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Vegetation responses to climate, fire and human impact during the Holocene in the Northern Apuseni Mountains (Romania)

- PhD thesis summary -

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INTRODUCTION

Palaeoecological research studies provide information on long-term changes in vegetation dynamics. The palaeoenvironmental techniques used to analyze past patterns of these ecosystems rely on data sets which offer both quantitative and descriptive information on biological and geological processes that hold climate as the main controlling factor. Peat bogs represent a valuable source of climatic records, as they encompass a large collection of proxy data with similar and/or subtle changes in the environment from the past.

The present thesis was based on the multi-variable analysis of ombrotrophic peat and lacustrine profiles from the northern Apuseni Mountains, with palynology as the main method for obtaining a representative temporal and spatial resolution of the Holocene vegetation changes. The aim of the research was to identify and correlate the interactive effects of climate, fire and anthropogenic impact on the vegetation patterns from these mountains, and to determine the amplitude of each controlling factor throughout the course of the last 11,700 years.

STUDY AREA

The study area is located between the drainage basin of the Someșul Cald River to the south, and the Hillock of Șimleu to the north. Two of the distinctive characteristics of the Someșul Cald river valley are the extensive karst landscape developed on top of mainly metamorphic bedrock and the thermal inversions that determine variations in the ecotone. The northern part of the study area is represented by the Șimleu Depression and adjacent massifs of Plopiș (west) and Meseș (east), and holds considerable archaeological evidence of a long-term human establishment in the area since prehistoric times.

The study sites from the Someșul Cald River valley lie on a metamorphic bedrock on the right banks of the river in the Apuseni Mountains. The surface of the Ic ponor peat bog is abundant in various species of *Sphagnum* and Ericaceae, as well as scattered stands of *Betula* (*B.*

pubescens and *B. verrucosa*) and dwarf *Picea abies* individuals. At Pietrele Onachi, the *Sphagnum* mire is completely covered by a dense *P. abies* forest with stands of *Betula* sp. and abundant *Vaccinium myrtillus*. The Doda Pilii is an isolated sinkhole overgrown by *Sphagnum* and Cyperaceae species, surrounded by dry meadows.

The study sites from the northern extensions of the Apuseni Mountains lie at the foot of slopes, in contact areas between the lowlands and highlands. The peat bog from Iaz is located at the foothill of the Plopiș Mountains and features several rare meso-oligotrophic vegetation assemblages. The site from Hereclean represents an infilled lake on the alluvial plain of the Zalău River.

MATERIAL AND METHODS

The sediment cores were extracted using a "Russian sampler" with a chamber length of 60-100 cm and 6 cm in diameter. Stratigraphical description was done on site and prior to the laboratory analysis. The palynological analyses were performed on 1 cm^3 of bulk sediment samples following the standard procedures of Bennett and Willis (2001) and, in some of the samples, *Lycopodium* tablets of known concentration were added in order to estimate the pollen and micro-charcoal concentrations (Stockmarr, 1971). Between 350 and 500 pollen grains were identified based on graphic reference materials (Reille, 1995, 1998). Non-pollen palynomorphs (e.g., fungal spores, insect remains, stomata) and charcoal fragments larger than 10 μm were counted on the same slides as pollen. The pollen diagrams were compiled using the Tilia software (Grimm, 1992) using the frequencies of terrestrial pollen types, excluding percentages of spores, aquatic pollen types and micro-charcoal.

In order to estimate the content of carbonate and organic matter, samples of ca. 5 g were collected from the cores and dried overnight, combusted for 4 hours at 550 °C and 2 hours at 950 °C, respectively. The input of minerogenic material into the catchment areas was determined by screening the sedimentary sequences with a magnetic susceptibility loop (Walden et al., 1999) using a Bartington MS3 meter.

The testate amoebae were extracted using a non-chemical procedure (Hendon and Charman, 1997) and the resulting residue was scored for at least 150 taxa per sample following the taxonomic classification of Charman et al. (2000). Macro-charcoal (>100 μm) was collected during pollen preparation and counted using a binocular microscope.

AMS radiocarbon datings were performed on bulk peat or gyttja and wood fragments and the age estimates were converted into calendar years BP using the CLAM package (Blaauw, 2010) in the R software and the INTCAL13 dataset of Reimer et al. (2013).

