HUMAN IMPACT DROVE IMPORTANT CHANGES TO FOREST ECOSYSTEMS DURING THE LAST FOUR MILLENNIA: CASE STUDIES FROM THE ROMANIAN CARPATHIANS

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Abstract. Pollen percentage and statistical data from four peat bogs are used to investigate the impact of past human activities on the composition and diversity of forest ecosystems beginning with the Bronze Age (2200–1200 BC). The studied sites (Avrig, Mohoș, Luci, Tăul Muced) are located at elevations ranging between 440 and 1360 m in the Romanian Carpathians, within distinctive vegetation zones and forest belts. The percentage values in pollen spectra of anthropogenic indicators (cereals and ruderal flora) as well as pollen richness suggest a gradual decline of main forest taxa (*Picea abies*, *Fagus sylvatica*, *Quercus*, *Carpinus betulus*) and increase in pollen diversity over the last four millennia, more evident in the lowlands. From the Medieval Period until recent times, enhanced floristic changes occurred at all sites, which together with the decline in primary forest constituents suggest the degradation of the original forests and the formation of mosaic landscapes. The pollen-based reconstruction of major forest loss over the last decades is also shown by modern satellite imagery.

Keywords: pollen analysis, palynological richness, anthropogenic indicators, elevational gradient, Romanian Carpathians.

Rezumat. Impactul uman a cauzat schimbări importante în ecosistemele forestiere în cursul ultimelor patru milenii: studii de caz din Carpații Românești. Date procentuale și statistice de polen din patru turbării ombrotrofe sunt folosite pentru a investiga impactul activităților umane din trecut asupra compoziției și diversității ecosistemelor forestiere începând cu epoca bronzului (2200–1200 BC). Siturile studiate (Avrig, Mohoș, Luci, Tăul Muced) sunt localizate la diferete altitudini cuprinse între 440 și 1360 m din Carpații Românești, în zone și etaje de vegetație caracteristice. Valorile procentuale din spectrele polinice ale indicatorilor antropici (cereale si floră ruderală) dar și diversitate polinică sugerează un declin treptat al principalilor taxoni lemnoși (*Picea abies*, *Fagus sylvatica*, *Quercus*, *Carpinus betulus*) și o creștere a diversității palinologice, mai evidente în zonele joase. Din perioada medievală până în prezent s-a remarcat începutul unor schimbări floristice semnificative în toate siturile, care împreună cu declinul constituenților primari din pădure sugerează degradarea pădurilor inițiale și formarea peisajelor mozaicate. Reconstituirea defrișărilor masive din ultimele decenii este ilustrată de asemenea de imaginile satelitare moderne.

Cuvinte cheie: analiză palinologică, diversitate palinologică, indicatori antropici, gradient altitudinal, Carpații Românești.

INTRODUCTION

Natural environments were transformed into anthropogenic landscapes by the long-term action of humans who have selected and exploited cultivated and wild plants for thousands of years (e.g., BEHRE, 1981; BIRKS et al., 1988; FAEGRI & IVERSEN, 1989; MARINOVA et al., 2012; MERCURI et al., 2013). The identification of the human impact on vegetation is largely based on the use of palynology, which attempts to identify the presence and development of human activities, phases of intensification and abandonment from fossil pollen spectra. The pollen types that are directly associated with human activities (anthropogenic pollen indicators) are usually grouped into primary indicators (cereals and arable weeds) and secondary indicators (ruderals and pastureland flora) (BEHRE, 1981; REILLE, 1999; BRUN, 2009). Furthermore, the heterogeneous and semi-open landscapes with origins often related to human activities have shown a higher floristic diversity than forested landscapes (FEURDEAN et al., 2013).

Changes in the composition and distribution of forested versus open landscapes in Romania are known to have occurred under direct or indirect human actions, particularly since the mid-Holocene (FEURDEAN & TANȚĂU, 2017). The first signs of crop cultivation were recorded from the early Neolithic (ca. 5500 BC) with human impact effects intensifying over millennia and especially during the last centuries (FĂRCAȘ et al., 2003, 2013; FEURDEAN et al., 2009, 2015; GEANTĂ et al., 2014; GRINDEAN et al., 2015, 2019; MAGYARI ET AL., 2009; TANȚĂU et al., 2003, 2006, 2014a).

This study focuses on the impact of humans on forest ecosystem composition, dynamics and diversity over the last 4000 years as depicted in fossil pollen spectra and statistical determination of palynological richness from four peat bogs from Romania (Fig. 1). These ombrotrophic wetlands are located within different vegetation zones and forest belts so there is the possibility to assess and compare the variability of vegetation response to anthropogenic disturbance over time at different elevations (Table 1).

The Avrig peat bog is part of a larger complex of peat bogs on an old terrace of the Olt River, in the southern part of the Transylvanian Depression (Fig. 1). It is located within the mixed oak-hornbeam forests (*Carpinus betulus*, *Quercus robur*, *Q. petraea* and partly *Fagus sylvatica*) vegetation zone. The current surrounding landscape is represented by intensely grazed meadows.

