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DOMAIN: GEOGRAPHY

DOCTORAL THESIS ABSTRACT

Paleolimnological investigations in northern Romanian Carpathians

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Summary of the doctoral thesis

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1. INTRODUCTION

Considerations on the study of lake sediments from a paleolimnological perspective

We live in a constantly changing environment. Its dynamics is given by the interaction between the main controls (climate, vegetation, humans), starting from a small spatial and temporal scale towards a global and multi-millennial perspective. The status of the environmental system at a specific point in time represents the temporal consequence of interactions and changes occurred at intra and inter-systemic levels; consequently, without a historical perspective we do not know how a particular environment has developed and what measures should be taken to preserve and protect it.

A long-term approach of the environmental development is not only descriptive, but also provides the necessary background for us to ask ourselves a fundamental question: where are we heading? Current global warming, generally considered an effect of human impact (IPCC, 2014) has generated a series of reactions from the international scientific community, directed towards identifying causes and finding solutions. This has prioritized prediction of changes which would be induced by this expected and modeled climatic evolution to the components of the Earth system.

In order to build more precise scenarios of future climate evolution and its impact on environmental components, there is the need for well documented paleoenvironmental information, with as good as possible territorial coverage and spanning at least hundreds of years. Moreover, next to the quantitative and semiquantitative results, particularly popular and highly topical are studies that attempt to distinguish between the impacts of different controls (drivers) of the medium and long term environmental development, at various spatial scales. And here we may comment upon the clear advantage of lake sediments and peat used as environmental archives[1]: they have the potential to respond to such problems, within the framework of a local to global perspective and spanning years to millennia, under various methodological approaches.

The study of lake sediments has a long history on the international scene (from the very first half of the nineteenth century). The paleolimnological perspective, however, represents the novelty in this area. In Europe and North America, paleolimnology has developed rapidly since the 60s, especially due to the discovery and applicability of the first methods of determining the absolute age of sediments (^{14}C, ^{210}Pb etc.) and especially after the World Meteorological Organization (WMO) acknowledged climate change as a global problem (1979). A new direction, this time focused on finding solutions to prevent the effects of global warming, has clearly emerged since 1988, when the IPCC (Intergovernmental Panel of Climate Change) was founded.

With regard to Romania, more than a century passed from the first sampling and analysis of lake sediments to the use of paleolimnological studies in past climate, vegetation and environmental reconstructions. In 1900, De Martonne and Murgoci published a rigorous geomorphological and sedimentological analysis of the catchment and lacustrine sediments of Lake Câlcescu in Parâng Mountains (*Sondage et analyse des boues du lac Calcescu*), in a pioneer attempt to link sediment properties to the evolution of the local climate. Although the lack of a sedimentation chronology was a serious impediment in establishing causal links between the properties of sediments and paleoenvironmental conditions, this initiative produced information on sediment mineralogy, grain size, structure and biological component. Despite being a pioneer study in Romania, the complexity

[1] Paleolimnology represents an interdisciplinary, border science, which refers to the study of physical, chemical and biological properties of sediments in lakes, swamps and bogs in order to reconstruct paleoenvironmental conditions and decipher the complex relationships between environmental components (Smol, 2009; Last & Smol, 2002a).

of sedimentological analysis employed is notable. However, at the international level, first attempts to relate lacustrine sediment properties with climatic fluctuations were performed in 1838 (Whittlesey 1838, 1850, cited by Cohen, 2003).

The early evolution of paleolimnology in Romania continued with the year 1928, when palynological studies performed on peat were published, with the development of pollen stratigraphies, however without absolute, independent sediment dating. Remarcable from this point of view is the research conducted by Pop (ex. 1929, 1934 in Erdtman, 1943). Later on, studies on sediment sources and dynamics published by Bojoi (1968), Pişota (1971), Rădoane (1983), etc., also employed techniques of lacustrine sediment assessment but without addressing paleoclimatic and paleoenvironmental aspects.

The milestone of the Romanian paleolimnological research is the year 1999, when Fărcaş et al published the first paleoecological study based on absolute chronology, determined using radiocarbon, for Iezerul Călimani and Taul Zănoguții sites (for comparison, the first use of the ^{14}C isotope in dating lacustrine sediments occured around the 50s' in Western Europe). From this point on, paleolimnological research in Romania undergoes an explosive and multidirectional development, also fueled by a favorable European background. One by one, paleolimnological studies add new information to the regional sketches of vegetation and climatic history, and further highlight vulnerabilities of local environments to climate change and human activities.