RESULTS AND INTERPRETATION

1. Ic Ponor

The stratigraphy of the sequence indicates the existence of different stages in the development of the actual peat bog. Starting with the early Holocene, the sandy clay layer of the alluvial plain was replaced by a more organic rich layer of clayey peat and afterwards by an accumulation of ombrotrophic peat. A clay soil layer near the top of the sequence indicates a depositional gap followed by the re-development of *Sphagnum* peat.

The radiocarbon measurements and pollen stratigraphic markers indicate the age 11,800 cal BP for the base of the sequence and thus, marking 11,700 cal BP as the onset of the acidic mire. The hiatus was dated back to 5830 cal BP and the new peat layer at 40 cal BP. The large depositional gap was probably due to the geomorphological shifts in the alluvial plain of the Someșul Cald River.

The pollen spectra indicate a vegetation succession pattern common for the Lateglacial/Holocene transition to the middle Holocene (11,800-5830 cal BP), and a brief portion of the late Holocene as well (40 cal BP-present). The sequence begins with an open woodland-tundra-steppe vegetation type, where *Pinus* was the dominant tree. The sequence from Ic Ponor offers the best resolution for the middle Holocene vegetation dynamics. The forests were mainly composed of *Picea abies* and *Corylus avellana* up until ca. 7200 cal BP, and *P. abies* throughout the rest of the middle Holocene. Patches of mixed-oak taxa and scattered occurrences of *Fagus sylvatica* and *Carpinus betulus* were also common in these forests. The herbaceous taxa regularly

present throughout the pollen spectra were Poaceae, Chenopodiaceae, *Urtica*, *Cannabis* type, Scrophulariaceae and Ranunculaceae.

The micro-charcoal curve was represented graphically for the period between 11,800 and 5800 cal BP. The intervals with higher abundance of micro-charcoal were 11,800-10,100; 9700-9350 and 9100-7500 cal BP, after which the values declined.

The non-pollen palynomorphs (NPPs) identified are types related to erosion phases (*Glomus*), local fire events (*Gelasinospora*), local presence of specific taxa (*Kretzschmaria deusta*, *Gaeumannomyces*, stomata) and indicators of palaeohydrological changes in peat (testate amoebae).

2. Pietrele Onachi

Although covering a short time period of the Holocene (5430-2500 cal BP) and lack of micro-fossils, the peat sequence from Pietrele Onachi shows various degrees of humification which, indirectly, give clues for climate oscillations. Thus, the less decomposed layers have a lighter shade of brown as a result of higher water tables, caused by wetter and/or cooler climatic conditions, while the darker layers indicate lower water tables, occurring in warmer and/or drier climates when vegetation becomes more decomposed.

The pollen spectra are dominated by trees such as *Picea abies*, *Fagus sylvatica*, *Carpinus betulus*, *Corylus avellana* and members of the *Quercetum mixtum* (*Quercus* and *Ulmus*). The most abundant herbaceous taxa were *Artemisia* and Poaceae, while ferns were mainly represented by Polypodiaceae.

The highest input of microscopic charcoal is recorded between 5430-4600 cal BP, 3800-3400 cal BP and during the last 300 years of the sequence (2800-2500 cal BP).

3. Doda Pilii

The sequence is composed of several types of lacustrine sediments accumulated since 10,000 cal BP and a top layer of *Sphagnum* peat. Plant macro-fossils of both woody and herbaceous taxa were identified.

The sediment contains ruditic and arenitic fragments, which correlated with other proxy data (magnetic susceptibility, organic matter content, and pollen), indicate the presence of gaps in the sedimentary accumulation between 8800 and 7800 cal BP, and between 7100 and 380 cal BP.

The pollen record shows a vegetation succession pattern associated with the early to middle Holocene, and the late Holocene. The first interval was characterized by a transition from a dense mixed *Picea abies*-deciduous (*Ulmus*, *Quercus*, *Betula*, *Corylus avellana*) forest to a rather open landscape colonized by various herbs and grasses (e.g., *Rhinanthus*, Apiaceae, Poaceae). Between 8800 and 7800 cal BP, the landscape is almost completely forested by *P. abies* and *C. avellana*. The sequence ends with forests of *P. abies*, *F. sylvatica* and *Carpinus betulus*, along with *Betula* and *C. avellana*, which are gradually declining from 100 cal BP in favor of various open landscape communities.

