anthropogenic indicators came from the pastures created by the forest openings, as can be seen in contemporary botanical research (Frink 2009, 2010).

The inferred tree species composition and vegetation dynamics from the Calul de Piatră pollen record agree well with other investigated pollen sequences from the Apuseni Mountains (Bodnariuc et al. 2002; Fărcaş et al. 2007; Feurdean, Willis, and Astaloş 2009; Feurdean and Willis 2008a, 2008b). Despite the differences in altitude, most palynological studies show the four periods of deforestation found in Calul de Piatră peat cores. The identified major deforestation phases can be linked to the following historical periods: the first took place during the late Avar period (ninth century), the second was in the early Árpádian period (eleventh century), the third was in the late Middle Ages (sixteenth century) and the fourth from the eighteenth century onwards. Research into the causes of medieval deforestation is particularly novel because changes that occurred after the eighteenth century (Figure 6) could be easily explained with the help of historical documents (Rotariu, Bolovan, and Bolovan 1995).

The first half of the ninth century represents a turning point in the history of Transylvania, which was inhabited mostly by a late Avar and Slavic population in this period (historical data point 1 on Figure 6). Around AD 827, the Bulgarian khan Omurtag expanded his empire far north of the Danube (Bóna 2001; Fiedler 2008; Madgearu 2005; Stanciu 2013) into territories that included areas of Southern Transylvania around Alba Iulia, called Belgrade in Slavic, which is 60 km from Calul de Piatră peat bog. Archaeological finds from this period indicate a significant population concentration in the Alba Iulia (Gyulafehérvár) area and imply that, besides agricultural activity, great emphasis was put on the exploitation of mineral resources (Beck, Ciugudean, and Quinn 2020). Historical data on the salt trade are known from AD 892, when Arnulf, king of the Franks, asked the Bulgarian khan Laodimir (Wladimir) not to sell salt to the Moravians with whom he was fighting (Bóna 2001; Madgearu 2003). Contemporary archaeological sites from the whole Transylvanian Basin, and the Slavic Nuşfalău–Someşeni Group northwest of Bistra, have detected a rising number of sites throughout and west of the Transylvanian Basin in the eighth and ninth centuries. The findings show an increasing extent of agriculture, including animal husbandry. The Transylvanian Basin is characterised in the archaeological record by the trading of meat from domestic animals, dominated by ruminants – mainly cattle and secondarily sheep (Cosma 2016; Cosma and Gudea 2002; Pop, Gudea, and Damian 2015). The palynological results indicate an intensification of human activity in the period. Nevertheless, it is important to emphasise that forest clearance in the eighth and ninth centuries was just an episodic event, primarily affecting beech and fir forests. Paleoclimatological evidence shows a pronounced drop in autumn/winter precipitation in the early ninth century (Warken et al. 2018), partially overlapping with persistent summer drought conditions between AD 830 and 900 (Cook et al. 2015).

The second major period of deforestation began in the eleventh century. The medieval network of settlements developed during the eleventh and twelfth centuries, and the secular and ecclesiastical centres of Transylvania were formed as part of the feudal Hungarian state (Bóna 1990) (historical data point 2 on Figure 6). It should be emphasised that palynological results suggest systematic deforestation over nearly 100 years in the fir and beech dominated forests. At the same time as fir and beech declined in forests, there was a secondary, successional taxa, such as hazel (*Corylus*), which suggests deliberate forest clearance. It is very likely that the forests were being exploited during this period to supply building material for the new and expanding settlements. In the wider region of our study area, this meant the establishment of Cluj (Kolozs) and Turda (Torda) counties, the foundation of a Benedictine monastery at Cluj-Mănăştur (Kolozsmonostor), the raising of the manor house and estate centre of the Bishop of Transylvania in Gilău (Gyalu) and the establishment of several new villages and Christian churches around them (Benkő 2000a, 2000b).

The mountain range north of Bistra belonged to one of the estates of the Transylvanian prince in the

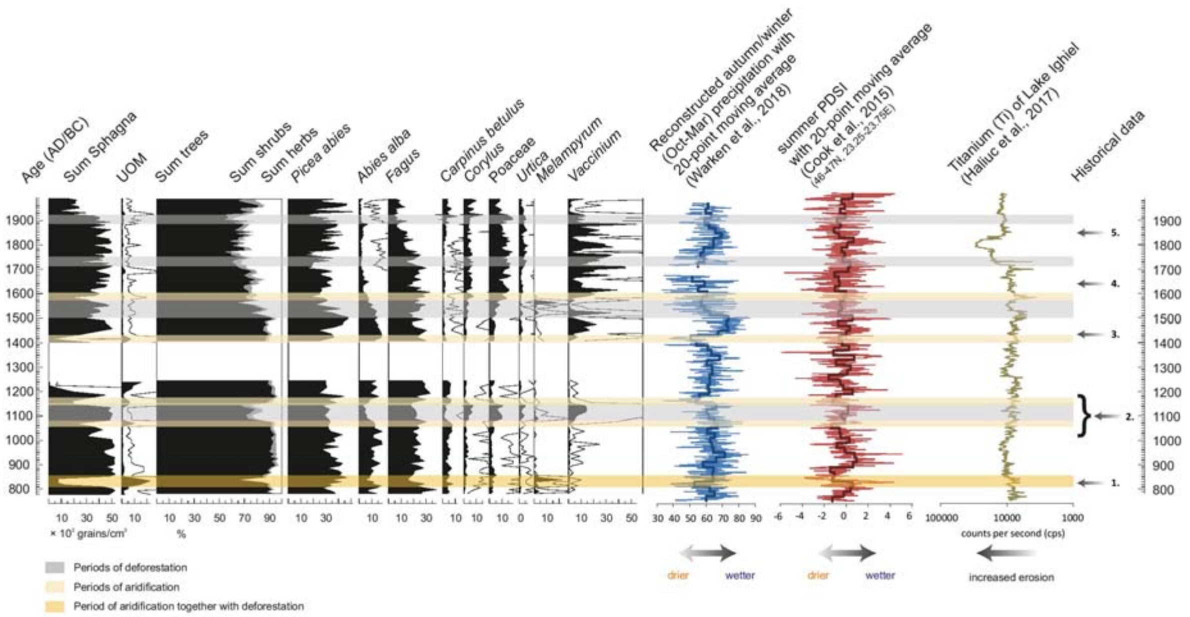

Figure 6. Comparison of dry periods and deforestation phases from Calul de Piatră peat bog with historical events and proxy climate data. Referenced regional historical events and processes: 1. AD 827: Bulgarian expansion in Transylvania; 2. Eleventh century: the settlement network of the Kingdom of Hungary is starting to develop in Transylvania; 3. AD 1437: first written mention of the city of Bistra; 4. AD 1640: the first written mention of alpine shepherding in the Apuseni Mountains; 5. AD 1850: significant population growth in the Apuseni Mountains.

early modern period, the centre of which was the market town of Gilău (Gyalu), west of Cluj-Napoca. We can therefore assume that the extraction of the wood needed for construction also affected the forests of the Apuseni Mountains. A significant settlement movement (organised population deployment) took place on abbatial and episcopal estates as well, with Hungarians, Germans, Romanians and Slavs listed in the thirteenth and fourteenth century documents (Györffy 1987). The abbey of Cluj-Mănăştur owned a considerable part of the Gilău Mountains, so in the thirteenth century this area was referred to as the Abbot's Mountains (Apáthavasa). Building timber was produced for the abbey from these mountains, and a false charter dated 1263 – but actually written around 1370 – mentions some temporary settlements over Gilău village (Jakó 1997, nr. 239). The decline in arboreal pollens might reflect increased logging to provide timber for the building activity, and the grasslands created by deforestation may have then been used for grazing. Although there is no direct data on the mountain grazing of this period, the use of subalpine meadows is firmly documented. For example, in AD 1339, the inhabitants of Tălmaciu village in southern Transylvania were forbidden to establish pastures in the place of forests falling towards the Sadu valley in case they accidentally(!) burnt down in the future (Jakó 2004, nr. 1027). Significant deforestation can be assumed in connection with the restorations that followed the Tartar invasion in 1241 and certain riots in Transylvania in the second half of the thirteenth century. In 1291 the bishop of Transylvania signed a contract with four carpenters for the restoration of the roof structure of the damaged bishop's cathedral in Alba Iulia – the carpenters could themselves cut the necessary wood in the bishop's forests (Jakó 1997, nr. 480). The strongly humified layer at ∼165 cm in the peat sequence might be related to this presumed disturbance, although it cannot be verified with the pollen record because of a hiatus recorded during this period (AD ∼1250–1400).

Dendrochronological evidence collected in the Eastern Carpathians confirms similar events at the end of the Árpádian period. The reconstructed felling periods of relict conifer logs preserved in a peat bog at the Farcau Massif (Maramureş Mountains) suggested a substantial landscape change from forest to pasture during the thirteenth century (Árvai 2019; Árvai et al. 2016). The lack of felling dates after the early fourteenth century in the assemblage of relict wood suggests the establishment of treeless subalpine meadows, and may represent the beginning of the vertical transhumance which became a characteristic livestock management strategy in the Maramureş region over the centuries that followed. In the Apuseni region, the Calul de Piatră pollen record suggests that vertical transhumance was likely established later, around the sixteenth century.