The Mohoș peat bog from the Ciomadul massif (Eastern Carpathians) is partly covered by *Pinus sylvestris* and *Betula pubescens* (Fig. 1). The mire is situated at the transition of the *Fagus sylvatica*-dominated and the mixed conifer-*Fagus sylvatica* vegetation belts. Current main protective management measures for this biodiversity-rich area include the interdiction of deforestation, pastoral activities and artificial draining channels. The Luci peat bog is located in the Harghita Mountains (Eastern Carpathians) (Fig. 1) and is the largest of its kind in Transylvania. The mire is covered

with *Pinus sylvestris* and surrounded by dense *Picea abies* forests. The challenging road and thick vegetation have provided protection for the local biodiversity to some extent.

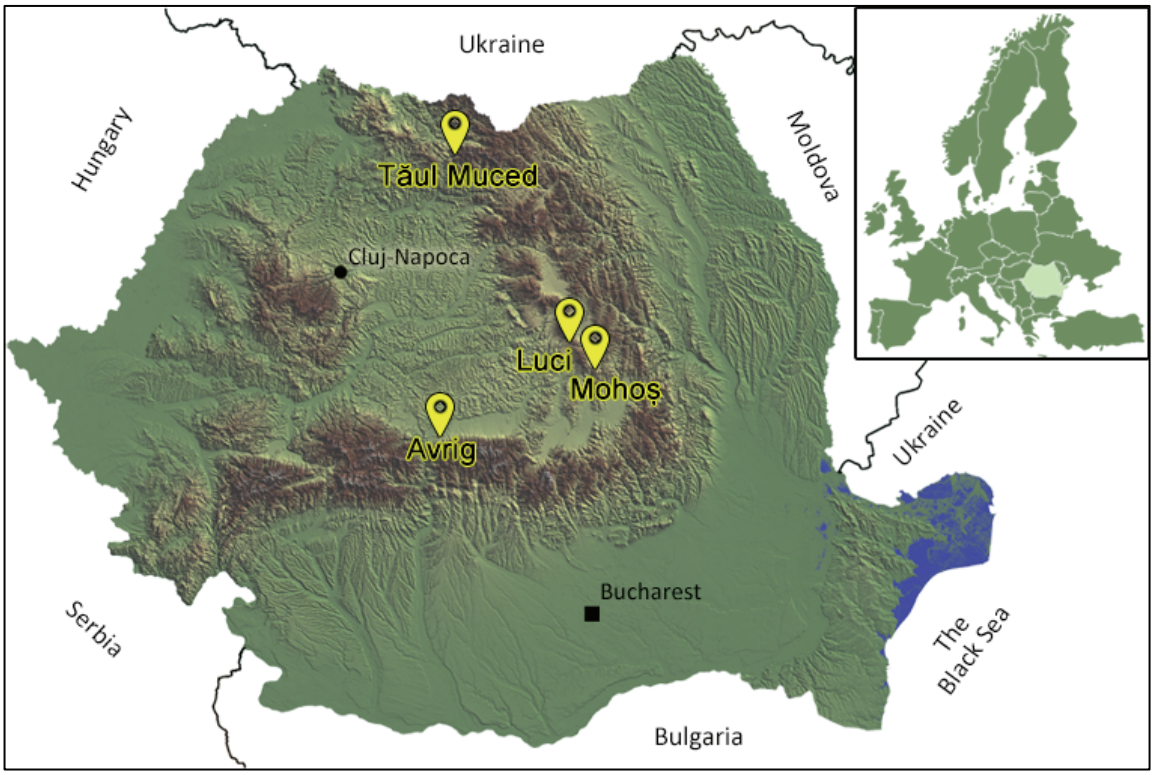

Figure 1. Location map of the studied sites from the Romanian Carpathians (original).

Table 1. Characteristics of the study sites.

Site/ Location	Type of basin	Basin area (ha)	Elevation (m)	Modern local vegetation	References
Avrig 45°43'N, 24°23'E	Peat bog	10	440	*Sphagnum* and Cyperaceae peat bog, surrounded by grazed meadows with patchy forests dominated by *Quercus petraea*	TANȚĂU et al., 2006
Mohoș 46°08'N, 25°54'E	Peat bog	80	1050	*Sphagnum* peat bog partly covered with *Pinus sylvestris* and *Betula pubescens*, with *Alnus glutinosa*, *Picea abies* and *Betula pendula* at the periphery	TANȚĂU et al., 2003
Luci 46°17'N, 25°44'E	Peat bog	120	1080	*Sphagnum* peat bog covered by *Pinus sylvestris* and surrounded by *Picea abies* forests	TANȚĂU et al., 2014a
Tăul Muced 47°34'N, 24°32'E	Peat bog	2	1360	*Sphagnum* peat bog surrounded by *Picea abies* forests	GRINDEAN et al., 2019

The Tăul Muced peat bog is located in the Rodna Mountains (Fig. 1) and surrounded by forests dominated by *Picea abies*. Despite being part of a protected area (Rodna National Park and Biosphere Reserve), the current landscape is exposed to ongoing deforestation.

MATERIALS AND METHODS

For a detailed description of the chronology and vegetation history from each sequence, please see the references mentioned in Table 1.

The groups of plants included in the present study are listed in Table 2. The main types were grouped following a protocol for assigning pollen taxa to functional types of plants (FEURDEAN et al., 2015). The selection and grouping of anthropogenic indicators (crops and ruderals) followed BEHRE (1986), BRUN (2009) and FEURDEAN et al. (2013).