The micro- and macro-charcoal concentrations were both rather high between 9600 and 8800 cal BP, with a minimum abundance during the dominion of spruce and hazel (7800-7100 cal BP) and rather distinct proportions during the late Holocene (380 cal BP-present).

4. Iaz

The stratigraphic record of the Iaz peat bog suggests three main evolutionary phases of the catchment area: as a palaeo-lake, with minerogenic rich sediment; a forested wetland, with various wood remains; and a meso-oligotrophic peat bog, with various vegetal macro-remains.

The physicochemical analyses of the sediment also reveal a minerogenic rich segment corresponding to the first two stages of the basin development, a transitional stage between organic and minerogenic rich content, with fluctuating magnetic susceptibility values as well,

and finally, a prevalent organic content for the second half of the peat bog accumulation in the basin.

The sediment composition and abundance of micro-charcoal particles mark a possible hiatus in the bottom of the sequence. Hence, known pollen stratigraphic markers, as well as comparison of vegetation dynamics with other available pollen records in the area were used to assign the beginning of the peat sedimentation in the Iaz sequence to 7000 cal BP.

The onset of the peat bog was characterized by a rather open-forest landscape dominated by *Corylus avellana*, *Tilia*, *Quercus* and *Ulmus*, herbs like Poaceae and Cyperaceae, and ferns between 7000 and 5700 cal BP. It continued with the subsequent development of *Alnus glutinosa* and *Carpinus betulus*, followed by *Fagus sylvatica* (5000 cal BP). The sequence concludes with the reduction of *F. sylvatica* and *C. betulus* and more abundant *C. avellana*, *Betula* and *Pinus*, along open herbaceous communities dominated by Poaceae, cultivated plants, Asteroideae, *Plantago lanceolata*, Chenopodiaceae and *Urtica*.

The microscopic fractions of charcoal display three periods with higher percentage values (7000-5900, 3600-2000, 600-0 cal BP) interconnected by two intervals with lower amount of charred vegetal micro-remains (5900-3600, 2000-600 cal BP).

The NPP record included various types of spores belonging to specialized fungi (e.g., coprophilous, parasitic), as well as stomata and numerous insect remains. The record for testate amoebae was compiled for the last 3000 years of the sequence. Although it clearly suggests a change in palaeohydrological conditions from about half the interval (ca. 1600 cal BP), the occurrence of mixed assemblages imply various fluctuations of the moisture in the mire throughout the middle to late Holocene.

5. Hereclean

The sequence was mainly minerogenic and yielded no palynological results. However, the macro-remains and physicochemical properties of the sediment representing the early to middle Holocene (11,700-7000 cal BP) were useful in determining potential links between the evolution of the basin and the surrounding vegetation.

The bottom of the sequence dates back to ca. 43,000 cal BP, although the coring did not reach the bedrock. The catchment area probably developed as a riverside lake during the Pleistocene, which then gradually became overgrown by grasses and herbs during the middle Holocene.

The carbonate bedrock could be a reason for the bad preservation of pollen grains in the sediment. The type of metamorphic fragments identified in the clayey sediment, indicate their origin from the Meseș Mountains. The vegetal macro-remains included fragments of wood, grass and roots, and small shell fragments. The origin of the basin is also probably related to the frequent landslides dating back to the Pleistocene that characterize the hilly region.

DISCUSSIONS: Holocene history of vegetation, climate, fire and human impact

1. Someșul Cald valley

The sites that were used for characterizing the vegetation dynamics along the upper course of the Someșul Cald valley were Ic Ponor (1050 m a.s.l.), Pietrele Onachi (1055 m a.s.l.) and Doda Pilii (1120 m a.s.l.).

Despite the fact, that the sequences are discontinued and individually do not cover the entire Holocene, coupled they contribute very well to the understanding of the additional effect of river activity of the river on the development of peat in the area. Depositional gaps were identified at 5830-40 cal BP (Ic Ponor), ca. 8800-7800 cal BP and 7100-380 cal BP (Doda Pilii), 2500 cal BP (Pietrele Onachii).

Archaeological records from the study area are scarce (Repertoriul Arheologic Național, 2008; Feurdean et al., 2009) and thus, the impact of the human presence in the study area was estimated mainly through palynological analysis.