Bistra appears in a charter issued in AD 1437. The mention of its leader (*kenezius de Byzere*) refers to an established Romanian village. Bistra's older name is Bizere (*possessio Byzere*), the latter being mentioned in the document of perambulation between the neighbouring settlements in AD 1486 (Csánki 1913). The western neighbour of Bistra is Câmpeni, a significant Romanian settlement, which appears in written sources from AD 1565 (Suciu 1968). From historical data sources, we can conclude that alpine grazing developed in the area much earlier than suggested by the pollen results, but this may have been on a small scale. With the growth of the human population, the effect of shepherding became more and more pronounced in environmental history data from the sixteenth century onwards. The pollen record suggests prolonged deforestation over the sixteenth century around Calul de Piatră peat bog, affecting mainly the conifers (fir and spruce) (Figure 6). The largest spike in the *Vaccinium* record in the Calul de Piatră peat profile closely matches a pronounced increase in the titanium (Ti) record at AD ~1530 measured in the Ighiel sediment (Figure 6). Lake Ighiel is located ~40 km southward from Calul de Piatră peat bog, so the correspondence supports the idea that deforestation was characteristic at other nearby regions in the Apuseni Mountains in this period. *Vaccinium* species are dominant in the surrounding spruce forests and can reproduce significantly in the stands that open after felling. Titanium is typically of terrigenous origin, so an abrupt increase in Ti concentration in the sediment is interpreted as suddenly enhanced erosional input (Davies, Lamb, and Roberts 2015), usually because of decreasing vegetation cover for a larger part of the catchment. Large charcoal pieces found in Calul de Piatră peat bog at the beginning of the sixteenth century are an unquestionable sign of human impact. In the Scărişoara Ice Cave (Figure 1), record high amounts of micro- and macrocharcoal particles were reported between AD 1600 and 1850 (Feurdean et al. 2011).

The deforestation continued during the seventeenth century, mainly affecting the beech–fir belt and to a smaller extent the spruce belt. The sudden drop in the abundance of spruce pollen and accompanied increase in *Vaccinium* accords very well with the largest increase in erosion activity at the Ighiel watershed in the 1710s (Haliuc et al. 2017). Hence the deforestation was again a regional phenomenon (Figure 6). This deforestation process also affected the deciduous belt, as documented by the gradual decrease in the abundance of beech pollen in the record. In a conscription issued in AD 1640 it is documented that in Câmpeni (Topánfalva), a settlement adjacent to Bistra, the inhabitants established several shepherds' lodges in the alpine forests belonging to the castle of Gilău (Jakó 1944) (historical data point 4 in Figure 6). Here they raised mostly sheep, but also kept horses, cattle and pigs. In connection with pig farming, the inscription from AD 1666 mentioned some acorn-bearing deciduous forests occupying the lower region of the mountains (Jakó 1944). The only evidence identifying pastoral activities in the mountains of the Romanian Carpathians is based on a brief account referring to summer grazing (Jakó 1944). This suggests only temporary summer use of the mountains at that time (Jakó 1944). In AD 1679 'good meadows' were mentioned at the top of the Gilău Mountains (the northern neighbour of Muntele Mare Mountains), which may have resulted from the earlier deforestations (Jakó 1944).

An important question is when this earlier deforestation could have happened. Since the earliest written sources on mountain grazing and forest use are available only from the early modern period, some historians have speculated that the shepherds' lodges and scattered settlements of the Gilău Mountains appeared very late, mostly in the seventeenth century (Jakó 1944). This hypothesis needs revision, because sedimentary data from Bistra clearly indicates that human activity can be detected as early as the late Middle Ages in the area surrounding Calul de Piatră peat bog (Figure 6).

After a brief review of the available historical data, a fundamental question cannot be avoided: what could have caused the growing intensity of deforestation and alpine shepherding from the sixteenth century onwards? According to the previous discussion, it seems obvious that the fiscal estates of the independent Transylvanian Principality, including the Gilău estate, attempted to maximise the benefits of the mountains (logging, mountain grazing, etc.). In earlier times, the mountains and the forests covering them belonged to the common property of village communities, while the mostly smaller-scale deforestations carried out here became the private property of families, under the usual, not very strict, regulation of the villages concerned. In contrast, the practice of ecclesiastical and secular estates of the late Middle Ages and the early modern period represented a new level of land use in the mountains. The economic leaders of the estates imposed various taxes on the users of the mountains and were interested in increasing these sums of money. Logically, mountain communities sought to produce processed products that were more valuable than harvested timber. In the written documents, we encounter the making of wooden vessels and shingles, the sawing of planks and the burning of coal. As is further detailed in the early modern sources, sawmills processed a lot of wood – in 1652 ash, oak, poplar, linden and maple boards were cut in a sawmill at the northeast foot of the Apuseni Mountains (Jakó 1944, 114). This pre-capitalist practice, which can be traced back to the end of the Middle Ages, led to a more systematic, more organised degradation of forests than before. As for wood, the increasing demand for building timber (beams and sawmill planks) was closely related to the construction of larger townhouses with wooden ceilings and high-pitched roofs according to the Renaissance cityscape, and to the numerous fortifications of this stormy historical period, as well as to the proliferation of multiroom rural houses with plank ceilings, heated by tiled stoves (Marcu Istrate 2004). The demand for timber (beams, planks) was undoubtedly increased by the Turkish Tatar predatory campaigns to Transylvania between 1658 and 1661, during which countless churches were burned and the collapsed vaults were replaced with painted wooden ceilings (Kovács 2003). There were also climatic reasons behind the changing construction, but we must consider the consequences of growing populations and growing civilian demands, too. In addition, there was a growing need for charcoal due to increased processing of iron (hammers, blacksmiths), which significantly promoted coal burning in the mountains. As a result of widespead deforestation, the extent of mountain pastoralism increased, together with long-distance animal trade as well as wool and leather processing to meet extensive urban needs (Wandycz 2001).

The exploitation of the mountains steadily intensified until the nineteenth century. This is clearly supported by evidence from the Gilau estate accounts which shows an increase in the amount of annual rent (AD 1679: 150 guldens; AD 1737: 500 guldens; AD 1746: 700 guldens). At the same time, certain documents inform us about the decline of forests, when a growing number of logs suitable for sawing were transported to the sawmill close to Gilău (Jakó 1944). The increasing exploitation of natural resources was also accompanied by a significant increase in population during the nineteenth century (historical data point 5 on Figure 6). This was particularly the case from AD 1850 and is argued to have been caused by regional migration (Rotariu, Bolovan, and Bolovan 1995). This population growth might be related to the fourth period of deforestation detected in the Calul de Piatră bog.

Many former seasonal shelters had been upgraded to permanent settlements by the early nineteenth century. These mountain settlements form the antecedents of the 34 villages belonging to the present-day municipality of Bistra. These permanent settlements have been mentioned since the 1950s, although their origin is undoubtedly older. The mountain population has been steadily declining since the 1950s and 1960s (Rotariu, Bolovan, and Bolovan 1995).

Climate-driven Subalpine Land use Changes in the Romanian Carpathians?

It is a quite popular opinion that subalpine land use intensified during warm and dry periods and that a reduction/abandonment took place during periods of increasing precipitation in Central Europe, and similar reasoning has been published for the Apuseni Mountains (Feurdean et al. 2011). Nevertheless, it is questionable how crucial the role of climate change has been to the economy of a larger, well-organised society. In the late Middle Ages and early modern times, the extraction of natural benefits was already much more organised than in earlier ages, so the search for analogies in the past can be misleading.

Nevertheless, the macrofossil record from Calul de Piatră peat bog allows direct comparison between the hydroclimatic regime and deforestation periods at the same location (Figure 6). The bog surface wetness studies aimed at understanding past climatic conditions via detailed analysis of peatland deposits have primarily focused on the investigation of *Sphagnum* peats of ombrotrophic peatlands (Barber and Charman 2005; Barber and Langdon 2001). Climatic conditions favouring the development of this type of peatland are mainly restricted to the western parts of Europe under oceanic climatic influence (Barber and Charman 2005; Barber and Langdon 2007) or in Fennoscandia (Väliranta et al. 2007), where the moisture gradient is unambiguously reflected in the distribution of certain *Sphagnum* taxa. According to Charman (2007), the moisture gradient of peatlands is controlled by summer precipitation in the Atlantic part of Europe, but by summer temperatures in the continental part of Europe. Bog surface wetness records are available for the Eastern Carpathians (Diaconu et al. 2020; Feurdean et al. 2015; Schnitchen et al. 2006). The concentration of *Sphagnum* is consistently high in the sequence from Calul de Piatră peat bog, due to the humid subalpine climate, and decreases in only a few cases (Figure 3), which is similar to the western Rodna Mountains (Feurdean et al. 2015). However, the effect of drier periods is clear, and several periods corresponding to dry bog surfaces have been detected over the past 1500 years. The retreat of *Sphagnum* in the mountain zone can be interpreted as an extension of the continental climate, provided that it was not caused by man-made drainage (Jakab and Sümegi 2011b).