Palynological richness was used to examine changes in vegetation diversity through time at the landscape scale. Recent detailed studies demonstrate that pollen-assemblage richness depicts a reliable representation of floristic richness, as well as a function of landscape structure, openness and diversity (BIRKS et al., 2016, and references therein). Pollen richness was determined by applying the rarefaction analysis (BIRKS & LINE, 1992) to the pollen proportions of all terrestrial taxa using the Psimpoll software (BENNETT, 2009). The lowest pollen count from each studied sequence (T110, T245, T170 and T328) was used to standardize the size of pollen counts.

Table 2. Groups of main pollen types included in this study: (a) pollen types included in the main terrestrial pollen sum; (b) herbaceous pollen types included in human impact indicators.

(a)	Main land cover type	Pollen types
	Conifers	*Pinus*, *Picea abies*, *Abies alba*, *Larix*, *Taxus*, *Juniperus*
	Cold deciduous trees	*Alnus*, *Betula*, *Salix*, *Populus*, *Vaccinium*
	Temperate deciduous trees and shrubs	*Ulmus*, *Quercus*, *Tilia*, *Corylus avellana*, *Acer*, *Fraxinus*, *Carpinus betulus*, *Fagus sylvatica*, *Hedera*, *Sambucus*, *Viscum*, *Viburnum*, *Juglans*, *Castanea*, *Vitis*
	Grassland and pastures	Poaceae, *Artemisia*, Chenopodiaceae, *Plantago lanceolata*, other NAP

(b)	Main land use categories	Herbaceous pollen types
	Crops	Cerealia (*Triticum*, *Zea mays*), *Secale cereale*, *Cannabis sativa*
	Ruderals	*Artemisia*, Chenopodiaceae, Brassicaceae, *Echium*, *Plantago lanceolata*, *P. major, Rumex*, *Urtica*, *Centaurea cyanus Verbascum*, *Mercurialis*, *Anchusa*, *Linaria*, *Melampyrum*, *Polygonum aviculare*

RESULTS

In all our sequences, palynological richness increased moderately from the oldest part towards the present, with generally low values between 2000 BC and 500 AD, moderate values between 500 and 1500 AD and high pollen diversity between 1500 AD and present (Figs. 2; 3). The highest values were recorded at Tăul Muced during the approximately last two millennia. Human impact was mainly derived from percentages of pollen associated with anthropogenic agro-pastoral activities (Fig. 3). Main changes in pollen diversity correspond to notable changes in vegetation composition and human impact along an elevational gradient (Fig. 2).

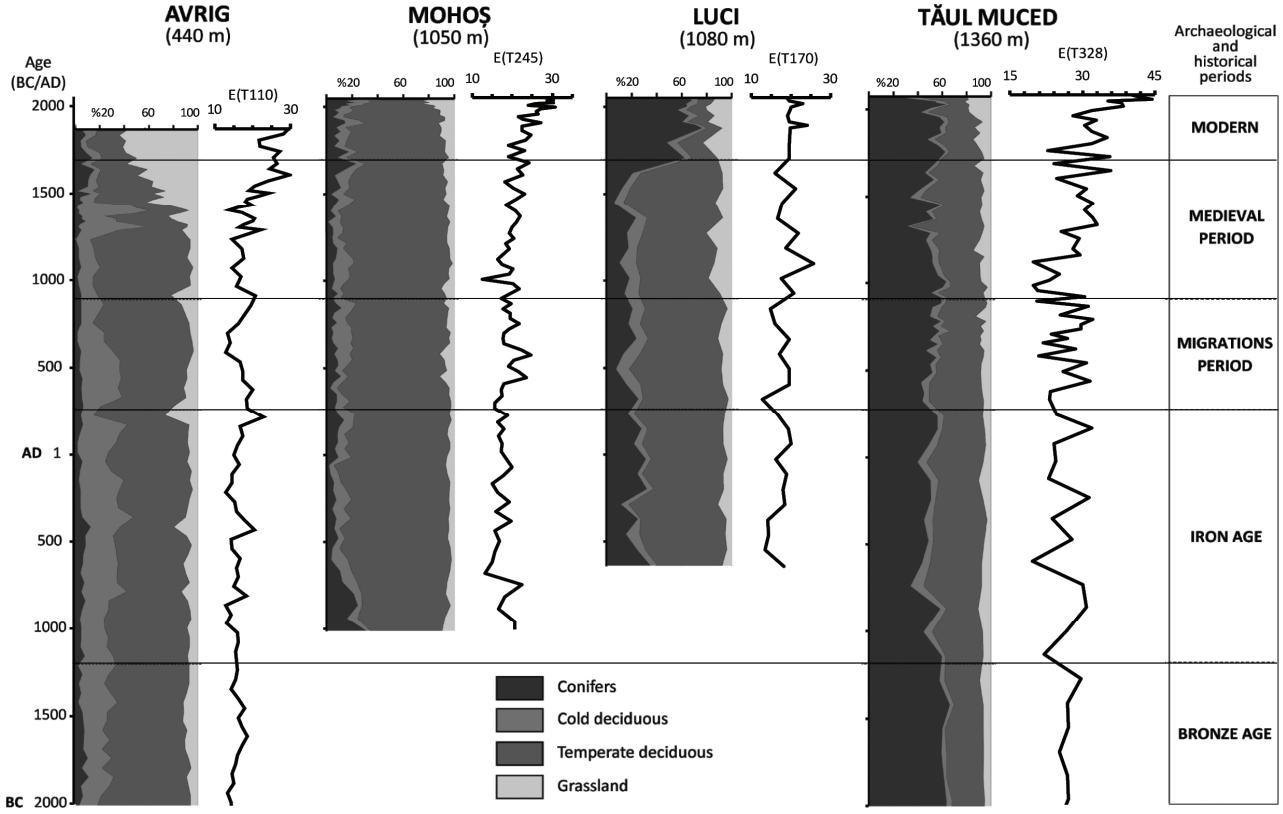

Figure 2. Summary percentage diagrams of vegetation changes since 2000 BC. See Table 2(a) for vegetation groups. Black curves represent palynological richness.