Despite this accelerated development, the year 2009 shows a relatively small number of paleolimnological sites in Romania, compared to the neighboring European countries. Thus, according to the database compiled by Buczko and collaborators (2009) for the entire Carpathian Region, a total of 120 sites were denominated, distributed as follows: 37 in Hungary, 38 in Poland, 6 in the Czech Republic, 15 in Slovakia, 24 in Romania. This paper reviews only radiometrically dated sites, with at least two proxies analyzed, of which one is a biological proxy. An overview of the spatial distribution of these sites reveals their concentration particularly in the mountain areas of the Carpathians outside Romania, which draws attention on the hypothesis that the Romanian territory is not yet entirely explored in this respect.

Motivation

Using lake sediments as paleoenvironmental archives (paleolimnology) is particularly interesting because it constitutes a relatively recent occurrence among the Romanian scientific studies. Hence our interest in a research direction with the potential to enrich the national paleoclimatic stratigraphy, to provide specific guidelines for employing sustainable environmental management and to contribute to the multidisciplinary development of Geography in Suceava.

Our doctoral thesis proposes to investigate the evolution of the Holocene paleoenvironment in the northern part of the Eastern Romanian Carpathians, Rodna Mountains and Bucovina Mountains respectively, based on the study of sediment properties from four sites (lakes and bogs). We intend to capture a significant part of the issues highlighted above, using a combination of modern and traditional methods in order to provide information on the behavior of local and extra-local environment to the variation of climatic and anthropogenic stressors.

We address two major topics, different in methodology, work steps and temporal and spatial coverage, but complementary in terms of results obtained. The first topic refers to the detailed reconstruction of local environmental response to climate variability, changes in land cover and human impact during the last millennium in the Bucovina (Flysch) Mountains, based on a complex analysis of lacustrine sediments from Iezerul Sadovei Lake (Feredeu Mountains). The second topic consists in the reconstruction of the Holocene regime of biomass burning in relation to climate, vegetation, local morphometry and humans, based on the analysis of charred organic fragments in the sediment of the sites Tăul Muced, Gropile and Ştiol (Rodna Mountains). Emphasis is placed on temporal assessment of the changes occurring in natural ecosystems (conifer timber belt, timberline ecotone, subalpine belt) over the last millennium, during which we believe the human impact on the environment was maximum in our study area.

We hope that this study contribute to building a broader vision of regional and local paleoenvironmental changes under different climatic, vegetation and human impact conditions, both in Romania and in the central-eastern Europe. Moreover, we hope that our results lead to a better understanding of the processes and interactions that occur within the system consisting of the lake and its catchment.

Aim and objectives of the doctoral thesis

In 2011, when we started our doctoral studies, the paleolimnological research in Romania, based on the use of absolute dating methods, slightly exceeded its early stage. The main paleolimnological proxy used was pollen, in combination with plant macrofossils and lithostratigraphical description of sedimentary sequences, while the assessment of physical and / or geochemical properties was spotted only sporadically. Although quantitative and semi-quantitative reconstructions of environmental parameters had already been performed, such studies were, however, very few (ex. Feurdean et al., 2008a). A number of valuable and extensive papers have added to the ensemble of national paleoenvironmental investigations so that today we can speak of a tumultuous development of this new field of research. Both methods and research directions have diversified, the number of investigated sites increased and Romanian climatic and palaeoenvironmental stratigraphy was at least partly compared to the stratigraphies of the Central-Western and Atlantic Europe.

However, for the northern part of the Romanian Carpathians, paleoenvironmental reconstructions based on the analysis of lake sediments and peat properties were at that time very scarce, i.e. focused only on Holocene vegetation dynamics and one study site, namely Poiana Ştiol peat bog, in Rodna Mountains (Tanţău & Fărcaş, 2004; Tanţău, 2006). Published studies massively covered the north-western extremity of the Eastern Carpathians (Wohlfarth et al., 2001; Björkman et al., 2002, 2003; Feurdean & Bennike, 2004); Feurdean, 2005; Feurdean & Astaloş, 2005; Feurdean et al., 2007a,b, 2008; Schnittchen et al., 2003, 2006 etc.). More recent work was published for the central area of Maramureş Mountains - Taul Mare Bardău and Cristina peat bogs (Fărcaş et al., 2013; Cristea et al., 2013) and the subalpine area of Rodna Mountains - Lake Buhăescu Mare (Geantă et al., 2014 a, b) and Gărgălău peat bog (Tanţău et al., 2014). A number of other studies are presently conducted, and the results have not been or will be published.