Based on the macrofossil analysis, three conspicuous arid periods were identified, but the wetter periods are also interrupted by several short drought events (Figure 6). The first arid period developed between AD 810 and 850, which coincides with the first major deforestation revealed by the pollen analysis (historical data point 1 on Figure 6). The macrofossil investigation shows that, in the first half of the ninth century, an arid period developed in the area to such an extent that it left a definite mark even in the fundamentally rainy subalpine belt. Supporting the regional dry conditions in this period, independent evidence shows a pronounced drop in autumn/winter precipitation in the early ninth century (Warken et al. 2018), partially overlapping with the most persistent summer drought conditions reconstructed, which lasted from the AD 830s to 900 (Cook et al. 2015).

Could the remarkable drop in winter precipitation and the subsequent long-lasting severe drought have caused the more intensive use of natural resources and therefore forest decline in this period? The decrease of *Fagus* and *Abies* in the pollen record was episodic and suggested human impact at lower elevations, not in the subalpine zone. Since the decrease in the proportion of *Fagus* pollen coincides with the detected dry period, it is conceivable that the climate is also responsible for the decline of *Fagus*. However, according to twentieth century observations in *Fagus* forests in Romania, the dry climate has only affected populations at low altitudes (Budeanu et al. 2016). Consequently, in this montane environment in the ninth century, we can reject the rapid transformation of forest stands due to climate.

Historical documents do not provide sufficient information on the social and economic reasons for the Bulgarian expansion, which took place during this time period in Transylvania. It can be stated that this change coincides with a dry period in the early ninth century and deforestation in subalpine areas (Figure 6). Nevertheless, warmer conditions in the subalpine environment would have been more favourable for arable and pastoral farming and thus would have helped to facilitate an expansion in farming. Furthermore, in the absence of archaeological finds it cannot be revealed what ethnic group carried out the deforestation in the subalpine zone, but, using a later analogy, the population living in the valleys may have been responsible for the subalpine landscape transformation.

Nevertheless, we cannot ignore that the reason for the early ninth century collapse of the Avar Empire, which ruled the central part of the Carpathian Basin, has long been the subject of scientific debate (Györffy 1995; Györffy and Zólyomi 1996) and climatic causes are often the first explanations (Preiser-Kapeller 2018; Rácz 1995; Vadas and Rácz 2013). On the basis of the macrofossil investigation of Calul de Piatră peat bog, the development of a dry period lasting several decades can indeed be assumed to have occurred in the ninth century, which of course does not exclude the possibility that the fall of the Avar Empire may have had other causes, not climatic but social or political (Preiser-Kapeller 2018).

From the middle of the ninth century to the middle of the twelfth century, palaeobotanical data suggest somewhat wetter mire conditions, interrupted by several short drought events. This is approximately consistent with the paleoclimate pattern reconstructed for the western Rodna Mountains (Feurdean et al. 2015) from the peat bog surface wetness studies. Diaconu et al. (2020) revealed wet periods between AD 1050 and 1300 in a peat bog in the Eastern Carpathians. From the middle of the ninth century, two short episodes of decrease in *Sphagnum* at AD ~1070s and 1160s are interpreted as aridification. Both episodes coincided with remarkable summer droughts and the later one was also accompanied by a drop in winter precipitation in this region (Figure 6). These drought episodes enclose the second period of drop in arboreal pollen and increase in herbs and shrubs (such as *Corylus* and *Vaccinium*) which can be interpreted as a deforestation (AD 1060–1170) (Figure 6). The sudden increase in Ti in the geochemical record of Lake Ighiel at AD ~1120s (Haliuc et al. 2017) points to increased erosion at the Ighiel watershed at this time, suggesting a regional deforestation in the early twelfth century in the Apuseni Mountains region. Nonetheless, the regional deforestation period and the short drought events do not coincide completely. Thus the causal link between drought and deforestation is far from obvious compared with the first period of deforestation. In the Cioumadul Mountains (Figure 1), the first clear sign of episodic forest clearance around Lake St Anne also dates to AD 1000–1100, when beech and hornbeam were selectively cut and the lake shore was used for grazing (Magyari et al. 2009). The timing of these changes is remarkably coincidental.

The second arid period developed between AD 1130 and 1400, although the beginning of this period is uncertain due to the hiatus. This is the most severe drought in the studied section: *Sphagnum* almost disappeared from the bog. The pause in *Sphagnum* deposition and a period of soil formation is estimated from the early thirteenth century to AD ~1400 and corresponds well with a period of dry mire surfaces between AD 1300 and 1450 from the Rodna Mountains (Feurdean et al. 2015). Based on the bog surface wetness investigation in the Eastern Carpathians, a drying trend was reported from the fourteenth century (Diaconu et al. 2020). Documentary sources often report extreme drought and low water levels in the late fourteenth and early fifteenth centuries in this region (Brázdil et al. 2020; Kiss 2017, 2019a, 2019b; Kiss and Nikolić 2015). Although the beginning of this arid stage overlaps with the end of the deforestation period in the Árpádian period, it was also long-lasting. Therefore, we interpreted it as a period of forest regeneration (Figure 6). Due to the hiatus in the studied record, the reconstruction of the palaeoenvironment around the peat bog is not possible for this time interval.

Following the restart of peat accumulation, a short arid event can be inferred in the early fifteenth century based on the low abundance of *Sphagnum*. The correspondence with the reconstructed lowest 20-year mean autumn/winter precipitation, seen between ~AD 1410 and 1430 at the Cloşani Cave (Figure 6), suggests that the deficit in winter precipitation probably induced the aridification in this period.

Plant macrofossil data indicate dominantly wet surfaces on the bog after AD 1450, which can be explained by the satisfactorily humid climate for the growth of *Sphagnum*. This abundance peak of *Sphagnum* coincides with the wettest reconstructed autumn/winter period (lasting from AD ~1450 to 1510) at the Cloşani Cave (Figure 6), suggesting that the hydrological balance of the bog might have benefited from the increased winter precipitation. This period also coincides with a remarkable increase in the frequency of reported flooding of the Danube and its tributaries across the medieval Hungarian Kingdom (Kiss 2019a, 2019b), supporting the existence of a relatively wetter period in the broader surroundings. The relatively high abundance of *Sphagnum* from the beginning of the sixteenth and middle part of the seventeenth centuries corresponds to a period of decreased winter precipitation. However, the reconstructed summer hydroclimate shows average or slightly wet conditions. So, the increase in *Sphagnum* could have been stimulated by the wetter summer conditions. Two short dry spells could, however, be tentatively marked at AD 1570 and 1730 in the Calul de Piatră sequence. Considering the chronological uncertainty (Figure 2), these dry spells could correspond to the warm summers around 1500 and the 1720s that have been observed in multiple annually resolved summer temperature reconstructions from the Carpathian region (Kern et al. 2016). The smaller drop in *Sphagnum* abundance at these times can be interpreted as aridification at Calul de Piatră peat bog, although the regional hydroclimate proxies could not provide climatological explanation for this process (Figure 6). Anyway, these dry events were episodic and the relationship with the continuous deforestation is not clear.

Therefore, from the fifteenth to the twentieth century we can reconstruct wetter bog surfaces from Calul de Piatră peat bog, which were interrupted by a few short drought events. The third deforestation period, beginning in the late Middle Ages and gradually intensifying in the early modern period, developed at a time of variable hydroclimate, contradicting theories that highlight the stimulating effect of warm/dry climate on mountain pastoralism. This pastoralism is clearly linked to the Romanian population in historical documents.

In the uppermost part of the section, between AD 1920 and 2016, the reduced amount of *Sphagnum* remains seemingly indicates intensifying peat surface aridity. Mire surface conditions in the Rodna Mountains have dried markedly since AD 1960, mainly as a result of anthropogenic climate change, and are approaching the driest conditions seen over the past 1000 years (Feurdean et al. 2015). However, the decrease in *Sphagnum* cannot be explained by drought alone. Experimental studies suggest that a number of *Sphagnum* species are sensitive to sulphur and nitrogen pollutants (Bayley et al. 1987; Ferguson, Lee, and Bell 1978), as released into the atmosphere in large quantities in the twentieth century.

Conclusions

The palaeoecological study of Calul de Piatră peat bog revealed the climate and land use history of the past 1500 years in the subalpine zone of the Apuseni Mountains. A combination of historical sources and palaeoecological data provided evidence demonstrating that significant phases of deforestation usually coincide with some social and political change, such as the construction of new centres of power, economic and cultural development, demographic growth or ethnic change: (1) In the ninth century, the expansion of the Bulgarian Empire; (2) in the eleventh century, the establishment of the state and ecclesiastical centres of the feudal Kingdom of Hungary; (3) in the sixteenth century; and (4) the eighteenth century onwards, when population growth and economic development were the causes of deforestation and the consequent subalpine shepherding. Only the deforestation phase during the Bulgarian expansion in the ninth century coincides undoubtedly with a climatically dry and warm period. These results clearly show that the increase in deforestation (especially in the sixteenth century) was most significant when a strong central power sought to maximise the exploitation of natural resources in subalpine areas. Economic growth, the development of settlements and the growth of the population have made the extraction of these resources continuous. Medieval land use became even more intense when a community adapted to mountain shepherding appeared in the subalpine zone.