During both the Bronze (2200–1200 BC) and Iron Age (1200 BC–271 AD), all our sequences had relatively low values of pollen richness (Fig. 3). In the lowlands (Avrig), the vegetation was characterized by dense forests (AP>80%) of *Quercus* and *Fagus sylvatica*, with increasing presence of cereals and decreasing *Carpinus betulus* proportions during the Iron Age (TANȚĂU et al., 2006). At mid and high elevations (Mohoș, Luci and Tăul Muced), the Bronze/Iron Age transition was marked by the rise and dominance of *Fagus sylvatica* and *Picea abies*, mostly to the detriment of *Carpinus betulus*. Scattered occurrences of cereals were recorded between 1200 BC and 271 AD (TANȚĂU et al., 2003, 2014a; GRINDEAN et al., 2019).

The palynological richness during the Migrations Period (271–900 AD) was low to moderate in the low- and midlands (Avrig and Mohoș), and low at mid (Luci) and high elevations (Tăul Muced) (Fig. 3). Pollen percentages indicate an overall forested landscape dominated by *Fagus sylvatica* admixed with *Picea abies* in the montane

environments (TANȚĂU et al., 2003, 2014a; GRINDEAN et al., 2019). In other cases (Avrig, Mohoș and Luci), higher proportions of cold deciduous taxa (*Alnus*) were also observed. Increasing occurrences of ruderal species as well as pastureland herbaceous taxa can be observed in all sequences (Fig. 3).

Starting with the Medieval Period (900–1700 AD), pollen diversity had increased, particularly in the lowlands (Fig. 3). The AP percentage values from the Avrig sequence gradually declined in favor of open-land taxa (cereals, ruderals and grasslands), with *Carpinus betulus* as the most affected tree species (TANȚĂU et al., 2006). At elevations above 1000 m, the AP decline was not as visible, although the proportions of open-land taxa slightly and gradually increase (Fig. 3).

The highest values of palynological richness in all sequences were recorded over the last three centuries (Fig. 3). Pollen percentages reveal a sharp decline of tree taxa (AP) and overall expansion of land openness (settlements and agricultural land) (Fig. 2).

DISCUSSIONS

Depending on the intensity of the anthropic impact, pollen records and palynological richness analyses from the four sequences indicate three distinct periods in the past vegetation dynamics: i) with negligible impact during the Bronze Age (2200–1200 BC) and Iron Age (1200 BC–271 AD); ii) with low to moderate effects during the Migrations Period (271–900 AD); and iii) with moderate to high impact from the Medieval Period (900–1700 AD) to the present (Fig. 3).

Low anthropogenic impact during the Bronze Age and Iron Age (2200 BC–271 AD)

The low values of pollen richness and irregular percentages of anthropogenic human indicators corresponded to a time period when the regional landscape was dominated by dense deciduous forests (*Quercus* and *Fagus sylvatica*) in the lowlands, and mixed forests (*Picea abies* and *Fagus sylvatica*) above 1000 m (TANȚĂU et al., 2003, 2006, 2014a; GRINDEAN et al., 2019) (Figs. 2; 3). The regional expansion of *F. sylvatica* and the corresponding decline of *Carpinus betulus* at the beginning of the Iron Age was associated with moist climate conditions and low disturbance by fire and human impact in many sequences of the Romanian Carpathians (e.g., DIACONU et al., 2017; FEURDEAN et al., 2009, 2016, 2017; PANAIT et al., 2017; TANȚĂU et al., 2011, 2014b). Archaeological research suggests that the Bronze Age and Iron Age periods were characterized by extensive deforestation phases associated with the construction of large fortified settlements, as well as the development of a primitive rotational crop agriculture and, eventually, the iron ploughshare (URSULESCU & ZUGRAVU, 2014). Thus, human impact may have had a larger role in the retreat of *Carpinus betulus* and the rise of *Fagus sylvatica* than what pollen percentages suggest in our study areas. Hornbeam usually grows at lower elevations (100–450 m), where it prefers organically rich soils, and it has hard and strong wood, particularly excellent for fuel wood and charcoal (PRACIAK et al., 2013). These characteristics would have made *Carpinus betulus*-dominated forests prone to partial devastation during periods of intense settlement of a growing population (Bronze/Iron Age transition), due to the productivity of the occupied habitats. The later regular occurrences of cereals during the Iron Age support the presence of progressing agricultural practices (Fig. 3).