The proxies analyzed for this valley include: radiocarbon measurements, litostratigraphy, pollen and spores, non-pollen palynomorphs, micro- and macro-charcoal, content in carbon matter, carbonates and silicates, and magnetic susceptibility.

Early Holocene (11,700-8200 cal BP)

11,700-10,200 cal BP

The main tree taxa between 11,700 and 11,200 cal BP were *Pinus* and *Betula*. However, the gradual increase in temperatures also allowed *Picea abies* and *Ulmus* to be present regularly throughout the early Holocene forests. Their early expansion in the forests from the Romanian Carpathians has been previously linked to their possible migration from source areas nearby (Feurdean et al., 2005; Tanțău et al., 2009). Favorable conditions between 11,200 and 10,300 cal BP led to the development of denser forests dominated by *P. abies* and *Ulmus*. Starting with 10,450 cal BP, mesophilous trees such as *Quercus*, *Tilia*, *Fraxinus*, *Corylus avellana* and *Alnus glutinosa* started to have an increased proportion in the woodland composition. The main herbaceous taxa at the time included *Artemisia*, Urticaceae, Ranunculaceae and Rosaceae.

The main trends in the forest composition were interrupted subsequently by cooler and wet climate conditions (11,500-11,200 cal BP) corresponding to the Preboreal Oscillation (e.g., Björck et al., 1997), and cooler and/or dry conditions (10,400-10,200 cal BP) synchronous with the 10,300 cal BP cooling event (e.g., Björck et al., 2001). The gaps in the forests following these climate oscillations were invaded by pioneer taxa such as *Pinus*, *Betula* and *Salix*.

Vegetation trends were similar to other sequences from the Romanian Carpathians (Feurdean, 2005; Tanțău et al., 2006, 2009, 2014; Feurdean et al., 2008).

The increasing density of the forests and favorable climatic conditions were also important contributing factors to the changes of the river channel between 10,300-10,200 cal BP (Perșoiu, 2010).

10,200-8200 cal BP

Between 10,200-9400 cal BP the forests were mainly composed of *Picea abies*, *Ulmus* and *Corylus avellana*. Cooler climate conditions around 9300 cal BP (e.g., Blockley et al., 2014) and the decline of most of the deciduous trees likely prompted the subsequent prevalence of *C. avellana* from ca. 9200 cal BP due to its greater climatic and soil type tolerance. The occurrence of *Glomus* and *Gaeumannomyces* fungi spores in the pollen slides indicate the possible persistence of alluvial input into the basin from Ic Ponor, which is correlated with increased

fluvial activity at 10,200-9200 cal BP (Perșoiu, 2010). Once the terrace finally became detached from the main watercourse at ca. 9400 cal BP, the catchment area began to be colonized by an extensive *Sphagnum* cover and tree individuals were scarcer on the surface of all the basins. Forests at higher elevation were dominated by *P. abies*.

Corylus avellana and *Picea abies* were the dominating trees between 9300-8200 cal BP along a regular proportion of *Quercus* and *Ulmus* as well. The decline of mesothermophilous trees around 8300-8150 cal BP and the growing proportion of Ericaceae indicate a possible deterioration of the soil surface related to the '8.2 kyr' cold event. Drier conditions near the river banks (Ic Ponor) were deduced from the presence of protists like *Trigonopyxis arcula* in the pollen slides and the decline of wetland herbs in favor of Urticaceae. At higher elevation (Doda Pilii) vegetal macro-remains indicate the local presence of *Pinus sylvestris* and species of *Betula*. However, the woodlands were rather open and dominated by *P. abies*. The landscape was dominated by open landscape communities composed of taxa like *Rhinanthus*, Apiaceae, Poaceae, Asteroideae, Cichorioideae and Filipendula.

Physicochemical properties of the sediments indicate a surface probably more prone to erosion during the cold and dry conditions associated with the '8.2 kyr' event. The lower temperatures and mean annual precipitation values were also recorded in various other palynological analyses across the Romanian Carpathians (Tanțău et al., 2006; Feurdean et al., 2008, 2013).

Although present, the occurrence of cereal pollen grains could not be specifically attributed to human activities, as most records suggest the anthropological impact to be associated with the Early Neolithic (around 8000 cal BP) in the area (Bodnariuc et al., 2002; Jalut et al., 2003; Feurdean et al., 2013).