The warmer or drier climate could stimulate the spread of alpine grazing and the related deforestation. In the ninth century, drought and deforestation occur at the same time, but this is mainly connected to local effects (e.g. selective use of timber) based on the observed arboreal pollen decline. In the later centuries, the most significant deforestation started in a period of variable hydroclimate during the late Middle Ages, so we can say that grazing and deforestation can be connected to a drier climate.

The beginnings of this process of burgeoning subalpine land use are not illuminated by the scarce written sources, so the scientific data emerging from the sedimentary archive are of key importance. It is hardly necessary to emphasise that, besides the paleoecological results, the historical and archaeological data are indispensable for the interpretation of the former. The multidisciplinary approach could identify that, in addition to the undoubted detectable climatic effects, key drivers of habitat change in the period from the late fifteenth century to the second half of the sixteenth century might have been the new needs of a rapidly transforming Renaissance society, expressed in the developing built environment and the more intense and complex associated economic activity.

Disclosure Statement

No potential conflict of interest was reported by the authors.

Funding

This study was supported by the Hungarian Scientific Research Fund [grant number OTKA NF 112318] and by the GINOP-2.3.2-15-2016-00019 project.

Notes on contributors

Gusztáv Jakab is an associate professor in the Institute of Environmental Sciences, Hungarian University of Agriculture and Life Sciences. His interest focuses on the vegetation development of the Quaternary period.

Ilona Pál has a scholarship in the Savaria University Centre (Eötvös Loránd University). Her research interests include Quaternary Palynology and Holocene climate anomalies, and she uses pollen analysis to reveal significant vegetation compositional changes which can be connected to these anomalies.

Lóránd Silye is a lecturer at the Department of Geology, Babeş-Bolyai University, Cluj-Napoca, Romania. He is involved in various research projects targeting the reconstruction of palaeoenvironments based on foraminiferal proxies.

Pál Sümegi is a full professor in the Department of Geology and Palaeontology at Szeged University. His interest focuses on the environment development of the Quaternary period.

Attila Tóth is a lecturer at the Sapientia Hungarian University of Transylvania Environmental Science Department. His main field of research is the geography of Transylvania.

Balázs Sümegi is a contractual research engineer at the Laboratory of Environmental Studies, Institute of Nuclear Research of the Hungarian Academy of Sciences. He specialises in the sedimentological development of the Quaternary period.

József Pál Frink is a researcher at the "Marin Drăcea" National Institute for Research and Development in Forestry. His main field of research is the recent vegetation of Transylvania.

Enikő Katalin Magyari is a full professor in the Department of Environmental and Landscape Geography, Eötvös Loránd University. Her main field of research is the vegatation and climate development of the Quaternary period.

Zoltán Kern is a researcher at the Institute for Geological and Geochemical Research, Research Centre for Astronomy and Earth Science, MTA Centre for Excellence. His interest focuses on the geochemical research of Quaternary sediments.

Elek Benkő is director at the HAS Research Centre for the Humanities Institute of Archaeology. He specialises in Medieval history and archaeology. He is the leader of the project called 'Environmental history of the Carpathian Basin in the Middle Ages'.

ORCID

Gusztáv Jakab http://orcid.org/0000-0002-2569-5967

References

Andronic, M., and B. P. Niculică. 2012. "The Occurrence and Evolution of Human habitat in the Carpathian Area of the Southern Part of Historical Bukovine (Suceava County, Romania)." *Fortecja. Zbirnyk zapovidnyka, Tustan* 2: 254–271.

Árvai, M. 2019. "Holtfaanyag évgyűrűvizsgálatával nyert információk környezettörténeti szempontú értelmezése egy hegyvidéki és egy alluviális lelőhely példáján" [Environmental-Historical Interpretation of Information Obtained from the Annual Ring Study of Dead Wood on the Example of a Mountainous and an Alluvial Site.] PhD diss., Eötvös University.

Árvai, M., I. Popa, M. Mîndrescu, B. Nagy, and Z. Kern. 2016. "Dendrochronology and Radiocarbon Dating of Subfossil Conifer Logs Excavated from a Peat Bog, Maramureş Mts, Romania." *Quaternary International* 415: 6–14.

Balintoni, I., C. Balica, M. Cliveţi, L.-Q. Li, H.-P. Hann, F. Cheng, and V. Schuller. 2009. "The Emplacement Age of the Muntele Mare Variscan granite (Apuseni Mountains, Romania)." *Geologica Carpathica* 60 (6): 495–504.

Barber, K. E., F. M. Chambers, D. Maddy, and J. Brew. 1994. "A Sensitive High Resolution Record of the Holocene Climatic Change from a Raised Bog in Northern England." *The Holocene* 4: 198–205.

Barber, K. E., and D. Charman. 2005. "Holocene Palaeoclimate Records from Peatlands." In *Global Change in the Holocene*, edited by A. Mackay, R. Battarbee, J. Birks, and F. Oldfield, 210–226. London: Hodder Arnold.

Barber, K. E., and P. G. Langdon. 2001. "Peat Stratigraphy and Climate Change." In *Handbook of Archaeological Sciences*, edited by D. R. Brothwell, and A. M. Pollard, 155–166. Chicester: Wiley.

Barber, K. E., and P. G. Langdon. 2007. "What Drives the Peat-Based Palaeoclimate Record? A Critical Test Using Multi-Proxy Climate Records from Nothern Britain." *Quaternary Science Reviews* 26: 3318–3327.

Bărbulescu, C., and G. H. Motcă. 1983. *Păşunile munţilor înalţi* [The Pastures of the High Mountains]. Bucureşti: Editura Ceres.

Bartosiewicz, L., and H. J. Greenfield, eds. 1999. *Transhumant Pastoralism in Southern Europe. Recent Perspectives from Archaeology, History and Ethnology.* Budapest: Archaeolingua.

Baur, B., C. Cremene, G. Groza, A. Schileyko, A. Baur, and A. Erhardt. 2007. "Intensified Grazing Affects Endemic Plant and Gastropod Diversity in Alpine Grasslands of the Southern Carpathian Mountains (Romania)." *Biologia* 62 (4): 438–445.

Bayley, S. E., D. H. Vitt, R. W. Newbury, K. G. Beaty, R. Behr, and C. Miller. 1987. "Experimental Acidification of a Sphagnum-Dominated Peatland: First Year Results." *Canadian Journal of Fisheries and Aquatic Sciences* 44 (1): 194–205.