Low to moderate anthropogenic impact during the Migrations Period (271–900 AD)

Palynological richness was estimated as moderate for Avrig and Mohoș and low for Luci and Tăul Muced (Fig. 3). *Fagus sylvatica* remained the dominant tree species, admixed with *Picea abies* above 1000 m, and with *Quercus* and *Carpinus betulus* in the lowlands (TANȚĂU et al., 2003, 2006, 2014a; GRINDEAN et al., 2019). A slight decline of the forested landscape is visible in all sequences and corresponds to an increase in the proportions of cold, early successional deciduous taxa (*Alnus* and *Betula*) especially during the first half of the period (Figs. 2; 3). This had a stronger effect around Avrig and Mohoș where pollen richness increased with these changes in vegetation. Another important shift in the vegetation composition and pollen richness was marked by the concomitant expansion of ruderal and grassland taxa noticeable in all sequences (Figs. 2; 3). These changes in vegetation could have been directly related to socio-economical changes during the Migrations Period. The migratory movements are believed to have been triggered by climate conditions on one hand, and the need for new pasturelands and settlement areas following a growing population and agricultural land (arable and pastures) degradation (CARPENTIER & FRANÇOIS, 2006). Thus, the lower abundance of cultivated plants (crops) and increase of ruderals and open land (pasture) species recorded in our sequences could be associated with the re-organization of rural settlements following the establishment and/or assimilation of migratory populations. Moreover, higher disturbances by fires during the last half of the period would have likely been promoted by human activities rather than climate conditions (cool and wet) (FEURDEAN et al., 2017), which was probably used for creating and/or expanding agricultural land.

Moderate to high anthropogenic impact from the Medieval Period (900-1700 AD) to the present days

Pollen richness values increased from moderate to high for most of the studied sequences during the Medieval Period, particularly in the lowlands (Fig. 3). The pollen percentages depict a gradual decrease of the main forest taxa (*Fagus sylvatica* and *Picea abies*) associated with an increase of cold deciduous taxa (*Betula* and *Alnus*) especially at the onset of an open landscape (AP<80%). These changes are less visible in the forests at higher elevations (above 1000 m), while in the lowlands *Carpinus betulus* declined rapidly (TANȚĂU et al., 2003, 2006, 2014a; GRINDEAN et al., 2019; Fig. 2). However, a common characteristic feature throughout the studied areas is the noticeable increased proportions of herbaceous anthropogenic indicators (crops and ruderals) (Fig. 3).

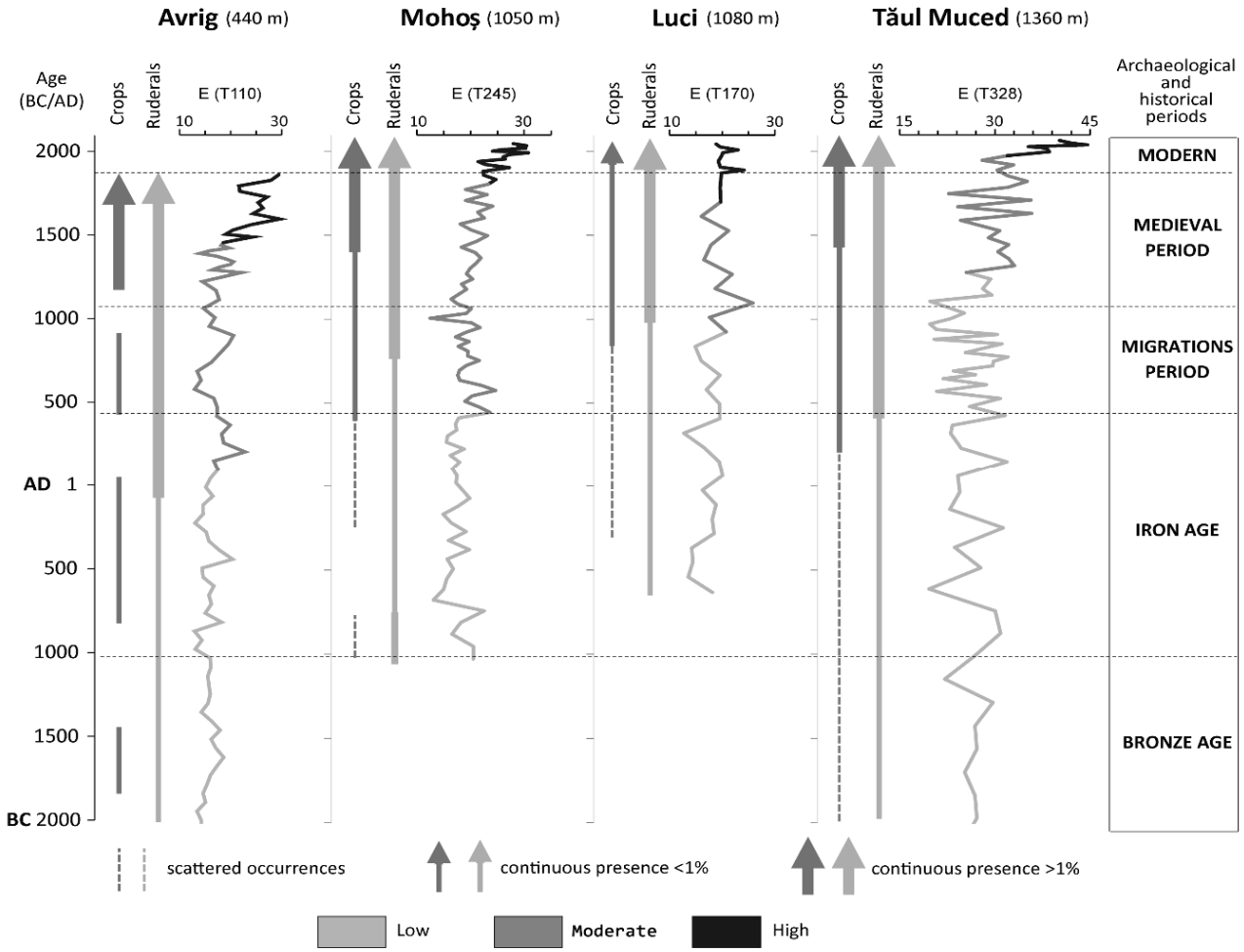

Figure 3. Schematic representation of the occurrence of crops and ruderal anthropogenic human indicators and values of palynological richness (grey gradient) at each site. See Table 2(b) for vegetation groups.