Intervals with higher biomass burning were recorded at 11,700-9600 cal BP and 10,200-9400 cal BP. These periods were generally associated with changes in the main forest composition, ultimately leading to the replacement of the main tree taxon with a more resilient species.

Middle Holocene (8200-4200 cal BP)

Picea abies was the main tree component in the woodlands of the Someșul Cald valley during the middle Holocene. Other major constituents were *Ulmus* (8150-7700 cal BP) and *Corylus avellana* (8150-7700 cal BP; 7700-7200 cal BP), *Quercus* (starting with 7200 cal BP). The abundance of Ericaceae at the site from Ic Ponor has led to changes in soil composition which eventually also allowed the spread of some tree taxa afterwards (e.g., *Ulmus* between 8200 and 7700 cal BP).

Disturbances in the composition of the main woodland were probably related to cooler climate conditions (7700-7200 cal BP) or contamination of the peat record from top layers (6600-6400 cal BP).

The main *Picea abies* forest declined gradually starting with 6000 cal BP and allowed the expansion and colonization by deciduous taxa (e.g., *Ulmus*, *Tilia*, *Quercus*, *Corylus avellana*) afterwards. Changes in the climate could be related to the 5900 cal BP Bond event (Bond et al., 2001) and favoring the expansion (5000 cal BP) and prevalence (4800-4300 cal BP) of *Carpinus betulus* in the area in the aftermath of the event when the climate was ameliorating. However, the human factor could also be taken in consideration for this change in vegetation pattern during the middle Holocene. The expansion and the prevalence of *Fagus sylvatica* in the area were likely favored by the changes in the climate associated with the 4200 cal BP event and the Middle Bronze Age Cold Period, respectively.

Although herbaceous communities which are often associated with human impact (e.g., Apiaceae, Urticaceae, *Plantago*, *Cannabis*) started to diversify around 6000 cal BP, their relation with cultivated fields or pastures in the area could not be well established (Bodnariuc et al., 2002; Fărcaș et al., 2005; Feurdean and Willis, 2008a).

Fire activity seems to have diminished concurrently with the development of the *Picea abies-Corylus avellana* forest (ca. 7700 cal BP)

Late Holocene (4200-2500 cal BP; 380 cal BP-present)

Picea abies and *Fagus sylvatica* were the main components of woodlands between 4200 and 2500 cal BP. Declines of the *F. sylvatica* were recorded at 3900-3700 cal BP, 3400-3150 cal

BP and 3100-2800 cal BP. The taxa that were at an advantage durind these intervals were *Quercus*, *Fraxinus* and *Acer*, and *Pinus*.

Starting with ca. 400 cal BP, forests in the area occupy a gradual reducing surface, while herbaceous communities indicating open landscape become more abundant and diverse. The increasing proportion of cultivated grasses and herbs and cultivated trees (*Juglans*) characterize the whole study area during the last 100 years.

The vegetation trend holds many similarities with various other records from Romania (e.g., Tanțău et al., 2006; Fărcaș et al., 2007; Feurdean et al., 2009; Geantă et al., 2012).

Human impact and fire activity

The sign of more pressure from human communities in the area was evident through the increase of ruderal and pasture herbaceous taxa and corresponding higher charcoal values since the Bronze Age (4200-3200 cal BP). Fire was likely used as a means of maintaining pastures and agricultural land during more recent times (Feurdean et al., 2009, 2012).

2. The Șimleu Depression and the northern extensions

The sites relevant for the description of the vegetation, climate, human impact and fire activity from this area were the peat bog from Iaz and the predominantly minerogenic deposition from Hereclean.

Together, the sequences cover the entire Holocene, with Hereclean providing litostratigraphical and physicochemical insight from the beginning of the Holocene until 7000 cal BP. The sequence from Iaz presents a good resolution of the vegetation patterns for the last 7000 years. Archaeological records are noted around both of the sites, starting with the Neolithic through the Medieval Period (Repertoriul Arheologic Național, 2008).

Proxies used for the thorough palaeoecological analysis included radiocarbon measurements, litostratigraphy, pollen and spores, non-pollen palynomorphs, micro-charcoal, testate amoebae, organic matter, carbonates and silicates content and magnetic susceptibility.