Beck, J., H. Ciugudean, and C. P. Quinn. 2020. "Bioarchaeology and Mountain Landscapes in Transylvania's Golden Quadrangle." *Bioarchaeology International* 4: 89–110.
Behre, K.-E. 1981. "The Interpretation of Anthropogenic Indicators in Pollen Diagrams." *Pollen et Spores* 23: 225–245.
Bell, J. N. B., and J. H. Tallis. 1973. "Biological flora of the British Isles. Empetrum nigrum L." *The Journal of Ecology* 61 (1): 289–305.
Benkő, E. 2000a. "Karlsburg (Gyulafehérvár, Alba Iulia)." In *Europas Mitte um 1000*, edited by A. Wieczorek, and H.-M. Hinz, 593–596. Stuttgart: Konrad Theiss Verlag.
Benkő, E. 2000b. "Mănăştur (Kolozsmonostor) bei Klausenburg." In *Europas Mitte um 1000*, edited by A. Wieczorek, and H.-M. Hinz, 597–599. Stuttgart: Konrad Theiss Verlag.
Bennett, K. D. 1994. "Confidence Intervals for Age Estimates and Deposition Times in Late-Quaternary Sediment Sequences." *The Holocene* 4: 337–348.
Bennett, K. D. 1996. "Determination of the Number of Zones in a Biostratigraphical Sequence." *New Phytologist* 132: 155–170.
Bennett, K. D. 2007. *Psimpoll 4.27*. http://chrono.qub.ac.uk/psimpoll/psimpoll.html.
Bennett, K. D., and K. J. Willis. 2001. "Pollen." In *Tracking Environmental Change Using Lake Sediments*, edited by J. P. Smol, H. J. B. Birks, W. M. Last, R. S. Bradley, and K. Alverson, 5–30. Dordrecht, The Netherlands: Kluwer Academic Publishers.
Berglund, B. E. 2000. "The Ystad Project–A Case Study for Multidisciplinary Research on Long-Term Human Impact." *PAGES News* 8 (3): 6–7.
Beug, H. J. 1982. "Vegetation History and Climatic Changes in Central and Southern Europe." In *Climatic Change in Later Prehistory*, edited by A. F. Harding, 85–102. Edinburgh: Edingburgh University Press.
Birks, H. H. 2001. "Plant Macrofossils." In *Tracking Environmental Change Using Lake Sediments. Volume 3: Terrestrial, Algal, and Siliceous Indicators*, edited by J. P. Smol, H. J. B. Birks, and W. M. Last, 49–74. Dordrecht: Kluwer Academic Publishers.
Blaauw, M., and J. A. Christen. 2011. "Flexible Paleoclimate Age-Depth Models Using an Autoregressive Gamma Process." *Bayesian Analysis* 6: 457–474.
Bobînă, B. 2015. "Mountain Archaeology in Romania: The Status of Research." *Terra Sebus* 7: 149–164.
Bodnariuc, A., A. Bouchette, J. J. Dedoubat, T. Otto, M. Fountugne, and G. Jalut. 2002. "Holocene Vegetational History of the Apuseni Mountains, Central Romania." *Quaternary Science Reviews* 21: 1465–1488.
Bogdan, O. 1983. "Regiunile climatice și topoclimatele" [Climatic Regions and Topoclimates.] In *Geografia României. Vol. 1: Geografia fizică* [Geography of Romania], edited by L. Badea, P. Gâștescu, and V. A. Velcea, 277–279. Bucureşti: Editura Academiei Republicii Socialiste România.
Bojnanský, V., and A. Fargašová. 2007. *Atlas of Seeds and Fruits of Central and East-European Flora. The Carpathian Mountains Region*. Dordrecht: Springer.
Bóna, I. 1990. "Siebenbürgen im frühen ungarischen Königreich." In *Kurze Geschichte Siebenbürgens*, edited by B. Köpeczi, 137–174. Budapest: Akadémiai Kiadó.
Bóna, I. 2001. "Southern Transylvania under Bulgar Rule." In *History of Transylvania I*, edited by L. Makkai, and A. Mócsy, 246–264. New York: Columbia University Press.
Brázdil, R., A. Kiss, L. Řezníčková, and M. Barriendos. 2020. "Droughts in Historical Times in Europe, as Derived from Documentary Evidence." In *Palaeohydrology*, edited by J. Herget, and A. Fontana, 65–96. Cham: Springer.
Brewer, S., J. W. Williams, P. Tarasov, and B. A. S. Davis. 2008. "Changes in European Tree Cover During the Holocene Based on Pollen and AVHRR Data." *Terra Nostra* 2: 37–38.
Budeanu, M., A. M. Petritan, F. Popescu, D. Vasile, and N. C. Tudose. 2016. "The Resistance of European Beech (Fagus sylvatica) from the Eastern Natural Limit of Species to Climate Change." *Notulae Botanicae Horti Agrobotanici Cluj-Napoca* 44 (2): 625–633.
Carter, V. A., P. Bobek, A. Moravcová, A. Šolcová, R. C. Chiverrell, J. L. Clear, W. Finsinger, et al. 2020. "The Role of Climate-Fuel Feedbacks on Holocene Biomass Burning in Upper-Montane Carpathian Forests." *Global and Planetary Change* 193: 103264.
Charman, D. J.. 2007. "Summer Water Deficit Controls on Peatland Water Table Changes: Implications for Holocene Palaeoclimate Reconstructions." *The Holocene* 17 (2): 217–227.
Coldea, G. 2003. "The Alpine Flora and Vegetation of the South-Eastern Carpathians." *Ecological Studies* 1 (167): 65–72.
Coldea, G., and V. Cristea. 1998. "Floristic and Community Diversity of Sub-Alpine and Alpine Grasslands and Grazed Dwarf-Shrub Heaths in the Romanian Carpathians." *Pirineos* 151-152: 73–82.
Cook, E. R., R. Seager, Y. Kushnir, K. R. Briffa, U. Büntgen, D. Frank, P. J. Krusic, et al. 2015. "Old World Megadroughts and Pluvials During the Common Era." *Science Advances* 1: E1500561. doi:10.1126/sciadv.1500561.
Cordova, C. E., and P. H. Lehman. 2005. "Holocene Environmental Change in Southwestern Crimea (Ukraine) in Pollen and Soil Records." *The Holocene* 15 (2): 263–277.
Cosma, C. 2016. "Notes on the Economy Structure in Crişana, Sătmar and Maramureş During the 8th–10th Centuries AD." *Banatica* 26: 169–191.
Cosma, C., and A. Gudea. 2002. "Habitat und Gesellschaft im Westen und Nordwesten Rumäniens in den 8.-10. Jahrhunderten n. Chr." *Napoca Star* 2: 163.
Coupland, R. T., ed. 1979. *Grassland Ecosystems of the World: Analysis of Grasslands and Their Uses (Vol. 18)*. Cambridge: Cambridge University Press.
Csánki, D. 1913. *Magyarország történelmi földrajza a Hunyadiak korában* [The Historical Geography of Hungary in the Time of the Hunyadians]. Budapest: Magyar Tudományos Akadémia.
Daniels, R. E., and A. Eddy. 1985. *Handbook of European Sphagna*. Wareham: Natural Environment Research Council. Institute of Terrestrial Ecology.
Darby, H. C. 1956. "The Clearing of the Woodland in Europe." In *Man's Role in Changing the Face of the Earth*, edited by W. L. Thomas Jr, 183–216. University of Chicago Press.
Davies, S., H. Lamb, and S. Roberts. 2015. "Micro-XRF Core Scanning in Palaeolimnology: Recent Developments." In *Micro-XRF Studies of Sediment Cores. Developments in Paleoenvironmental Research, 17*, edited by I. Croudace, and R. Rothwell. Dordrecht: Springer. doi:10.1007/978-94-017-9849-5_7.
Dearing, J. A. 2006. "Climate-Human-Environment Interactions: Resolving our Past." *Climate of the Past* 2: 187–203.

De Vleeschouwer, F., F. M. Chambers, and G. T. Swindles. 2010. "Coring and Sub-Sampling of Peatlands for Palaeo Environmental Research." *Mires and Peat* 7: 1–10.

Deza-Araujo, M., C. Morales-Molino, W. Tinner, P. D. Henne, C. Heitz, G. B. Pezzatti, A. Hafner, and M. Conedera. 2020. "A Critical Assessment of Human-Impact Indices Based on Anthropogenic Pollen Indicators." *Quaternary Science Reviews* 236: 106291.

Diaconu, A. C., I. Tanţău, K. H. Knorr, W. Borken, A. Feurdean, A. Panait, and M. Gałka. 2020. "A Multi-Proxy Analysis of Hydroclimate Trends in an Ombrotrophic Bog Over the Last Millennium in the Eastern Carpathians of Romania." *Palaeogeography, Palaeoclimatology, Palaeoecology* 538: 109390.

Dolek, M., and A. Geyer. 2002. "Conserving Biodiversity on Calcareous Grasslands in the Franconian Jura by Grazing: a Comprehensive Approach." *Biological Conservation* 104 (3): 351–360.

Dragoman, Al, D. Pop, B. Bobînă, M. Ardeleanu, C. Şuteu, and C. Astaloş. 2018. "An Archaeology of the Mountains in Maramureş, Romania: The Beginning of a Long-Term Project, People in the Mountains. Current Approaches to the Archaeology of Mountainous Landscapes." In *Archaeopress Archaeology*, edited by A. Pelisiak, M. Nowak, and C. Astaloş, 61–78. Oxford: Archaeopress.

Fărcaş, S., I. Tanţău, A. Bodnariuc, and A. Feurdean. 2007. "L'histoire des forets et du paléoclimat Holocène dans les Monts Apuseni." *Contribuţii Botanice* 42: 115–126.

Ferguson, P., J. A. Lee, and J. N. B. Bell. 1978. "Effects of Sulphur Pollutants on the Growth of Sphagnum Species." *Environmental Pollution (1970)* 16 (2): 151–162.

Feurdean, A., M. Galka, E. Kuske, I. Tanţău, M. Lamentowicz, G. Florescu, and T. Hickler. 2015. "Last Millennium Hydro-Climate Variability in Central–Eastern Europe (Northern Carpathians, Romania)." *The Holocene* 25 (7): 1179–1192.

Feurdean, A., A. Perşoiu, A. Pazdur, and B. P. Onac. 2011. "Evaluating the Palaeoecological Potential of Pollen Recovered from ice in Caves: A Case Study from Scărişoara Ice Cave, Romania." *Review of Palaeobotany and Palynology* 165 (1-2): 1–10.

Feurdean, A., A. Spessa, E. K. Magyari, K. J. Willis, D. Veres, and T. Hickler. 2012. "Trends in Biomass Burning in the Carpathian Region Over the Last 15,000 Years." *Quaternary Science Reviews* 45: 111–125.

Feurdean, A., and K. J. Willis. 2008a. "The Usefulness of a Long-Term Perspective in Assessing Current Forest Conservation Management in the Apuseni Natural Park, Romania." *Forest Ecology and Management* 256: 421–430.

Feurdean, A., and K. J. Willis. 2008b. "Long-term Variability of Abies alba (Mill.) Populations in the NW Romanian Forests - Implications for its Conservation Management." *Diversity and Distributions* 14: 1004–1017.

Feurdean, A., K. J. Willis, and C. Astaloş. 2009. "Legacy of the Past Land Use Changes and Management on the 'Natural' Upland Forests Composition in the Apuseni Natural Park, Romania." *The Holocene* 19: 967–981.

