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POLLEN ANALYSIS FROM A HIGH ALTITUDE SITE IN RODNA MOUNTAINS (ROMANIA)

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Abstract. Pollen and spore analysis from a 150 cm long peat sequence taken from a high altitude oligotrophic peat bog (1810 m) located in the Rodna Mountains and constrained by AMS radiocarbon dates provides new insights into the postglacial vegetation history, human activities and paleoclimate in the high elevation area of the Eastern Carpathians. *Betula*, *Pinus* and *Alnus* were the first taxa that have spread in the area, due to the temperature increase that characterized the early Holocene (ca. 11200 cal yr BP). *Pinus* diploxylon type (*P. mugo* and *P. sylvestris)* dominated the local and regional landscapes during the early Holocene until 10500 cal yr BP, but receded markedly afterwards. After 10500 cal yr BP *Picea abies* was the most important constituent in the local vegetation below the site. The dynamic of the thermophilous deciduous forest (*Ulmus*, *Quercus*, *Tilia*, and *Fraxinus*) is poorly recorded because of the high altitude of the studied site. *Corylus avellana* became regionally established around 10500 cal yr BP. *Carpinus betulus* and *Fagus sylvatica* were established at 6500 and 5300 cal yr BP respectively. Pollen evidences for human influence are represented by cereals and herbaceous taxa specific to grazed surfaces from about 1050 cal yr BP on. The grazing pressure increased between 600 and 160 cal yr BP.

Keywords: pollen analysis, vegetation history, Holocene, Rodna Mountains.

1. INTRODUCTION

Given the current and future global climate changes it is important to understand the plant species' dynamics and interactions with their environment (Seddon et al., 2014). One way to gain a better understanding of the current vegetation composition and relationship with both human societies and the environment is to look at historical patterns through palaeoecological records (Tanţău et al., 2003, 2006, 2011a; Feurdean et al., 2010; 2013a). Pollen and spores analysis is the most commonly used proxy for reconstructions of past vegetation dynamic and diversity (Birks & Birks, 2006).

Romania is located at the convergence of three biogeographical regions: southern (Balkans), central and eastern Europe. In addition, Romania contains the largest part of the Carpathian Mountains, with one of the largest tracts of natural forests in Europe (Feurdean et al., 2009). Although still insufficient, emerging pollen records from Romania have provided some insights into the natural vegetation dynamics as well as the anthropogenic disturbance on these landscapes (Pop, 1960; Tanţău et al., 2011b; Fărcaş & Tanţău, 2012; Fărcaş et al., 2013). Few pollen records have specifically addressed questions associated with the long-term forest management and conservation (Feurdean & Willis, 2008; Feurdean et al., 2009). However, given the large elevation stretch and steep topographic gradient there is need for more palaeoecological records to better assess the sensitivity of the high elevation zone to the environmental and land use changes.

In the present study we use preliminary pollen and spore analysis complemented by radiocarbon dates on a high altitude peat sequence from the Rodna Mountains, with the aim of deepening our knowledge of past vegetation dynamics, diversity and the relationship with human societies and environmental change in Northern Romania.

2. STUDY AREA

The studied peat bog is located in a glacial cirque under the Gărgălău Saddle (47°34'24"N, 24°48'9"E, 1810 m altitude), in the Rodna Mts., near Lake Ştiol (Izvorul Bistriţei Aurii) (Fig. 1). The bog is currently drained by a rivulet.

Rodna Mountains are part of the Northern group of the Eastern Romanian Carpathians and they are the highest mountains in this area. Because of their high altitude, Rodna Mountains were affected by Quaternary glaciations. Glaciations have left traces such as glacial cirques harboring lakes, glacial valleys and moraines (Mîndrescu et al., 2010), especially on the Northern slopes (Fig. 1).

The area where the peat bog is located is characterized by a temperate continental climate. The mean annual temperatures vary with altitude and exposure: -1.5°C above 2200 m, 0°C at 2000 m, and 1.2°C from 1700 to 1800 m (Buta & Buta, 1979; Dragotă & Kucsicsa, 2011). On the slopes facing West and South-West and above 2000 m a.s.l., the annual precipitation exceeds 1400 mm, while at 1800 m a.s.l. the annual average is 1300 mm (Coldea, 1990). At the altitude of the studied site (1810 m) the mean annual temperature is ca. 1°C and the annual precipitations vary between 1200 and 1400 mm (Dragotă & Kucsicsa, 2011).