Regional palaeoenvironmental records (e.g., Björkman et al., 2003; Jalut et al., 2003; Feurdean, 2005; Tanțău et al., 2006; Feurdean et al., 2007) were used to provide a description of the vegetation dynamics between 11,700 and 7000 cal BP.

Early Holocene (11,700-8200 cal BP)

11,700-10,400 cal BP

The early Holocene was generally characterized by a warm and dry climate (Feurdean et al., 2008) with slow but gradual increase in atmospheric precipitations (Feurdean et al., 2008; Tămaș et al., 2005). The milder climate conditions favored the rapid expansion of *Picea abies* and *Ulmus* with a few other deciduous trees (*Corylus avellana, Quercus, Fraxinus, Alnus*).

These features can also be derived, to some extent, from the phsysicochemical and lithological aspects of the sequence from Hereclean. The basin was functioning as a palaeo-lake on the floodplain of the Zalău River. Arid but rather stable conditions favored the constant influx into the basin of allochtonous material (schist, silica and carbonate) by the local rivers crossing the nearby slopes. Because the flow energy was probably still rather high, the organic productivity of the basin was very low. The forest was however, present on the nearby landscape as the numerous wood fragments found in the sediments suggest.

10,400-8200 cal BP

The favorable climate allowed mesophilous trees to migrate into the region and to expand, eventually becoming an important part of the forests (*Quercus, Fraxinus, Tilia, Corylus avellana*) from low and medium altitudes. The increasing warm conditions eventually led by 9300 cal BP (Björkman et al., 2003) and 9600 cal BP (Bodnariuc et al., 2002; Jalut et al., 2003) to the prevalence and maximum abundance of *C. avellana* in the forests at the expense of the *Quercetum mixtum* communities. In the Șimleu Depression, the interval 10,500-9600 cal BP was characterized by several shifts in the type of matter influx and sediment. Between 10,500 and 10,200 cal BP, the sediment contained more silica particles and could indicate colder and drier conditions, which probably favored the stagnation of water and grain accumulation into the lake. Low values of the magnetic susceptibility also suggest the probable standstill of the

accumulation. Forests were likely still dense and present on the nearby slopes and riverbanks as implied by the presence of numerous wood remains in the clayey sediment.

Middle Holocene (8200-4200 cal BP)

The basin from Hereclean functioned as a mineral-rich peat bog between 8000 and 7000 cal BP. The minerogenic content of the sediment prevented the good preservation of pollen. The increasing values of carbonates and input of more magnetic minerals could be due to episodic runoffs from the nearby slopes affected by weathering during the dry periods. The last ca. 1200 years of the evolution of the basin from Hereclean could also be representative and correlated with the development of the sequence from Iaz, in the western extremity of the Șimleu Depression.

The main components of the forest between 7000 and 4200 cal BP, as the pollen record from Iaz suggests, were *Corylus avellana* and members of *Quercetum mixtum* (*Quercus, Tilia* and *Ulmus*) up until 4900 cal BP, and *Carpinus betulus* for the following 700 years of the sequence. These tree taxa indicate the continuity of the warm climate since the prevalence of *C. avellana* in the region (9600 cal BP; Bodnariuc et al., 2002; Jalut et al., 2003). The sharp decline of the hazel-oakwood at 5200 cal BP that enabled hornbeam to prevail afterwards could have been connected to the shift from wetter to drier climate conditions.

Late Holocene (4200 cal BP-present)

4200-1600 cal BP

The continuous high abundance of tree taxa during this period, as well as the high amount of parasitic/wood-decay and coprophilous fungi, suggest lasting optimal climate conditions auspicious for the prevalence and amelioration of dense forests in the area. The woodlands were dominated by *Fagus sylvatica* but *Carpinus betulus* and *Quercus* were also a common occurrence in these dense forests.

The interval 3600-1600 cal BP was characterized by several shifts in global climatic conditions. The cold events (Middle Bronze Age Cold Period-3800-3500 cal BP; Iron Age Cold Period-2900-2400 cal BP) were generally associated with an increased fluvial activity of the Someșul Mic River (Perșoiu, 2010), while the warmer periods (Bronze Age Climatic Optimum-

3500-2900 cal BP; Roman Warm Period-2400-1600 cal BP) were correlated well with intense fluvial activity in Central Europe (Starkel et al., 2002).