The Medieval Period was characterized by extensive deforestation and agricultural practices as the main economy followed a demographic rise. Trees were mainly used for firewood and large quantities were also used in the mining industry (WILLIAMS, 2003; KAPLAN et al., 2009). The fallow land maintained for agricultural purposes, as well as abandoned terrain, were probably the media for increasing floristic richness during this period. Recent studies have emphasized the importance of mosaic landscapes (semi-open sites) over forested sites, as a driver of greater palynological diversity (CIOCÂRLAN, 2000; FEURDEAN et al., 2013). Forest clearance, expansion of cropland and tree plantations over the past 300 years have led to a severe change in the autochthonous woody species and grasses across the Romanian Carpathians. These changes were intensified during more recent decades due to increased human pressure, which, if not approached by future forestry policy and conservation measures, could lead to significant losses in Romania's remaining old-growth forests.

Furthermore, recent studies focused on the deforestation process throughout the Romanian Carpathians based on state-of-the-art satellite imagery technology, having issued similar concerns regarding the rapid changes on the forest cover under the recent increased anthropogenic activities (Global Forest Watch, 2016; KNORN et al., 2012; KUCSICSA & DUMITRICĂ, 2019; MURARIU et al., 2017; PETRIȘOR, 2015; PINTILII et al., 2017).

CONCLUSIONS

Starting with the late Bronze Age a continuous and abundant presence of ruderal and crop plant species occurred, which gradually increased thereafter and expanded rapidly at the onset of the Medieval Period. Human impact on the vegetation was earlier and stronger in the lowlands than at high elevations. However, the continuous occurrence of secondary anthropogenic pollen indicators (ruderals) at pollen sites from mountainous areas indicates the increasing use of these habitats for seasonal pastoral activities. The ongoing rise in the abundance of pollen types associated to human impact starting with the late Iron Age was paralleled by a gradual decrease in forest cover mainly involving dominant tree taxa.

From the Medieval Period onwards, heavily exploited ecosystems have led to irreversible changes following the decline of main forest taxa (*Fagus sylvatica*, *Picea abies*, *Quercus*, *Carpinus betulus*), the increase of secondary

forest taxa (*Pinus*, *Betula* and *Alnus*) and herbaceous anthropogenic pollen indicators. Thus, the composition and proportion of contemporary forests of the Romanian Carpathians are different from the original forests. Our results are further supported by the satellite imagery of recent forests changes in the Romanian Carpathians in that ongoing deforestation is markedly affecting the vestigial forests, particularly those from within protected areas.

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REFERENCES

BEHRE K. E. 1981. The interpretation of anthropogenic indicators in pollen diagrams. *Pollen et spores*. Muséum national d'histoire naturelle Published. Paris. **23**: 225-245.

BEHRE K. E. 1986. *Anthropogenic indicators in pollen diagrams*. A. A. Balkema Press. Rotterdam. 232 pp.

BENNETT K. D. 2009. Psimpoll 4.27: C program for plotting pollen diagrams and analyzing pollen data. Available online from Queen's University of Belfast, Department of Archaeology and Palaeoecology. http://www.chrono.qub.ac.uk/psimpoll/psimpoll.html. (Accessed: February 10, 2019).

BIRKS H. H., BIRKS H. J. B., KALAND P. E., MOE D. 1988. *The cultural landscape: past, present and future*. Cambridge University Press. Cambridge. 540 pp.

BIRKS H. J. B. & GORDON A. D. 1985. *Numerical Methods in Quaternary Pollen Analysis*. Academic Press. London. 470 pp.

BIRKS H. J. B. & LINE J. M. 1992. The use of rarefaction analysis for estimating palynological richness from Quaternary pollen-analytical data. *The Holocene*. SAGE Publishing. New York. **2**: 1-10.

BIRKS H. J. B., FELDE VIVIAN ASTRUP, BJUNE ANNE, GRYTNES J. A., SEPPÄ H., GIESECKE T. 2016. Does pollen-assemblage richness reflect floristic richness? A review of recent developments and future challenges. *Review of Palaeobotany and Palynology*. Elsevier. Paris. **228**: 1-25.

BRUN CECILE 2009. Biodiversity changes in highly anthropogenic environments (cultivated and ruderal) from the Neolithic to present day in the eastern part of France. *The Holocene*. SAGE Publishing. New York. **19**: 861-871.

CARPENTIER J. & FRANÇOIS L. 2006. *Istoria Europei*. Edit. Humanitas. București. 528 pp.

CIOCÂRLAN V. 2000. *Flora ilustrată a României (Pteridophyta et Spermatophyta)*. Ceres Press. Bucharest. 1138 pp.