From a phytogeographical standpoint the oligotrophic peat bog is located in the Carpathian province of the Centro-European region (Ciocârlan, 2000). The specific vegetation stage for the altitude above 1600 m is characterized by the "Rhododendro myrtifolii–Pinetum mugi" plant community (Coldea, 1990). The main taxa surrounding the site are *Pinus mugo*, *Juniperus communis* ssp. *nana*, *Rhododendron myrtifolii*, *Vaccinium myrtillus*, and *Carex* sp.

3. METHODOLOGY

The peat sequence was sampled from an open outcrop using metallic U-shaped cases (50x8x4 cm). The peat was carefully wrapped in plastic foil and described in detail prior to sub-sampling in the lab.

Subsamples for pollen analysis were taken at 4 or 5 cm intervals. The samples' preparation followed a standard procedure: acetolysis in the case of peat samples and flotation in a heavy liquid for clay.

The pollen diagram was graphically realized using the GpalWin software (Goeury, 1997). The pollen percentages for each taxon were calculated as percentages of the total pollen sum. A minimum of 300 grains of tree pollen were counted for each sub-sample, except when pollen concentration was low. To facilitate the interpretation of the pollen diagram with respect to vegetation changes, local pollen assemblage zones (LPAZ) were established (Birks, 1986).

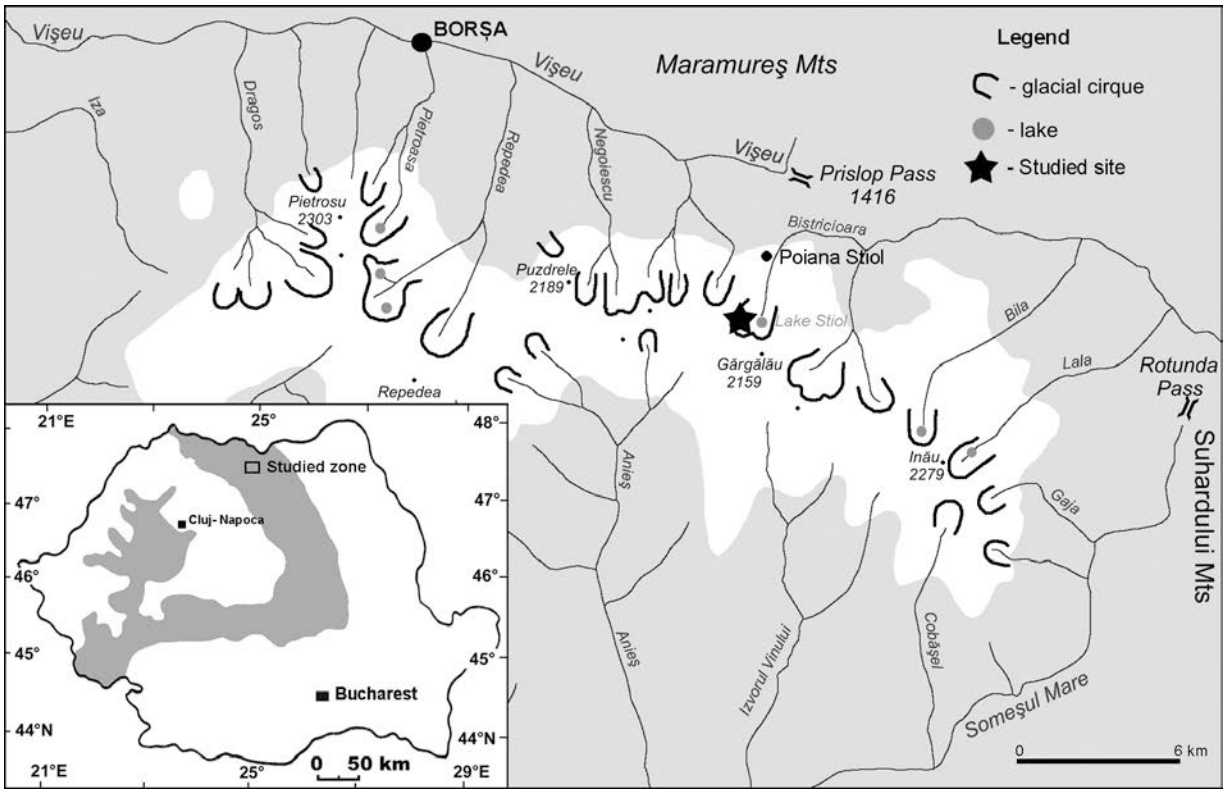

Figure 1. Location map of the study site in the Rodna Mountains (after Mîndrescu et al., 2010, modified).