1600-650 cal BP

In this interval, the sediment from Iaz presented the highest abundance of organic matter and corresponding lowest allochthonous input. Magnetic susceptibility is also low, with a short sharp increase at about 1450-1350 cal BP. Two well established climate periods are concurrent with this interval: the Dark Ages Cold Period (1450-1100 cal BP) and the Medieval Warm Period (1100-650 cal BP).

The main characteristic of the vegetation pattern from Iaz between 1600 and 1100 cal BP was the high abundance of hygrophilous species of Scrophulariaceae (*Gratiola officinalis* and *Limosella aquatica*) and *Sphagnum*. The rise of pioneer taxa (*Salix*, *Corylus avellana*, *Betula*, *Pinus*, and *Fraxinus*) during this period also give support to the extensive clearings in the main forest. During the following period (1100-650 cal BP), the beech and alder forests recovered to some extent. However, the high abundance of *Carpinus betulus* and *Quercus* at the time could indicate the presence of large gaps in the main forest, which were primarily colonized by these two tree species.

650 cal BP-present

Following the change in lithology to a *Sphagnum* peat bog and the continuing anthropogenic pressure, significant shifts in the vegetation composition and distribution also took place. The landscape cover was slowly changing from a forested one to an open vegetation cover with secondary forest taxa, including *Quercus*, prevailing.

The testate amoebae assemblages indicate a wet to moderately wet conditions between 650-300 cal BP when both *Sphagnum* and *Lycopodium annotinum* were abundant, very wet at ca. 300-100 cal BP when *L. annotinum* thrived, and drier peat surface in the recent 100 years dominated by *Sphagnum.*

2.1. Human impact and fire activity during the middle and late Holocene

Human occupation in this region of the Apuseni Mountains was recorded since the Neolithic and an almost constant presence of communities belonging to the Starčevo-Criș III B complex, dated around 7600-7300 cal BP (Băcueț, 2008). Activities of these groups included pottery, primordial agriculture and animal husbandry.

A 40 km buffer zone around the site from Iaz was established in order to encompass a relevant number of archaeological sites from the study area (Șimleu Depression), significant enough for the analysis of the level of habitation, as well as providing a wider view of the various altitudinal habitats and therefore, possible source areas for the pollen producing taxa with large dispersal area before man-made plantations in recent times (e.g. *Pinus*).

3. Vegetation responses to climate, fire and human impact during the Holocene in the Northern Apuseni Mountains (Romania)

The vegetation succession characterizing the onset of the Holocene was a response to a sharp rise in temperatures indicated by various palaeo-records from the Northern Hemisphere. The main factors influencing the changes in vegetation starting with 11,700 cal BP were the migration of taxa and the forest configuration from the Lateglacial. The initial forests from the early Holocene were mainly composed of *Pinus* and *Betula*. Species like *Salix*, *Picea abies*, *Ulmus* and *Alnus* were also present in the early woodlands, but their proportion was more restricted.

More favorable climate conditions between 11,200 and 10,300 cal BP have facilitated the rapid spread and prevalence of woodlands dominated by *Picea abies* and *Ulmus*. Support of their dominance in the landscapes especially at mid altitudes is given by the fact that both species were found to be underestimated in the raw pollen percentages (Feurdean et al., 2015).

The ongoing optimal climate conditions between 10,500 and 9400 cal BP were favorable for the expansion of mesophilous trees in the area (*Quercus*, *Tilia*, *Fraxinus* and *Corylus avellana*). The delay in forest development affected by colder and drier conditions associated

with the 10,300 cal BP event probably enabled the more resistant *C. avellana* to gain a significant head start into the following vegetation succession.

The deterioration of soil composition induced by the colder and arid climate conditions associated with the 8200 cal BP event was clearly recorded in the vegetation responses from the study area. These changes consist in the decline of most of the mesophilous trees, which consequently led to increased soil erosion and interruption in sediment accumulation in some parts. Although forests were mainly composed of *Picea abies* and *Corylus avellana* during the middle Holocene, short-term anomalies associated with the long-lasting effects of the 8200 cal BP event have led to several transitional changes in the forest. These changes were more noticeable in the records from mid-altitude.