Therefore, when our doctoral research began, no information was available on the paleoenvironment of Bucovina Mountains, while results for Rodna Mountains were based on vegetation history reconstructed from a single site. Although new paleolimnological data have recently added to our study area, the information is not sufficient to help build a complete and integrated picture of the paleoenvironmental and palaeoclimatic development in the northern Romanian Carpathians. Published results require further investigations and comparative analyses in order to better understand the relationships built over time between climate, local environment and human communities in this area of great ecological and socio-economic value.

To find at least a partial solution to such an important issue, this paper provides a multi-directional, interdisciplinary approach regarding the sites studied, methods and proxies employed, thus generating relevant paleoenvironmental information that should provide a better territorial assessment for the Northern Romanian Carpathians and contribute to the understanding of the dynamics of local environments in relation to natural and anthropogenic drivers.

In order to achieve this **aim**, we employed the analysis of several physical properties (lithological description, water percentage loss, magnetic properties and grain size), chemical (elemental geochemistry, organic matter and carbonates content) and biological properties (macro and microcharcoal, pollen, stomata, macrofossils of woody plants) of sediments from a number of sites distributed at different elevations, in distinct vegetation belts, and with ages spanning from about 1000 cal. yr BP to ca. 9500 cal yr BP. The main proxy assessed for all sites was macrocharcoal, on which we wanted to obtain qualitative and semi-quantitative reconstructions of vegetation fire regime during the Holocene.

Moreover, based on high-resolution, multi-proxy analysis (physical, geochemical and biological proxies employed) we aimed to identify local (at catchment level, in the low elevation, flysch mountain area) and extra-local palaeoenvironmental response to the three main climatic events documented for the last millennium: the Medieval Warm Period (AD 950-1200), the Little Ice Age (AD 1450-1850) and the recent warming. Here we used the site with the best temporal resolution, as well as laminated sediment structure, that facilitated such an approach.

The **objectives** of our doctoral thesis are listed below:

1) to make a high resolution geochemical, palynological and charcoal-based stratigraphy that spans the last millennium, for the Bucovina Mountains;

2) to qualitatively reconstruct – based on this stratigraphy – the dynamics of sedimentation rate, erosion types and intensity (sheet and rill), composition and structure of vegetation and types of human activities over the last millennium in Bucovina Mountains;

3) to determine whether changes in geochemical and biological sediment stratigraphy is due to climatic variability, land-use changes or to cumulative causes / other causes;

4) to construct macrocharcoal stratigraphies for Rodna Mountains, spanning the medium and late Holocene;

5) to reconstruct fire activity, qualitatively and semiquantitatively (where sedimentation rate and temporal resolution allow such analysis), for different elevations and vegetation belts in Rodna and Bucovina Mountains;

6) to qualitatively determine the weight of different controls (climate, vegetation, man, local topography etc.) in defining fire regime for the entire study area during well-defined periods of the Holocene.

2. STUDY AREA AND STUDY SITES

The study area referred to by this thesis partly overlaps the northern group of the Eastern Romanian Carpathians. It includes Bucovina and Rodna Mountains, but in the interpretation of our results we refer punctually to the neighboring low elevation areas, such as valleys and lowlands.