The chronology was established by AMS (Accelerator Mass Spectrometry) radiocarbon measurements obtained at the Laboratory of the Radiocarbon in Poznań (Poland).

4. RESULTS

4.1. Lithostratigraphy

The Gărgălău sequence (150 cm long) is made of fairly decomposed, dark brown *Carex*-peat and is formed on top of a bluish-gray clay with angular clasts of metamorphic rocks.

4.2. Chronology

Seven AMS radiocarbon dates were used to constrain the temporal phases of the pollen record for the Gărgălău site (Table 1, Fig. 2). The age-depth model shows that the peat deposition started at about 11200 cal yr BP and was continuous until 160 cal yr BP (Figs. 2 and 3).

The peat accumulation rate was about 0.01 cm/yr between 10000 and 1500 cal yr BP, and had slightly higher values i.e. 0.02 cm/yr between 1500 and 160 cal yr BP, and between 11200 and 10000 cal yr BP (Fig. 2).

Table 1. AMS ^{14}C dates from the Gărgălău peat sequence

Depth (cm)	***^{14}C age (yr BP)***	***Calibrated age Cal yr BP***
9-11	615 ± 30	549 – 656
34-36	1750 ± 30	1562 – 1731
51-53	3675 ± 35	3900 – 4091
80-82	5690 ± 40	6409 – 6501
101-103	7690 ± 50	8401 – 8561
124-126	9000 ± 50	10119 – 10246
148-150	9800 ± 50	11149 – 11306

4.3. Pollen analysis

For the Gărgălău sequence we analyzed 30 samples and identified 69 taxa. Based on changes in composition and frequency (as percentage of the total pollen sum) of the main pollen taxa, six local pollen assemblage zones were separated (Fig. 3).

LPAZ 1 (11 260-10 600 cal yr BP)

Pinus pollen varied between 35-65%, whereas *Picea* pollen percentages between 10-40% (Fig. 3A). Deciduous trees such as *Betula*, *Ulmus*, and *Corylus avellana* are present with less than 5% each. The high altitude shrub taxa such as *Alnus viridis* and *Betula* occurred with values around 3%. Among herbaceous plants, pollen percentages of Poaceae varied between 5 and 12%, *Artemisia* is present with ca. 2%, while pollen of other herbaceous plants is only recorded sporadically. Cyperaceae pollen and monolete spores are present with values over 10%.

LPAZ 2 (10600-9750 cal yr BP)

This pollen zone is characterized by the highest pollen percentage of *Picea* (60%), while *Pinus* regressed to 10% (Fig. 3A). *Ulmus* increased from 5% to 10%. Other taxa that showed an increasing trend during this LPAZ are *Betula*, *Alnus viridis* and *Corylus avellana*. Compared to the previous zone, pollen percentages of Poaceae and *Artemisia* declined slightly to 5%. Cyperaceae pollen and monolete spores decreased to their minimum values in the diagram (7% and 3%).

LPAZ 3 (9750 – 9100 cal yr BP)

There is a short-lived decline in *Picea* from 60 to 25% during this zone, synchronous with an increase in the percentages of *Ulmus* to its maximum values of 25% and of *Pinus*. Cyperaceae and Poaceae were at their maximum values. *Alnus viridis* pollen increased to 7%.

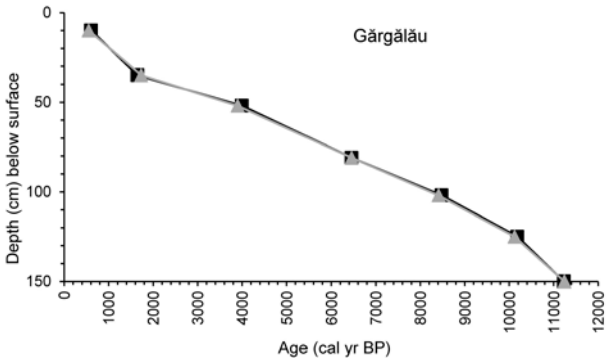

Figure 2. Calibrated AMS radiocarbon dates and age-depth model

LPAZ 4 (9100 – 6000 cal yr BP)

This zone was characterized by a maximum of *Corylus avellana* pollen (30%) while *Picea abies* pollen percentages declined from 30% to 20%. *Pinus* pollen percentages decreased slightly to 10% then remained constant. The *Carpinus betulus* curve begins in this zone, at around 6500 cal yr BP. The Poaceae pollen frequencies remained relatively constant at around 12% and there was an increase in the proportion and diversity of many herbaceous plants including Chenopodiaceae, Rosaceae, Ranunculaceae, and Scrophulariaceae.