DIACONU A. C., TÓTH MONIKA, LAMENTOWICZ M., HEIRI O., KUSKE E., TANȚĂU I., PANAIT A. M., BRAUN M., FEURDEAN ANGELICA 2017. How warm? How wet? Hydroclimate reconstruction of the past 7500 years in northern Carpathians, Romania. *Palaeogeography, Palaeoclimatology, Palaeoecology*. Elsevier. Paris. **482**: 1-12.

FAEGRI K. & IVERSEN J. 1989. *Textbook of Pollen Analysis*. Wiley Press. New York. **4**. 328 pp.

FĂRCAȘ SORINA, TANȚĂU I., BODNARIUC A. 2003. The Holocene human presence in Romanian Carpathians, revealed by the palynological analysis. *Würzburger Geographische Manuskripte*. Springer. Berlin. **63**: 113-130.

FĂRCAȘ SORINA, TANȚĂU I., MÎNDRESCU M., HURDU B. 2013. Holocene vegetation history in the Maramureş Mountains (Northern Romanian Carpathians). *Quaternary International*. Elsevier. Paris. **293**: 92-104.

FEURDEAN ANGELICA & TANȚĂU I. 2017. The evolution of vegetation from the Last Glacial Maximum until the present. In: Rădoane & Vespremeanu-Stroe (Eds.) *Landform dynamics and evolution in Romania*. Springer. Berlin: 67-83.

FEURDEAN ANGELICA, WILLIS KATHERINE JANE, ASTALOȘ C. 2009. Legacy of the past land use changes and management on the 'natural' upland forests composition in the Apuseni Natural Park, Romania. *The Holocene*. SAGE Publishing. New York. **19**: 967-981.

FEURDEAN ANGELICA, PARR C., TANȚĂU I., FĂRCAȘ SORINA, MARINOVA ELENA, PERȘOIU I. 2013. Biodiversity variability across elevations in the Carpathians: parallel change with landscape openness and land use. *The Holocene*. SAGE Publishing. New York. **23**: 869-881.

FEURDEAN ANGELICA, MARINOVA ELENA, NIELSEN ANNE BIRGITTE, LIAKKA J., VEREȘ D., HUTCHINSON S. M., BRAUN M., TIMAR-GABOR ALINA, ASTALOȘ C., MOSSBRUGER V., HICKLER T. 2015. Origin of the forest steppe and exceptional grassland diversity in Transylvania (central-eastern Europe). *Journal of Biogeography*. Wiley-Blackwell Publisher. London. **42**: 951-963.

FEURDEAN ANGELICA, GAŁKA M., TANȚĂU I., GEANTĂ ANCA, HUTCHINSON S. M., HICKLER T. 2016. Tree and timberline shifts in the northern Romanian Carpathians during the Holocene and the responses to environmental changes. *Quaternary Science Reviews*. Elsevier. Paris. **134**: 100-113.

FEURDEAN ANGELICA, FLORESCU GABRIELA, VANNIERE B., TANȚĂU I., O'HARA R. B., PFEIFFER M., HUTCHINSON S. M., GAŁKA M., MOSKAL-DEL HOYO MAGDALENA, HICKLER, T. 2017. Fire has been an important driver of forest dynamics in the Carpathian Mountains during the Holocene. *Forest Ecology and Management*. Elsevier. Paris. **389**: 15-26.

GEANTĂ ANCA, GAŁKA M., TANŢĂU I., HUTCHINSON S. M., MÎNDRESCU M., FEURDEAN ANGELICA 2014. High mountain region of the Northern Romanian Carpathians responded sensitively to Holocene climate and land use changes: a multi proxy-analysis. *The Holocene*. SAGE Publishing. New York. **23**: 869-881.

GRINDEAN ROXANA, LĂZĂRESCU V. A., DIACONU A. C., OPREANU H., FĂRCAȘ SORINA, TANȚĂU I. 2015. The usefulness of interdisciplinary studies: palaeoecological and archaeological aspects from NW Romania. *Ephemeris Napocensis*. Romanian Academy Publishing House. Cluj-Napoca. **XXV**: 105-134.

GRINDEAN ROXANA, TANȚĂU I., FEURDEAN ANGELICA 2019. Linking vegetation dynamics and stability in the old-growth forests of Central Eastern Europe: Implications for forest conservation and management. *Biological Conservation*. Elsevier. Paris. **229**: 160-169.

KAPLAN J. O., KRUMHARDT K. M., ZIMMERMANN N. 2009. The prehistoric and preindustrial deforestation of Europe. *Quaternary Science Reviews*. Elsevier. Paris. **28**: 3016-3034.

KNORN J., KUEMMERLE T., SZABÓ A., MÎNDRESCU M., KEETON W. S., RADELOFF V. C., ABRUDAN I., GRIFFITHS P., GANCZ V., HOSTERT P. 2012. Forest restitution and the protected area effectiveness in post-socialist Romania. *Biological Conservation*. Elsevier. Paris. **146**(1): 204-212.

KUCSICSA G. & DUMITRICĂ CRISTINA 2019. Spatial modelling of deforestation in Romanian Carpathian Mountains using GIS and Logistic Regression. *Journal of Mountain Science*. Springer. Berlin. **16**(5): 1005-1022.