Fiedler, U. 2008. "Bulgars in the Lower Danube Region. A Survey of the Archaeological Evidence and of the State of Current Research." In *The Other Europe in the Middle Ages*, edited by F. Curta, 151–236. Cambridge: Brill.

Finsinger, W., and W. Tinner. 2019. "New Insights on Stomata Analysis of European Conifers 65 Years after the Pioneering Study of Werner Trautmann (1953)." *Vegetation History and Archaeobotany* 29: 393–406.

Frink, J. P. 2009. "Overview of the Semi-Natural Grassland Communities from the Middle and Lower Arieş River Valley. Syntaxonomical Checklist." *Transylvanian Review of Systematical and Ecological Research* 7: 29–40.

Frink, J. P. 2010. *Pajiştile de pe Valea Arieşului între Lupşa şi Turda: structură, ecologie, folosinţă durabilă* [The Meadows on the Arieş Valley between Lupşa and Turda: Structure, Ecology, Sustainable Use]. Cluj-Napoca: Presa Universitară Clujeană.

Gaillard, M. J. 2007. "Detecting Human Impact in the Pollen Record." In *Encyclopedia of Quaternary Science*, edited by S. A. Elias, 2570–2595. London: Elsevier, University of London.

Gaillard, M. J., K. D. Morrison, M. Madella, and N. Whitehouse. 2018. "Past Land-use and Land-Cover Change: the Challenge of Quantification at the Subcontinental to Global Scales." *Past Land Use and Land Cover* 26 (3): 8–9.

Gałka, M., G. Miotk-Szpiganowicz, T. Goslar, M. Jęśko, W. O. van der Knaap, and M. Lamentowicz. 2013. "Palaeohydrology, Fires and Vegetation Succession in the Southern Baltic During the Last 7500years Reconstructed from a Raised bog Based on Multi-Proxy Data." *Palaeogeography, Palaeoclimatology, Palaeoecology* 370: 209–221.

Gałka, M., I. Tanţău, V. Ersek, and A. Feurdean. 2016. "A 9000 Year Record of Cyclic Vegetation Changes Identified in a Montane Peatland Deposit Located in the Eastern Carpathians (Central-Eastern Europe): Autogenic Succession or Regional Climatic Influences?" *Palaeogeography, Palaeoclimatology, Palaeoecology* 449: 52–61.

Gałka, M., I. Tanţău, and A. Feurdean. 2017. "Plant Succession in a Peatland in the Eastern Carpathian Mts.(CE Europe) During the Last 10,200 Years: Implications for Peatland Development and Palaeoclimatic Research." *Review of Palaeobotany and Palynology* 244: 203–216.

Gałka, M., K. Tobolski, A. Górska, K. Milecka, B. Fiałkiewicz-Kozieł, and M. Lamentowicz. 2014. "Disentangling the Drivers for the Development of a Baltic bog During the Little Ice Age in Northern Poland." *Quaternary International* 328-329: 323–337.

Geanana, M. 1991. "The Influence of Geographical Position on the Upper Tree Line in the Romanian Carpathians." *Studia Universitatis Babeş-Bolyai: Geographia* 40-41: 61–63.

Geantă, A., M. Gałka, I. Tanţău, S. M. Hutchinson, M. Mîndrescu, and A. Feurdean. 2014. "High Mountain Region of the Northern Romanian Carpathians Responded Sensitively to Holocene Climate and Land use Changes: a Multi-Proxy Analysis." *The Holocene* 24 (8): 944–956.

Grigulis, K., S. Lavorel, U. Krainer, N. Legay, C. Baxendale, M. Dumont, E. Kastl, et al. 2013. "Relative Contributions of Plant Traits and Soil Microbial Properties to Mountain Grassland Ecosystem Services." *Journal of Ecology* 101 (1): 47–57.

Györffy, G. 1987. *Az Árpád-kori Magyarország történeti földrajza. Geographia historica Hungariae tempore stirpis Arpadianae. II–III*. Budapest: Akadémiai Kiadó.

Györffy, G. 1995. "Hová lettek az avarok? [Where the Avars Diappeared?]." *História* 17: 3–9.

Györffy, G., and B. Zólyomi. 1996. "A Kárpát-medence és Etelköz képe egy évezred elõtt [The Landscape of the

Carpathian Basin and the Etelköz a Thousand Year Ago].” *Magyar Tudomány* 8: 899.
Habel, J. C., J. Dengler, M. Janišová, P. Török, C. Wellstein, and M. Wiezik. 2013. “European Grassland Ecosystems: Threatened Hotspots of Biodiversity.” *Biodiversity and Conservation* 22: 2131–2138.
Hájková, P., J. Roleček, M. Hajek, M. Horsák, K. Fajmon, M. Polák, and E. Jamrichova. 2011. “Prehistoric Origin of the Extremely Species-Rich Semi-dry Grasslands in the Bílé Karpaty Mts (Czech Republic and Slovakia).” *Preslia* 83 (2): 185–204.
Haliuc, A., D. Veres, A. Brauer, K. Hubay, S. M. Hutchinson, R. Begy, and M. Braun. 2017. “Palaeohydrological Changes During the mid and Late Holocene in the Carpathian Area, Central-Eastern Europe.” *Global and Planetary Change* 152: 99–114.
Huband, S., D. I. McCracken, and A. Mertens. 2010. “Long and Short-Distance Transhumant Pastoralism in Romania: Past and Present Drivers of Change.” *Pastoralism* 1 (1): 55–71.
Hughes, J. D., and J. Thirgood. 1982. “Deforestation, Erosion, and Forest Management in Ancient Greece and Rome.” *Journal of Forest History* 26 (2): 60–75.
Isselstein, J., B. Jeangros, and V. Pavlu. 2005. “Agronomic Aspects of Biodiversity Targeted Management of Temperate Grasslands in Europe–a Review.” *Agronomy Research* 3 (2): 139–151.
Jakab, G., and P. Sümegi. 2011a. “The Role of Bryophyte Paleoecology in Quaternary Climate Reconstructions.” In *Bryophyte Ecology and Climate Change*, edited by Z. Tuba, N. G. Slack, and L. R. Stark, 335–358. Cambridge: Cambridge University Press.
Jakab, G., and P. Sümegi. 2011b. *Negyedidőszaki makrobotanika* [Quaternary Macrobotany]. Szeged: Geolitera.
Jakab, G., P. Sümegi, and E. Magyari. 2004. “A New Palaeobotanical Method for the Description of Late Quaternary Organic Sediments (Mire-Development Pathways and Palaeoclimatic Records from S Hungary).” *Acta Geologica Hungarica* 47: 373–409.
Jakó, Zs. 1944. *A gyalui vártartomány urbáriumai* [Urbaria of the Gilău Castle Estate]. Kolozsvár: Pécsi Egyetemi Könyvkiadó és Nyomda.
Jakó, Zs. 1997. *Erdélyi Oklevéltár. Codex Diplomaticus Transsylvaniae. I.* Budapest: Akadémiai Kiadó.
Jakó, Zs. 2004. *Erdélyi Oklevéltár. Codex Diplomaticus Transsylvaniae. II.* Budapest: Magyar Országos Levéltár.
Juler, C. 2014. “După coada oilor: Long-Distance Transhumance and its Survival in Romania.” *Pastoralism: Research, Policy and Practice* 4 (1): 4.
Kampmann, D., F. Herzog, P. Jeanneret, W. Konold, M. Peter, T. Walter, O. Wildi, and A. Lüscher. 2008. “Mountain Grassland Biodiversity: Impact of Site Conditions Versus Management Type.” *Journal for Nature Conservation* 16 (1): 12–25.
Kaplan, J. O., K. M. Krumhardt, and N. Zimmermann. 2009. “The Prehistoric and Preindustrial Deforestation of Europe.” *Quaternary Science Reviews* 28 (27-28): 3016–3034.
Katz, N. J., S. V. Katz, and M. G. Kipiani. 1965. *Atlas and Keys of Fruits and Seeds Occurring in the Quaternary Deposits of the USSR*. Moscow: Nauka.
Kern, Z., A. Németh, M. Horoszné Gulyás, I. Popa, T. Levanic, and I. G. Hatvani. 2016. “Natural Proxy Records of Annual Temperature- and Hydroclimate Variability from the Carpathian-Balkan Region for the Past Millennium: Review & Recalibration.” *Quaternary International* 415: 109–125. doi:10.1016/j.quaint.2016.01.012.
Kienlin, T. L., and P. Valde-Nowac. 2004. “Neolithic Transhumance in the Black Forest Mountains, SW Germany.” *Journal of Field Archaeology* 29 (1–2): 29–44.
Kiss, A. 2017. “Droughts and Low Water Levels in Late Medieval Hungary II: 1361, 1439, 1443-4, 1455, 1473, 1480, 1482 (?), 1502-3, 1506: Documentary Versus Tree-Ring (OWDA) Evidence.” *Journal of Environmental Geography* 10 (3-4): 43–56.
Kiss, A. 2019a. “Droughts, Dry Spells and Low Water Levels in Late Medieval Hungary (and Slavonia) III: Potential Dry Spells and the Drought of (1516-) 1517.” *Journal of Environmental Geography* 12 (3-4): 53–67.
Kiss, A. 2019b. *Floods and Long-Term Water-Level Changes in Medieval Hungary*. Cham: Springer, 139–243.
Kiss, A., and Z. Nikolić. 2015. “Droughts, Dry Spells and Low Water Levels in Medieval Hungary (and Croatia) I: The Great Droughts of 1362, 1474, 1479, 1494 and 1507.” *Journal of Environmental Geography* 8 (1-2): 11–22.
Kleijn, D., M. Rundlöf, J. Scheper, H. G. Smith, and T. Tscharntke. 2011. “Does Conservation on Farmland Contribute to Halting the Biodiversity Decline?” *Trends in Ecology & Evolution* 26 (9): 474–481.
Kovács, A. 2003. *Késő reneszánsz építészet Erdélyben* [Late Renaissance Transylvanian Architecture]. Budapest-Kolozsvár: Teleki László Alapítvány, Polis Könyvkiadó.
Kuneš, P., P. Pokorný, and P. Šída. 2008. “Detection of the Impact of Early Holocene Hunter-Gatherers on Vegetation in the Czech Republic, Using Multivariate Analysis of Pollen Data.” *Vegetation History and Archaeobotany* 17: 269–287.
Lavoie, C., K. Marcoux, A. Saint-Louis, and J. S. Price. 2005. “The Dynamics of a Cotton-Grass (Eriophorum vaginatum L.) Cover Expansion in a Vacuum-Mined Peatland, Southern Québec, Canada.” *Wetlands* 25 (1): 64.
Lemaire, G., J. Hodgson, and A. Chabbi, eds. 2011. *Grassland Productivity and Ecosystem Services*. Wallingford: Cabi.
Madgearu, A. 2003. “Salt Trade and Warfare in Early Medieval Transylvania.” *Ephemeris Napocensis* 11: 271–283.
Madgearu, A. 2005. “Transylvania and the Bulgarian Expansion in the 9th and 10th Centuries.” *Acta Musei Napocensis* 39-40 (2): 41–61.
Magyari, E., K. Buczkó, G. Jakab, K. Braun, Z. Pál, D. Karátson, and I. Pap. 2009. “Palaeolimnology of the Last Crater Lake in the Eastern Carpathian Mountains: A Multiproxy Study of Holocene Hydrological Changes.” *Hydrobiologia* 631 (1): 29–63.
Magyari, E. K., J. Chapman, A. S. Fairbairn, M. Francis, and M. De Guzman. 2012a. “Neolithic Human Impact on the Landscapes of North-East Hungary Inferred from Pollen and Settlement Records.” *Vegetation History and Archaeobotany* 21 (4-5): 279–302.
Magyari, E. K., G. Jakab, M. Bálint, Z. Kern, K. Buczkó, and M. Braun. 2012b. “Rapid Vegetation Response to Lateglacial and Early Holocene Climatic Fluctuation in the South Carpathian Mountains (Romania).” *Quaternary Science Reviews* 35: 116–130.
Magyari, E., I. Vincze, I. Orbán, T. Bíró, and I. Pál. 2018. “Timing of Major Forest Compositional Changes and Tree Expansions in the Retezat Mts During the Last 16,000 Years.” *Quaternary International* 477: 40–58.
Mann, M. E., Z. Zhang, S. Rutherford, R. S. Bradley, M. K. Hughes, D. Shindell, C. Ammann, et al. 2009. “Global