LPAZ 5 (6000 – 2150 cal yr BP)

Compared to the previous interval, *Picea* pollen had a peak at 40% then a slight decrease, while *Pinus* and *Alnus viridis* increased to 10%. *Tilia, Quercus,* and *Betula* were present with values under 3%. The *Ulmus* and *Corylus avellana* pollen became almost absent towards the end of this zone. *Fagus* pollen started to increase around 5300 cal yr BP. The first occurrence of the *Abies alba* pollen is recorded around 2350 cal yr BP. *Fagus sylvatica* became established around 5500 cal yr BP.

Herbaceous plants such as Rosaceae, Urticaceae, *and Artemisia* were present with values over 2% and Poaceae with over 12%. The first occurrence of Cereals pollen is noted in this zone. Cyperaceae pollen remained at percentages over 10%.

LPAZ 6 (2150 – 160 cal yr BP)

The main characteristic of this zone is the continuous pollen curve of *Abies alba* reaching a maximum of 15%. *Fagus sylvatica* was well represented throughout the interval, especially in the beginning where it reached the maximum of 12%. Compared to the previous interval, *Picea abies* had a slight decrease at the beginning of the interval. *Pinus* pollen percentages show a peak around 18%, decreasing again towards the top of the profile. *Carpinus betulus* was on a decreasing trend from 7 to 3%. *Juglans* pollen had its first occurrence here.

The Poaceae pollen was well represented while other herbaceous plants (Chenopodiaceae, Scrophulariaceae, *Plantago*, Urticaceae, *Cannabis* type, Ranunculaceae) were present with small percentages but in greater variety than in the previous pollen zones. Cereals are increasing over 1%. *Selaginella* (Lycopsida) spores are present with percentages going up to 20%. Monolete spores have their lowest values here (3%).

5. DISCUSSIONS

The results of the pollen analysis from the Gărgălău peat sequence provide new insights into the postglacial vegetation history, human activities and paleoclimate in the Northern part of the Eastern Romanian Carpathians.

5.1. Expansion of the *Pinus* dominated forest between 11200 and 10000 cal yr BP

The early Holocene timber composition illustrated by the Gărgălău sedimentary profile was characterized by the abundant occurrence of *Pinus* sp. and *Picea abies.* Given the altitude of this site (1810 m), timber at lower elevation consisted mainly of *P. sylvestris* with scattered occurrences of *P. cembra*, whereas the local *Pinus* stands were likely represented by the subalpine species *P. mugo*. The expansion of *Pinus* forests during the early Holocene is observable in all pollen sequences from the Carpathians and connected to the existence of local glacial refugia for *Pinus* in this region (Björkman et al., 2003; Tanţău et al., 2006; Feurdean et al., 2011).

The regional forest including some meso-thermophilous taxa such as *Ulmus, Tilia, Fraxinus* and *Corylus avellana* gradually became established at lower elevations. Pollen records from lower elevation sites in Romania indicate that *Ulmus* expanded rapidly at the beginning of the Holocene (around 11,300 cal yr BP) and replaced *Betula* as the dominant tree (Feurdean, 2005, Tanţău et al., 2006, 2011a; Fărcaş et al., 2013). The early Holocene establishment of deciduous thermophilous forests in Romania is associated to warmer and drier climate conditions compared to the Late Glacial, consequence of higher summer insolation (Tămaş et al., 2005; Feurdean et al., 2013b).

Although the percentages of pollen of open ground indicator plants were not considerably high, Poaceae and *Artemisia* were a constant presence in the Early Holocene of this sequence, reflecting both a more open character of regional forests following the cold Late Glacial, and the high altitude location of the site.