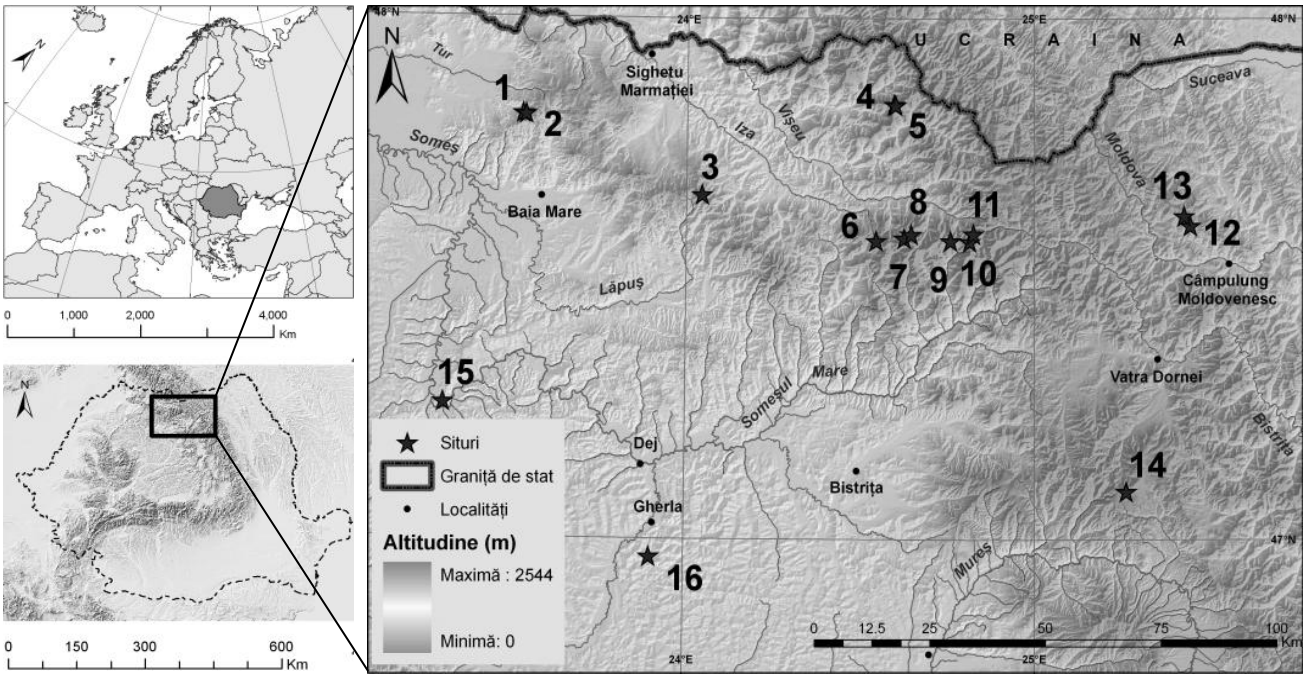

Fig. 1 a) Location of the study area in Romania; b) Main landforms of the study area and distrbution of study sites (6, 7, 10, 12), additional sites (8, 16) and sites used for comparison (1, 2, 3, 4, 5, 9, 11, 13, 14, 15), as rendered below.
1) Preluca Țiganului; 2) Steregoiu; 3) Văratec; 4) Tăul Mare Bardău; 5) Cristina; 6) Tăul Muced; 7) Gropile; 8) Buhăescu Mare Lake; 9) Gărgălău; 10) Știol Lake; 11) Poiana Știol; 12) Iezerul Sadovei Lake; 13) Bolătău Lake; 14) Iezerul Călimani Lake; 15) Turbuța; 16) Ştiucilor Lake.

Within this study we selected a total number of four sites (Fig. 1, Tab. 1), distributed as follows:

i) Iezerul Sadovei Lake located in the southwestern part of Feredeu Mountains;

ii) Știol glacial lake,Tăul Muced and Gropile peat bogs, located in the Rodna Mountains National Park and Biosphere Reserve.

Sediment analysis for Iezerul Sadovei Lake follows the first three objectives of our thesis, while the study sites in Rodna Mountains center around the last three objectives.

We add to our analysis the lakes Buhăescu Mare (Geantă et al., 2014) and Ştiucile (Feurdean et al., 2013), with detailed description found in the papers referred to. We underline our contribution which justifies the use of these two additional sites: we conducted macrocharcoal analysis on the recent sediments (last 150 years) of Buhăescu Mare Lake (Rodna Mountains), and for the Ştiucile Lake (the northern part of Transylvania Plateau) we statistically assessed in detail macrocharcoal concentration and accumulation in recent sediments (last 50 years).

The next step consisted in linking the data obtained to information already published on vegetation dynamics in the study area and neighboring areas. Additional sites, as well as sites used for comparative purposes are shown in Figure 1.

Tab. 1. General information on the study sites

	Tăul Muced	Gropile	Ştiol	Iezerul Sadovei
Spatial coordinates	47°34'26.17" N 24°32'40.39" E	47º34’46.41’’ N 24º37’37.64’’ E	47° 34’ 30’’ N 24° 48’ 55’’ E	47º 36’ 13’’ N 25º 26’ 58’’ E
Geographic location	Rodna Mountains, fnorthern flank, western aspect	Rodna Mountains, fnorthern flank, north-western aspect	Rodna Mountains, northern flank, northern aspect	South-western Feredeu Mountains, south-western aspect
Elevation (m a.s.l.)	1340	1920	1670	930
Area (ha)	0.15	0.38	1.06	0.75
Maximum depth (m)	1.5	1.15	5.7	4.47
Climate	[Tan] =2ºC [Pan]=1200 mm	[Tan] =0.3ºC [Pan] =>1400 mm	[Tan] =1.2ºC [Pan] =1300 mm	[Tan] =4ºC [Pan]=800 mm
Type of site	Oligotrophic bog with two small pools	Peat bog with pool	Glacial lake, anthropogenically dammed	Landslide-dammed lake
Origin of lake basin	Former cavity in Eocene conglomerates, filled with precipitation water	Glacial origin, morraine-dammed basin	Glacial origin, central position within the glacial cirque	Basin formed behind landslide material
Catchment area (ha)	32.2	12.8	156	355.2
Dominant vegetation	Surrounded by *Picea Abies* trees; protected area with rare plant species	Grasses, subalpine vegetation, rare shrubs (*Pinus mugo* etc.)	Vegetation typical of timberline ecotone (grasses, *Pinus mugo* shrubs, rocks, scattered *Picea abies* trees etc.)	*Picea abies* forest, grasses, palustrine and aquatic vegetation
Lithology	Conglomerate (Eocene)	Quartz sericite schists	Quartz chlorite schists	Flysch (black shales, red and striped clays, sandstones etc,)