Signatures and Dynamical Origins of the Little Ice Age and Medieval Climate Anomaly." *Science* 326 (5957): 1256–1260.

Marcu Istrate, D. 2004. *Cahle din Transilvania și Banat de la începuturi până la 1700* [Tiles from Transylvania and Banat from the Beginning Until 1700]. Cluj-Napoca: Accent.

Matějková, I., R. van Diggelen, and K. Prach. 2003. "An Attempt to Restore a Central European Species Rich Mountain Grassland Through Grazing." *Applied Vegetation Science* 6 (2): 161–168.

Matley, I. M. 1970. "Traditional Pastoral Life In Romania*." *The Professional Geographer* 22: 311–316.

Maxim, Z. 1988–1991. "Cercetările etno-arheologice din Munții Cerna-Vâr." *Sargetia* 21–24: 15–24.

Mertens, A., and S. Huband. 2004. "Romanian Transhumance - the Past, the Present and Future Scenarios." In *Transhumance and Biodiversity in European Mountains*, edited by R. G. H. Bunce, M. Pérez-Soba, R. H. G. Jongman, A. G. Sal, F. Herzog, and I. Austad, 155–170. Wageningen: Alterra.

Messerli, B., and J. D. Ives. 1997. *Mountains of the World*. New York: The Publishing Group.

Michalcová, D., M. Chytrý, V. Pechanec, O. Hájek, J. W. Jongepier, J. Danihelka, V. Grulich, et al. 2014. "High Plant Diversity of Grasslands in a Landscape Context: A Comparison of Contrasting Regions in Central Europe." *Folia Geobotanica* 49 (2): 117–135.

Mihai, B., I. Savulescu, and I. Sandric. 2007. "Change Detection Analysis (1986–2002) of Vegetation Cover in Romania: A Study of Alpine, Subalpine, and Forest Landscapes in the Iezer Mountains, Southern Carpathians." *Mountain Research and Development* 27 (3): 250–258.

Moga, V., and H. Ciugudean, eds. 1995. *Repertoriul arheologic al județului Alba* [The Archaeological Repertoire of Alba District]. Alba Iulia: Muzeul Naţional al Unirii.

Moore, P. D., J. A. Webb, and M. E. Collinson. 1991. *Pollen Analysis*. Oxford: Blackwell Scientific Publications.

Nedelea, A., and L. Comănescu. 2009. "Effects of Transhumance on the Southern Slope of the Făgăraş Mountains." *GeoJournal of Tourism and Geosites* 4 (2): 125–132.

Pérez-Soba, M., R. H. Jongman, A. Gómez Sal, F. Herzog, and I. Austad. 2004. *Transhumance and Biodiversity in European Mountains*. Wageningen: Ponsen & Looijen.

Péterfi, L. S., and L. Momeu. 1993–1994. "Comunitățile algale din "Molhaşul de la Calul de Piatră" (M-ții Apuseni)." *Contribuții Botanice* 32: 39–46.

Pilgrim, E. S., C. J. Macleod, M. S. Blackwell, R. Bol, D. V. Hogan, D. R. Chadwick, L. Cardenas, et al. 2010. "Interactions among Agricultural Production and Other Ecosystem Services Delivered from European Temperate Grassland Systems." *Advances in Agronomy* 109: 117–154.

Piotrowska, N., M. Blaauw, D. Mauquoy, and F. M. Chambers. 2011. "Constructing Deposition Chronologies for Peat Deposits Using Radiocarbon Dating." *Mires and Peat* 7 (10): 1–14.

Pop, E. 1939. "Semnalări de tinoave şi de plante de mlaştini din România. II (Angaben über Hochmoore und Moorpflanzen aus Rumänien. II)." *Buletinul Gradinii Botanice si al Muzeului Botanic dela Universitatea din Cluj* 19 (3-4): 109–121.

Pop, E. 1960. *Mlaştinile de turbă din Republica Populară Romînă*. Bucureşti: Editura Academiei R. P. R.

Pop, G. P. 2006. *Carpații și Subcarpații României* [The Carpathians and Subcarpathians of Romania]. Cluj-Napoca: Cluj University Press.

Pop, X., A. Gudea, and A. Damian. 2015. "Archaeozoological Data from the 8th Century Archaeological Diggings Carried out in Iernut (Mureş County)." In *International Zoological Congress of "Grigore Antipa" Museum*, edited by L. O. Popa, A. Costică, G. Chişamera, E. Iorgu, D. Murariu, and O. P. Popa, 147–148. Bucuresti: "Grigore Antipa" Museum.

Popescu, A., and V. Sanda. 1998. "Conspectul florei cormofitelor spontane din România" [The Conspectus of Spontaneous Cormophytes Flora from Romania.] *Acta Botanica Horti Bucurestiensis Suppl.* 3–336.

Poschlod, P., A. Baumann, and P. Karlik. 2009. "Origin and Development of Grasslands in Central Europe." In *Grasslands in Europe*, edited by P. Veen, R. Jefferson, J. de Smidt, and J. van der Straaten, 15–25. Zeist: KNNV Publishing.

Poschlod, P., and M. F. Wallis DeVries. 2002. "The Historical and Socioeconomic Perspective of Calcareous Grasslands-Lessons from the Distant and Recent Past." *Biological Conservation* 104 (3): 361–376.

Preiser-Kapeller, J. 2018. "The Climate of the Khagan. Observations on Palaeo-Environmental Factors of the History of the Avars (6th-9th Century AD)." In *Sonderdruck Monographien des RGZM*, edited by J. Drauschke, E. Kislinger, K. Kühtreiber, T. Kühtreiber, G. Scharrer-Liška, and T. Vida, 311–324. Verlag des Römisch-Germanischen Zentralmuseums.

Price, T. D. 2000. *Europe's First Farmers*. Cambridge: Cambridge University Press.