5.2. Expansion of *Picea* and establishment of thermophilous forests at lower elevations 10000 – 6200 cal yr BP)

At 10,200 cal yr BP, the timber composition became dominated by *Picea abies* and spruce remained the main timber constituent in the montane forest until the present (Fig. 3). Today's limit of *Picea abies* forests in the Rodna Mts., ranges between 1100 and 1500. Regional forest at lower elevation also included *Ulmus*, *Corylus avellana*, *Tilia* and *Fraxinus*, while near the site it is probable that only cold-adapted deciduous shrubs such as *Betula* and *Alnus viridis* were common. The increased proportion of *A. viridis* at about 8000 cal yr BP together with the increase in the presence of Cyperaceae and ferns suggests a change towards wetter conditions (Fig. 3A), an inference that is supported by other climate reconstructions and simulations from NW Romania (Tămaş et al., 2005; Schnitchen et al., 2006; Feurdean et al., 2013b).

The overall decline of herbaceous cover shows that the tree cover became denser or widespread (Fig. 3B).

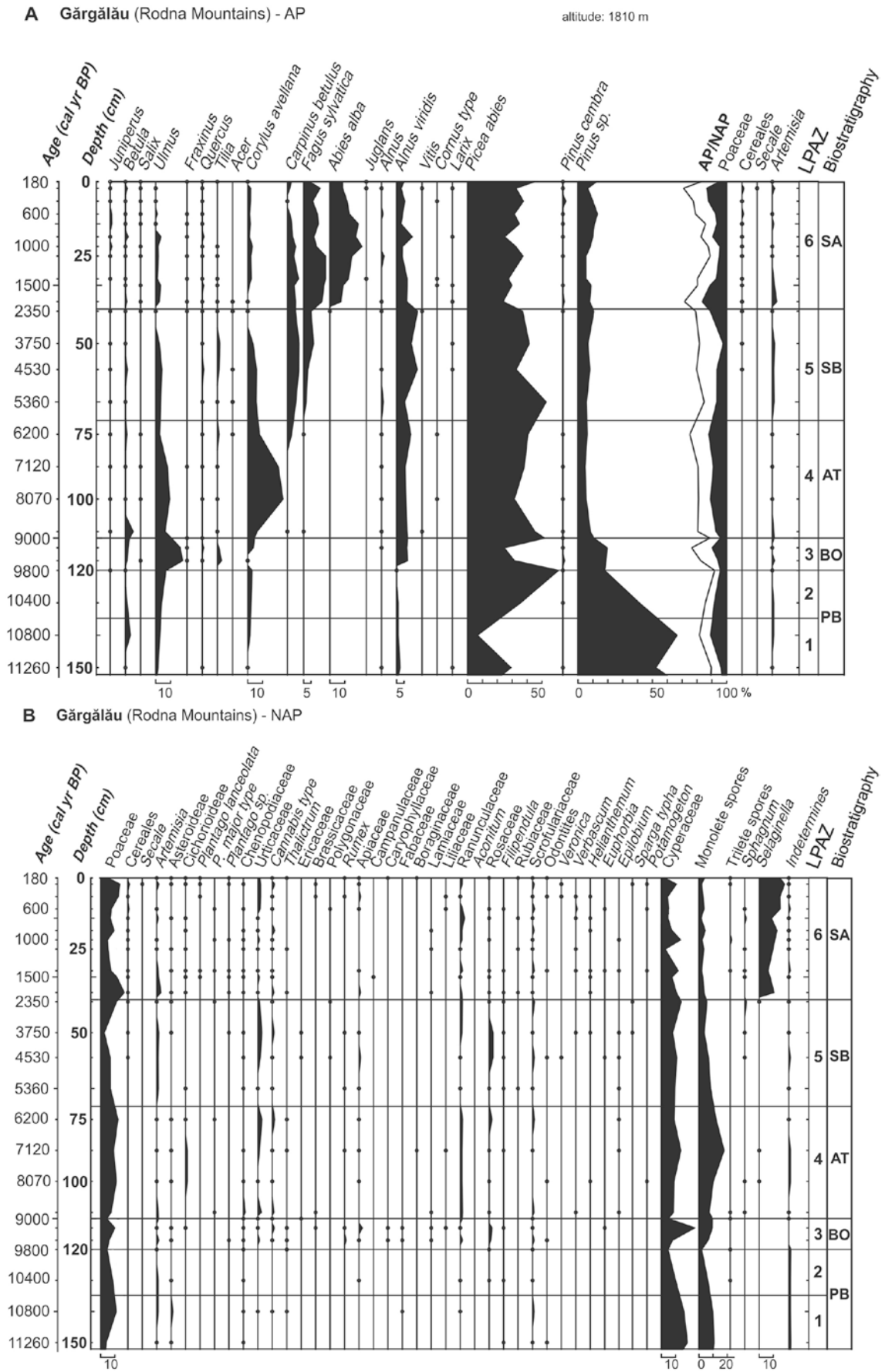

Figure 3. Pollen diagram from Gărgălău: A) Arboreal pollen (AP); B) Non arboreal pollen (NAP). SA-Subatlantic, SB-Subboreal, AT-Atlantic, BO-Boreal, PB-Preboreal.

5.3. Forests with *Carpinus betulus, Fagus sylvatica* and *Abies alba*; first human impact indicators (6200 – 2300 cal yr BP)

In this period corresponding mostly to the Atlantic phase, *Picea abies* remained the dominant taxon in the upland vegetation and probably immediately below the study site. Populations of *Pinus* (especially *P. mugo*) and *Alnus viridis* remained stable throughout this period. However, important changes in the composition of the vegetation occurred in the regional forests at lower elevations, where *Carpinus betulus* and *Fagus sylvatica* became established around 6500 cal yr BP and 5300 cal yr BP, respectively. The spread of *C. betulus* is later than in the South-Western and South-Eastern Romania (7500-7200 cal yr BP; Fărcaş et al., 1999; Tanţău et al., 2009), but earlier than in the Western and North-Western Carpathians (5700-5500 cal yr BP; Feurdean and Willis, 2008; Björkman et al., 2003), suggesting a spread from the South towards the North and East. In case of *F. sylvatica*, it is present earlier in West (ca. 7000 cal yr BP; Bodnariuc et al., 2002) than in the East (ca. 3500 cal yr BP; Tanţău et al., 2009).