3. AN INTEGRATED PERSPECTIVE ON THE CLIMATE – VEGETATION – MAN DYNAMICS ON THE ROMANIAN TERRITORY

The vast majority of published research based on the paleolimnological study of lakes and bogs in Romania spans the Late Glacial and the Holocene. Following the assessment of results published so far, several general conclusions can be drawn for the studied territory of the country, concerning the paleoclimatic evolution, vegetation dynamics and impact of human communities on the natural environments.

1. The highest sensitivity to climate change during Late Glacial and early Holocene is specific to sites located at mid elevation (730-1100 m), followed by sites located at lower elevations (Feurdean et al., 2011); only such sites have also recorded climatic variations of lower intensity and duration (Feurdean et al., 2007b; Magyari et al., 2013).

2. During the Late Glacial, temperature fluctuations were more pronounced in winter than in summer, resulting in the manifestation of a pronounced seasonality (Feurdean et al., 2008b; Buczko et al., 2012); vegetation response to the climate changes characteristic of the Late Glacial - Holocene transition showed lower amplitude compared to the North Atlantic Europe.

3. The magnitude of climate fluctuations between 14.7 - 8 ka cal BP was much lower compared to the Western oceanic Europe (Feurdean et al., 2014); the start of the cold intervals during the Late Glacial was accompanied by strong decrease in precipitation (equivalent to increase in continentality); the Late Glacial was characterized by low fire activity; short-lived climatic fluctuations, at ca. 13.9 and 13.2 ka cal BP were generally reflected in changes in vegetation composition (Tanțău et al., 2006, 2014; Feurdean et al., 2007, 2012, b; Magyari et al., 2012).

4. Decreasing temperatures characteristic of the Younger Dryas (12.8-11.7 cal ka BP) were felt strongest in winter; the marked decrease in average precipitation, associated to cooling indicates a gradual transition to more continental and seasonally variable climatic conditions (Feurdean et al., 2014).

5. During the Early Holocene (11.7-8 ka cal BP), high insolation values in the summer led to higher summer temperatures, thus influencing seasonality; biomass burning peaked due to favorable conditions for occurrence and extension of vegetation fires.

6. According to pollen diagrams, the first indications of the presence of human communities in areas neighboring the investigated sites occur in 7900 cal yr BP (Gutâiului Mountains), 7800 cal yr BP in Apuseni Mountains, 6500 cal yr BP in southern Transylvania at Avrig and latest in the southeastern part of Eastern Carpathians (ca. 4000 cal. yr BP);

7. The anthropogenic impact manifested through changes induced by human communities in the vegetation structure and composition, starting with an increase in landscape heterogeneity and continuing with a marked change in the regime of biomass burning, especially from 5500 cal yr BP in lowlands and 3500- 3000 years later in the mountain areas.

8. During the past 2500 years, environmental imbalances caused by anthropogenic interventions (land use change) became more evident compared to previous times, when natural causes had prevailed (Feurdean et al., 2010); the close connection between the main tools employed by prehistoric societies for land management and land-use changes (the use of fire for deforestation and extension of grasslands) and changes in vegetation diversity were highlighted by Feurdean et al (2013).

9. For the last millennium, wet and cold intervals caused reduction in the length of pastoral season at high elevations and coincided with a reduced activity of vegetation fires (eg. during the Little Ice Age), while warm intervals are characterized by expanding agricultural - pastoral activities and implicitly by enhancement in biomass burning (eg. the Medieval Warm Period); the different evolution trends in biomass burning in lowlands compared to the highlands during the Holocene suggest that forests in the Romanian Carpathians began to be cleared much later than in the rest of the Europe (Feurdean et al., 2012).

4. METHODS AND MATERIALS

In the field, site selection was based on morphometric characteristics of catchments and lake basins, elevation and origin of lake basins. Coring was performed using an Uwitec gravity corer for recent, non-compacted or poorly compacted sediments (Last & Smol, 2002; Akinyemi et al., 2013), as well as Russian and Livingstone corers for deeper sediments (Last & Smol, 2002).