Rácz, L. 1995. "A Kárpát-medence éghajlattörténete a kora újkor idején (1490-1800). A környezettörténeti források feldolgozásának módszerei" [Climate History of the Carpathian Basin During the Early Modern Period (1490-1800). Methods of Processing Environmental Historical Sources.] *Történelmi Szemle* 4: 487–507.

Reille, M. 1992. *Pollen et spores d'Europe et d'Afrique du Nord*. Marseille: Laboratoire de Botanique Historique et Palynologie.

Reille, M. 1995. *Pollen et spores d'Europe et d'Afrique du Nord. Supplement 1*. Marseille: Laboratoire de Botanique Historique et Palynologie.

Reille, M. 1998. *Pollen et spores d'Europe et d'Afrique du Nord. Supplement 2*. Marseille: Laboratoire de Botanique Historique et Palynologie.

Reimer, P. J., E. Bard, A. Bayliss, J. W. Beck, P. G. Blackwell, C. Bronk-Ramsey, C. E. Buck, et al. 2013. "IntCal13 and MARINE13 Radiocarbon Age Calibration Curves 0-50000 Years calBP." *Radiocarbon* 55: 1869–1887.

Roleček, J., I. I. Čornej, and A. I. Tokarjuk. 2014. "Understanding the Extreme Species Richness of Semi-dry Grasslands in East-Central Europe: A Comparative Approach." *Preslia* 86 (1): 5–27.

Rotariu, T., S. Bolovan, and I. Bolovan. 1995. "Evoluția populației Munților Apuseni." In *Istorie și demografie: Studii privind societatea românească între secolele XVI-XX*, edited by S. Manuilă, 96–112. Cluj-Napoca: Centrul de Studii Transilvane, Fundația Culturală Romă nă.

Salisbury, R. B., G. Bácsmegi, and P. Sümegi. 2013. "Preliminary Environmental Historical Results to Reconstruct Prehistoric Human-Environmental Interactions in Eastern Hungary." *Central European Journal of Geosciences* 5 (3): 331–343.

Sandu, I., V. I. Pescaru, and I. Poiană, eds. 2008. *Clima României* [Romania's Climate]. Bucharest: The Publishing House of the Romanian Academy.

Sârbu, A., G. Coldea, G. Negrean, V. Cristea, J. Hanganu, and P. Veen. 2000. *Grasslands of Romania. Final Report on National Grasslands Inventory 2000-2003*. Bucharest: University of Bucharest.

Schnitchen, C., D. J. Charman, E. Magyari, M. Braun, I. Grigorszky, B. Tóthmérész, and Zs. Szántó. 2006. "Reconstructing Hydrological Variability from Testate Amoebae Analysis in Carpathian Peatlands." *Journal of Paleolimnology* 36 (1): 1–17.

Schumacher, M., W. Schier, and B. Schütt. 2016. "Mid-Holocene Vegetation Development and Herding-Related Interferences in the Carpathian Region." *Quaternary International* 415: 253–267.

Silvan, N., E. S. Tuittila, H. Vasander, and J. Laine. 2004. "Eriophorum Vaginatum Plays a Major Role in Nutrient Immobilisation in Boreal Peatlands." *Annales Botanici Fennici* 41 (3): 189–199.

Šolcová, A., L. Petr, P. Hájková, J. Petřík, P. Tóth, J. Rohovec, J. Bátora, and M. Horsák. 2018. "Early and Middle Holocene Ecosystem Changes at the Western Carpathian/Pannonian Border Driven by Climate and Neolithic Impact." *Boreas* 47 (3): 897–909.

Stanciu, I. 2013. "The Problem of the Earliest Slavs in Intra-Carpathian Romania (Transylvania and the North-West Vicinity)." *Slovenská Archeológia* 61 (2): 323–370.

Stockmarr, J. 1971. "Tablets with Spores Used in Absolute Pollen Analysis." *Pollen et Spores* 13: 614–621.

Stoica, A. I. 2011. "Diversitatea floristică şi fitosociologică din bazinul superior al văii Ierii, între Valea Ierii şi Vârful Muntele Mare (Masivul Gilău-Muntele Mare)" [The Floristic and Phytosociological Diversity from the Upper Basin of the Ierii Valley, Between the Ierii Valley and the Muntele Mare Peak (Gilău-Muntele Mare Massif).] PhD diss., Universitatea Babeş-Bolyai, Cluj-Napoca.

Suciu, C. 1968. *Dicţionar istoric al localităţilor din Transilvania. I–II.* [Historical Dictionary of the Localities from Transylvania. I-II.]. Bucureşti: Ed. Academiei.

Sümegi, P. 2001. *A negyedidőszak földtanának és őskörnyezettanának alapjai* [Fundamentals of Quaternary Geology and Palaeoecology]. Szeged: JATEPress.

Suttie, J. M., S. G. Reynolds, and C. Batello, eds. 2005. *Grasslands of the World (No. 34)*. Rome: Food & Agriculture Org.

Sweeney, C. A. 2004. "A key for the Identification of Stomata of the Native Conifers of Scandinavia." *Review of Palaeobotany and Palynology* 128: 281–290.

Tanţău, I., M. Reille, J. L. de Beaulieu, S. Farcas, and S. Brewer. 2009. "Holocene Vegetation History in Romanian Subcarpathians." *Quaternary Research* 72 (2): 164–173.

Tanţău, I., M. Reille, J. L. de Beaulieu, S. Farcas, T. Goslar, and M. Paterne. 2003. "Vegetation History in the Eastern Romanian Carpathians: Pollen Analysis of Two Sequences from the Mohoş Crater." *Vegetation History and Archaeobotany* 12 (2): 113–125.

Tinner, W., A. F. Lotter, B. Ammann, M. Conedera, P. Hubschmid, J. F. van Leeuwen, and M. Wehrli. 2003. "Climatic Change and Contemporaneous Land-use Phases North and South of the Alps 2300 BC to 800 AD." *Quaternary Science Reviews* 22 (14): 1447–1460.

Troels-Smith, J. 1955. "Karakterisering af lose jordater [Characterization of Unconsolidated Sediments]." *Danmarks Geologiske Undersogelse* 4/3: 1–73.

Vadas, A., and L. Rácz. 2013. "Climatic Changes in the Carpathian Basin During the Middle Ages. The State of Research." *Global Environment* 6 (12): 198–227.

Väliranta, M., A. Korhola, H. Seppä, E. Tuittila, K. Sarmaja-Korhonen, J. Laine, and J. Alm. 2007. "High Resolution Reconstruction of Wetness Dynamics in Southern Boreal Raised bog, Finland, During the Late Holocene: A Quantitative Approach." *The Holocene* 17 (8): 1093–1107.

van der Linden, M., J. Barke, E. Vickery, D. J. Charman, and B. van Geel. 2008. "Late Holocene Human Impact and Climate Change Recorded in a North Swedish Peat Deposit." *Palaeogeography, Palaeoclimatology, Palaeoecology* 258: 1–27.

Vermoere, M., E. Smets, M. Waelkens, H. Vanhaverbeke, I. Librecht, E. Paulissen, and L. Vanhecke. 2000. "Late Holocene Environmental Change and the Record of Human Impact at Gravgaz Near Sagalassos, Southwest Turkey." *Journal of Archaeological Science* 27 (7): 571–595.

Vincze, I., I. Orbán, H. H. Birks, I. Pál, W. Finsinger, K. Hubay, E. Marinova, et al. 2017. "Holocene Treeline and Timberline Changes in the South Carpathians (Romania): Climatic and Anthropogenic Drivers on the Southern Slopes of the Retezat Mountains." *The Holocene* 27 (11): 1613–1630.

Wandycz, P. S. 2001. *The Price of Freedom. A History of East Central Europe from the Middle Ages to the Present.* London-New York: Routledge.

Warken, S. F., J. Fohlmeister, A. Schröder-Ritzrau, S. Constantin, C. Spötl, A. Gerdes, J. Esper, et al. 2018. "Reconstruction of Late Holocene Autumn/Winter Precipitation Variability in SW Romania from a High-Resolution Speleothem Trace Element Record." *Earth and Planetary Science Letters* 499: 122–133.

Wiezik, M., P. Hájková, E. Jamrichová, R. Hrivnák, and M. Hájek. 2019. "Pre-industrial Composition of Woodlands and Modern Deforestation Events in the Southern Part of the Western Carpathians." *Review of Palaeobotany and Palynology* 260: 1–15.

Willis, K. J., P. Sümegi, M. Braun, K. D. Bennett, and A. Tóth. 1998. "Prehistoric Land Degradation in Hungary: Who, How and Why?" *Antiquity* 72 (275): 101–113.

Willis, K. J., P. Sümegi, M. Braun, and A. Tóth. 1995. "The Late Quaternary Environmental History of Bátorliget, N.E. Hungary." *Palaeogeography, Palaeoclimatology, Palaeoecology* 118 (1-2): 25–47.

Zoppi, U., J. Crye, Q. Song, and A. Arjomand. 2007. "Performance Evaluation of the new AMS System at Accium BioSciences." *Radiocarbon* 49 (1): 171–180.