The expansion of *Carpinus betulus* in the study area was set to 5700 cal BP in the lowlands and recorded around 5000 cal BP in the mountain valleys. The differences related to the onset and spread of this taxon could be due to the particular edaphic conditions at each site, as *C. betulus* prefers organically rich soils. The relatively short interval of abundance for this taxon could be related to the partial devastation during periods of intense settlement due to the fertility of the occupied habitats (Godwin, 1975).

On the other hand, the expansion and prevalence of *Fagus sylvatica* in the sequences studied was mostly similar, around 4800 cal BP and starting with ca. 4200 cal BP, respectively. The long dominance of *F. sylvatica* in both lowlands and highlands of the study area was probably a result a general moist and cooler climate (Holzhauser et al., 2005) which favored the regeneration of this taxon throughout most of the late Holocene, as well as human activity (Küster, 1997).

Eventhough archaeological records are very scarce, the presence of human pressure on the Someșul Cald valley is indicated by the diversification of anthropogenic indicators starting with ca. 6000 cal BP. The late Holocene is also characterized by the occurrence of several climate oscillations, with rather contrasting changes in the vegetation cover. In general, the colder episodes induced a reduction of the mesophilous trees and a lower degree of human pressure and thus, allowed the regeneration of the beech forest. During the warmer phases the anthropogenic pressure on the landscape increased, through several short-term declines of the

forest as well as diversification of numerous herbaceous taxa, which indicate human activity. Throughout the last ca. 350 years, significant changes in the forest composition were noted, which usually also lead to the partial or complete change of the natural vegetation cover. Large areas were transformed into arable land and the surface of the peat bogs in the study area started to lose moisture through drainage or desiccation due to noxious runoff into the catchment areas from the nearby slopes. The open landscape was maintained using fire (Feurdean and Willis, 2008b; Feurdean et al., 2009).

CONCLUSIONS

The present study focused on the responses of the vegetation from the Northern Apuseni Mountains (Romania) to the interactive effects of climate, human impact and fire during the Holocene. The study area consists of a varied assemblage of landforms, which provided suitable sites at both low and mid altitudes, and comprising different intervals of the last 11,700 years.

During the Lateglacial/Holocene transition and early Holocene the vegetation dynamics were likely controlled more by the climatic oscillations and by the ecological requirements and tolerances of the various taxa. The pioneer forest with *Pinus* and *Betula* were gradually being replaced following the sharp rise in temperatures at 11,700 cal BP, by taxa which have also survived in Romania during the Last Glacial: *Picea abies*, *Ulmus*, *Alnus* and *Salix*. The following expansions of *Corylus avellana*, *Quercus*, *Tilia* and *Fraxinus* at ca. 10,500 cal BP support their migration from more distant residual populations.

As forests became denser and closed, short-term changes in climate were the main factor triggering and controlling the changes in taxa distribution and abundance. The regional similarity of the expansion of both *Carpinus betulus* (ca. 4800 cal BP) and *Fagus sylvatica* (ca. 4200 cal BP) suggests that climate fluctuations were probably the cause that favored their enlargement at the expense of slower responsive taxa.

Starting with ca. 7000 cal BP, human pressure on the environment became noticeable and thus, its influence on the dynamic of certain taxa is not excluded. Human impact is more visible at sites from lower altitudes of the Apuseni Mountains and, despite their accessibility, the inner

mountainous valleys were subjected to animal grazing and deforestations, rather than intensive cultivation of crops. Nevertheless, phases of short-term decline of the main forest taxa throughout the middle to late Holocene were usually associated with human impact related to clearance and burning in order to obtain larger grazing and arable land for the growing population and/or for the implementation of new agricultural practices (viticulture, crop rotation, and arboriculture).

The high fire activity during the early Holocene (11,700-7000 cal BP) was probably a factor which also facilitated the expansion of the mesophilous trees at the expense of the more flammable coniferous forests. The dramatic changes in forest and general landscape composition characterizing the last ca. 600 years from the study area was also influenced by the common use of fire for maintaining pastures and arable land.

Considering the radical changes of the landscape from the past three centuries, the awareness of the way past land-use by human societies have altered the natural landscape is a compulsory method in order to better understand the evolution of the relationships between society, environment and biodiversity through time, and develop efficient strategies for the preservation and restoration of the natural and cultural landscape.

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