The age of the sediment profile extracted from Iezerul Sadovei Lake was determined using ^{14}C isotope concentration for the last 2 m of the profile and by identifying particular historical events for more recent sediments (the uppermost meter). The age-depth models were constructed using Clam (run in R) (Blaauw, 2009) and the MS Excel package. Age-depth models were also constructed for Taul Muced, Gropile and Ştiol sites, based on ^{14}C and ^{210}Pb chronologies, using Clam (Blaauw, 2009).

Determination of water percentage loss for the sediments of Iezerul Sadovei Lake followed the procedure described in Byrne (2004). We determined the elemental geochemical concentration using a portable, shielded X-ray spectrometer Niton XL3t900. The certified reference material used to calibrate the device is NCS DC73308. Interpretation of results was based on the specifications of Mackereth (1966), Engstrom & Wright (1984), Last & Smol (2002b), Cohen (2003) etc.

We assessed the magnetic properties of the sediments of Iezerul Sadovei Lake using a portable Bartington Ltd MS3 susceptibility meter for measuring volumetric magnetic susceptibility and a Bartington Ltd MS2 susceptibility meter with MS2B attached sensor for determining the mass dependent and frequency dependent magnetic susceptibility, following a protocol adapted from Dearing (1994).

Anhysteretic remanent magnetization (ARM) for the same site was determined using a Molspin Limited Alternating Field Demagnetizer - Shielded Demagnetizer AF in combination with Minispin Fluxgate Magnetometer, according to the procedures described by Hutchinson (1995) and Akinyemi et al. (2013). Isothermal remanent magnetization (IRM) was measured using a Molspin Ltd Pulse Magnetiser, in conjunction with Minispin Fluxgate Magnetometer (according to the procedures described in the user manual). Saturation isothermal remanent magnetization (SIRM) was acquired at 1 Tesla, by means of the same combination of equipments as in the case of IRM measurement. Calculation of selected parameters (ex. S-ratios, ARM/SIRM, SIRM/χ, HIRM/ χ_{FD} etc.) was performed following the methodological specifications and interpretations of Thompson & Oldfield (1986), Dearing (1991, 1994), Blundell et al. (2009), Evans & Heller (2003).

Organic matter and carbonate content for the sediments of Iezerul Sadovei Lake were determined following the methodology described by Heiri et al. (2001), while the interpretation of results was based on the specifications outlined by Dean (1974), Heiri et al. (2001), Veres (2002).

Particle size measurement on sediment samples from Iezerul Sadovei Lake was performed automatically by a laser diffraction particle size analizer Horiba LA-950V2 partica, according to the User's Guide (Horiba, 2009). Interpretation was based on Tövissi (1972), Anastasiu (1983), Alin & Cohen (2003) etc.

Pollen preparation for Iezerul Sadovei followed the protocol developed by Bennett & Willis (2001, in Smol et al., 2002, p. 5-32) with modifications. For identification of pollen grains and spores we used the key of Reille (1992) for Europe, descriptions and drawings by Erdtman (1943) and the online database at http://www.geo.arizona.edu/palynology/polonweb.html. Stomata identification followed the taxonomic guide of Sweeney (2004) and Macdonald (2001, in Smol et al., 2002). Stomata, spores and microcharcoal were tallied with pollen.

Identification of woody plant macrofossils for Iezerul Sadovei was performed for wood fragments using the key of Schweingruber (1990). For other fragments of woody plants, taxonomic identification was based on the key included in the corresponding chapter of the Encyclopedia of Quaternary Science (Elias (ed.), 2007, p. 2266-2486), in combination with the Atlas of Seeds and Fruits of Central and East-European Flora: The Carpathian Mountains Region (Bojňanský & Fargašová, 2007).

Macrocharcoal identification and counting for all sites was performed following a protocol derived from Higuera et al. (2005). In interpreting the results we used the specifications of Patterson et al. (1987), Smol et al. (2009), Whitlock & Anderson (2003), Carcaillet et al (2009), etc. Semiquantitative reconstruction of fire regime followed the methodology and specification of Higuera et al. (2009) and Feurdean et al. (2013).

Construction and analysis of the cartographic and graphic material was performed using ArcGIS 9.3, MS Excel 2007, Strater 3 Golden Software and Advanced Grapher 2.2.

5. RESULTS AND DISCUSSIONS

The palaeoenvironment of the Bucovina Mountains during the last millennium

The paleolimnology of Iezerul Sadovei Lake for the last millennium reveals a pronounced variability of environmental conditions in Bucovina Mountains, due to the cumulative action of natural and anthropogenic factors. Based on the analysis of specific physical, geochemical and biological sediment proxies we distinguished four major phases in the evolution of the paleoenvironment at local and extra-local scales. These phases seem to correspond to large scale climatic anomalies documented in the literature for the last millennium (eg. Medieval Warm Period, Little Ice Age, recent/modern warming).