The first presence of cereal pollen together with increased values of ruderal plants (Chenopodiaceae, Urticaceae and *Cannabis* type) from about 4500 cal yr BP is indication of agriculture at lower altitudes and grazing activities below or at the site.

5.4. Increased landscape openness and diversity between 2300 and 160 cal yr BP

Abies alba became established in the regional forest around 2300 cal yr BP, and the vegetation close to the study site was dominated by coniferous woodlands including *Picea abies, A. alba*, *Pinus* and *Alnus virids* (Fig. 3). The expansion of *A. alba* took place much later at Gărgălău, than in other neighboring sites (Fărcaş et al., 2013; Geantă et al., 2013). The forest in the lower mountain belts and at lower elevation, were occupied by *Fagus sylvatica* mixed with small amounts of other deciduous trees such as *Carpinus betulus* and *Corylus avellana* (Fig. 3). The proportion and diversity of herbaceous plants including anthropogenic indicators (Asteroideae, *Artemisia*, *Secale*, *Cannabis* type, *Plantago lanceolata* and Poaceae) increased between 3000 and 1700 cal yr BP, then again over the last 1000 years. This parallels a decrease in the proportion of arboreal pollen, and may indicate deforestation and/or possible use of fires to open the landscape for grazing, which eventually led to increased landscape fragmentation and diversity. This finding is in agreement to other studies from the Carpathians (Tanţău et al., 2003, 2009; Feurdean et al. 2009; 2013a; Fărcaş et al., 2013; Geantă et al., 2012). The marked rise in *Selaginella selaginoides* spores indicates a wet environment and possibly points to local, morphological changes in the bog.

6. CONCLUSIONS

The Gărgălău sequence represents a good record of the Holocene forest and human impact at high elevation in Rodna Mountains.

(1) The record begins in Preboreal with *Pinus-Picea abies* forests.

(2) The mixed oak forests' are dominated by *Ulmus* during the Boreal and by *Corylus avellana* during the Atlantic. The presence of other taxa (*Fraxinus, Quercus* and *Tilia*) is not continuous and their participation in the regional forests is minor.

(3) At lower elevations *Carpinus betulus* and *Fagus sylvatica* became established in the regional forests around 6500 cal yr BP and 5300 cal yr BP respectively.

(4) During the last 2300 years, *Abies alba* was an important taxon in the vegetation close to the site.

(5) The first occurrences of cereal pollen, evidences of human activities, are recorded at about 4500 cal yr BP. Human impact increased in the last 3000 years.

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