MAGYARI ENIKO, BUCZKÓ KRISZTINA, JAKAB G., BRAUN M., PÁL Z., KARÁTSON D., PAP I. 2009. Palaeolimnology of the last crater lake in the Eastern Carpathian Mountains: a multiproxy study of Holocene hydrological changes. *Hydrobiologia*. Springer. Berlin. **631**: 29-63.

MARINOVA ELENA, KIRLEIS W., BITTMANN F. 2012. Human landscapes and climate change during the Holocene. *Vegetation history and Archaeobotany*. Springer. Berlin. **21**: 245-248.

MERCURI A. M., BANDINI MAZZANTI M., FLORENZANO A., MONTECCHI M. C., RATTIGHIERI E., TORRI P. 2013. Anthropogenic pollen indicators (API) from archaeological sites as local evidence of human-induced environments in the Italian Peninsula. *Annali di Botanica*. University La Sapienza of Rome Published. Roma. **3**: 143-153.

MURARIU G., HAHUIE V., MURARIU A., GEORGESCU L., ITICESCU CĂTĂLINA, CĂLIN MIHAELA, PREDA C., BURUIANA DANIELA LAURA, CARP G. B. 2017. Forest Monitoring Method using Combinations of Satellite and UAV Aerial Images. Case Study - Bălăbăneşti Forest. *International Journal of Conservation Science*. University Al. I. Cuza Press. Iași. **8**(4): 703-714.

PANAIT A. M., DIACONU A. C., GAŁKA M., GRINDEAN ROXANA, HUTCHINSON S. M., HICKLER T., LAMENTOWICZ M., MULCH A., TANŢĂU I., WERNER C., FEURDEAN ANGELICA. 2017. Hydrological conditions and carbon accumulation rates reconstructed from a mountain raised bog in the Carpathians: a multi-proxy approach. *Catena*. Elsevier. Paris. **152**: 57-68.

PETRIȘOR A. I. 2015. Using CORINE data to look at deforestation in Romania: Distribution & possible consequences. *Urbanism. Arhitectură. Construcţii*. INCD URBAN-INCERC Press. Bucharest. **6**(1): 83-90.

PINTILII R. D., ANDRONACHE I., DIACONU D.C., DOBREA R.C., ZELEŇÁKOVÁ MARTINA, FENSHOLT R., PEPTENATU D., DRĂGHICI C. C., CIOBOTARU ANA-MARIA 2017. Using Fractal Analysis in Modeling the Dynamics of Forest Areas and Economic Impact Assessment: Maramureș County, Romania, as a Case Study. *Forests*. **8 (1)**: 25.PRACIAK A., PASIECZNIK N., SHEIL D., VAN HEIST MIRIAM, SASSEN MARIEKE, CORREIA CRISTINA SOUSA, DIXON C., FYSON G., RUSHFORTH K., TEELING CLAIRE 2013. *The CABI encyclopedia of forest trees*. Oxfordshire Press. London. 536 pp.

REILLE M. 1999. *Pollen et Spores d'Europe et d'Afrique du Nord. Seconde édition*. Laboratoire de Botanique Historique et Palynologie Published. University Marseille Press. 535 pp.

TANȚĂU I., REILLE M., BEAULIEU J. L., FĂRCAȘ SORINA, GOSLAR S., PATTERN M. 2003. Vegetation history in the eastern Romanian Carpathians: pollen analysis of two sequences from the Mohoș crater. *Vegetation History and Archaeobotany*. Springer. Berlin. **12**: 113-125.

TANȚĂU I., REILLE M., BEAULIEU J. L., FĂRCAȘ SORINA. 2006. Late Glacial and Holocene vegetation history in the southern part of Transylvania (Romania): pollen analysis of two sequences from Avrig. *Journal of Quaternary Sciences*. Elsevier. Paris. **21**: 49-61.

TANȚĂU I., FEURDEAN ANGELICA, BEAULIEU J. L., DE MAURICE R., FĂRCAȘ SORINA 2011. Holocene vegetation history in the upper forest belt of the Eastern Romanian Carpathians. *Palaeogeography Palaeoclimatology Palaeoecology*. Elsevier. Paris. **309**: 281-290.

TANȚĂU I., FEURDEAN ANGELICA, BEAULIEU J. L., REILLE M., FĂRCAȘ SORINA 2014a. Vegetation sensitivity to climate changes and human impact in the Harghita Mountains (Eastern Romanian Carpathians) over the past 15,000 years. *Journal of Quaternary Sciences*. Elsevier. Paris. **29**: 141-152.

TANȚĂU I., GEANTĂ ANCA, FEURDEAN ANGELICA, TĂMAȘ T. 2014b. Pollen analysis from a high altitude site in Rodna Mountains (Romania). *Carpathian Journal of Earth and Environmental Sciences*. North University of Baia Mare Press. Baia Mare. **9**: 23-30.

URSULESCU N. & ZUGRAVU N. 2014. *Civilizații preistorice și antice pe teritoriul României (Civilizații preistorice și protoistorice pe teritoriul țării noastre)*. Facultatea de Istorie, Universitatea "Alexandru Ioan Cuza", Iași. 126 pp.

WILLIAMS M. 2003. *Deforesting the Earth: from Prehistory to Global Crisis*. University of Chicago Press. Chicago. 715 pp.
***. Global Forest Watch. 2016. https://www.globalforestwatch.org/ (Accessed: 21st January 2019).

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