Our results indicate that these stages identified for Iezerul Sadovei were not uniformous in terms of temperature and precipitation regimes, vegetation dynamics and human activities, as well as in what concerns local environmental response to natural and anthropogenic stressors.

Thus, during the first phase, which seems to overlap the second half of the Medieval Warm Period (AD 1060 to 1150, according to our reconstruction) we can differentiate an interval with regional moisture deficit, followed by intervals of moisture excess, with torrential precipitation manifested occasionally. These fluctuations occurred in a climate warmer than today, characterised by intense human activities reflected in the expansion of regional grassland areas (including the use of burning), pastoral activities and cereal cultivation in low elevation areas. The extension of anthropogenic activities, favoured by the climate, led to regional and local changes in vegetation composition and structure, increasing soil vulnerability to erosive action of the environmental factors and contributing to slope destabilization (torrential erosion and mass movement). The vegetation dynamics in this interval is characterized by an accelerated reduction in the share of dominant tree species (spruce, beech, fir) at the expense of pioneer species such as birch, alder or willow. The forested area has maximum extent at the onset of the phase, but varies throughout on a general trend of reduction.

The second phase (AD 1250-1450) appears as a transition between the previous period, warmer, and the climatic cooling specific to the Little Ice Age. Our results indicate a succession of moderately moist of intervals, with less precipitation compared to the onset of the previous period. It is characterized by manifestation at local and extra-local scales of relatively intense rainfall events followed by sheet and deep erosion, on the background of a continuous reduction in forested areas. The dynamics of woody and grass species is particularly active and evident in the landscape, by a reduction of the area occupied by common species such as fir, hornbeam and spruce, whith the increasing importance of herbs. Human presence manifests actively in the form of pastoral activities and deforestation.

The third phase identified (AD 1450-1850) temporally should correspond to the manifestation of the Little Ice Age. It is characterized by colder climatic conditions compared to the neighboring periods and generally moderately dry, with dryness felt mainly in the summer. Abundant biomass corresponds to local and regional increase in fire activity, with direct consequences on the dynamics of sheet erosion (upper soil horizons). However we may observe minimum torrentiality, slope stability and persistence of calmer sedimentation conditions in the lacustrine environment. The dynamics of the regional vegetation structure and composition is characterized in the first part of the interval by expansion of cultivated areas at low elevations, followed by a marked decrease towards the end of the phase. Reduction to minimum of areas occupied by species such as beech, fir and alder occurs parallel with the expansion of the areas occupied by spruce, pine, birch and grassland. Despite such ample changes, the dynamics of forested areas is rather constant, both locally and regionally.

The fourth phase overlaps the last 150 years (AD 1850-2013). The first half of this interval is characterized by higher humidity compared to the second half, due to increase in temperature and precipitation. Under the favorable climatic conditions, reduction of forested areas continued, as compared to the extension of grassland and cultivated areas. Given that at the beginning of the millennium beech represented an important forest constituent in Bucovina Mountains (~ 20%), its

share currently falls below 5% (according to pollen diagrams). Similarly fir, with a share decreasing from ca. 30% around the year AD 1100 to less than 5% at present. Massive reduction of forested areas at regional and local levels overlaps an intensification of human presence at various spatial scales (by the building and expansion of the road network, deforestation and direct interventions on water resources, mining, etc.). As a direct consequence of the extensive removal of forest vegetation, local soil acidification processes occurred, followed by reinstalment of surface erosion and intensification of rill erosion.

We may thus opine on future development directions of the local environment in the Bucovina Mountains. The direct connection between expansion of forest vegetation and slope stability gains importance in the context of intensive human presence and recent changes in the temperature and rainfall amounts and regime, as highlighted by instrumental data.

The Holocene dynamics of fire activity drivers in northern Romanian Carpathians

Analysis of fire activity in northern Romanian Carpathians in relation to natural factors and human activities developed on two levels. The first level consists of a high esolution assessment of fire activity drivers for the last ca. 150 years, a period characterized by marked changes, both climatic and socio-economic. The second level of analysis extends the considered time interval by about 9000 years, thus entirely spanning the medium and late Holocene. The dynamics of local and regional fire activity drivers is assessed based on both qualitative and semi-quantitative reconstructions (obtained in this paper) and qualitative, semi-quantitative and quantitative results (previously published for the study area and neighboring regions).

Over the last 150 years we may observe a general tendency of reduction in fire activity in Rodna Mountains. This trend reaches minimum during the last decade, is also observable for Bucovina Mountains and is attributed to the limiting action and control exercited by the human factor.

For the subalpine and alpine areas, the end of the 19th century and the beginning of the 20th century are characterized by maximum fire activity of the last 150 years, during which historical sources document an intense pastoral activity.

Since 1920, fire activity experienced a sharp decline in coniferous forests, subalpine and alpine belts in Rodna Mountains, with maintaining positive deviations until around 1990. On the background of similar trends, differences in vegetation and morphometry generated additional variability, reflected in fire activity at local level. This decline in fire activity after 1920 is partly a consequence of biomass reduction by anthropogenic removal of subalpine shrub associations to extend grassland areas, doubled by livestock increase (i.e. increase in pressure on the alpine and sub alpine environments) during the socialist regime. The mountains received protected status through the establishment of the Rodna Mountains National Park after 1990, which contributes to the diminishment of vegetation fires over the past two decades.

The control exerted by the climate is clearly shown in the first part of the analyzed interval. Sites at high elevations (high subalpine belt) apparently support a more active influence of climatic factors in shaping local fire activity, while sites located in or near the coniferous forest belt, as well as lowland sites (northern part of Transylvania) appear influenced by other factors.

The influence of the main climatic parameters on fire activity appears negligible since the 1960s, especially for areas located near or within the conifer forest belt. However, for sites located in the mountains, changes in fire activity appear mainly influenced by moisture decrease and secondly by temperature fluctuations.

For the hilly areas of northern Transylvania, the general trend in fire activity contrasts to that recorded in the mountain areas. Fire activity remained low in the first part of the interval. The marked increase in fire activity during the 1980-2005 growing season was not favored by the climate, but represents the result of agricultural land abandonment, which provided support for installation of flammable vegetation through the amount and typology of available biomass.

On the background of this trend recorded for lowlands, we may note for Rodna Mountains both the decrease in pastoral activity after 1990, and the current process of global warming (which

manifests in our study area by an increase in average annual temperature, a slight reductions in precipitation and an extension of the growing season). Based on these observations we consider that conditions are met for a future increase in fire activity in areas located at the upper forest limit, as well as in subalpine and alpine belts in Rodna Mountains.

These natural and anthropogenic influences on fire activity observed during the last 150 years appear clearly outlined within the long-term perspective. The preliminary reconstruction of fire activity in Rodna and Bucovina Mountains confirms research results (i.e. published) for the high and mid-elevation areas of the Carpathians, at various time intervals during the Holocene.

Important similarities are observed in local fire activity for coniferous timber belt and timberline ecotone on the one hand, and subalpine and alpine belts on the other hand. The influence of the dominant type of vegetation on biomass burning appears evident both by the specific type of microclimate created and by the general climatic conditions. Local factors (eg. morphometry) may cause differences in fire activity on the long term, but common trends are maintained for similar conditions of altitude and vegetation.

Although succession of intervals favorable for fire activity showed an increased spatial variability in the northern and northwestern parts of the country during the last 9000 years, the enhancing / restrictive role of the climate appears evident in the biomass burning regime in Rodna Mountains throughout the middle and late Holocene, except for the recent period. The mean fire return interval (FRI) calculated for the coniferous forest belt is 168 years and frequency of fire events is between 8 and 4 events reported per thousand years.

Increased fire activity in the subalpine and alpine vegetation belts starting with about 2500-2000 years BP coincides with a first intensification in human impact, visible in regional vegetation structure and composition. This increased fire activity is also observable for lowlands (Northern Transylvania), and occurs during a documented warmer period (the Roman Climatic Optimum). Moreover, a new intensfication in fire activity is observed at the onset of the Medieval Warm Period in the lowlands and coniferous forest belt (although the trend is also observed in the high subalpine belt) and put again on the manifestation of anthropogenic factors on the background of favorable climatic conditions. During this period at high elevations burned areas extended from the alpine and subalpine belts towards the upper limit of the forest.

Human influence on the vegetation structure and composition (e.g. by using fire as a tool for extension and management of grasslands) is therefore initially observable at low elevations, since about 3000 calibrated years BP (according to information published), later on extending to high mountain areas (approx. 2500-2000 year BP) and subsequently to mid altitudes (ca. 1500 cal. yr. BP) by lowering of the upper forest limit and increase of subalpine and alpine meadow areas. Superimposed on the influence of climate, the human factor intensively altered natural fire regime during the last ca. 1500-1000 cal. BP in the coniferous forest belt, particularly by trigerring an increase in fire magnitude. In other words, the human driver contributed to an increase in either the intensity of fires or the extension of the areas burned, or perhaps both alternatives at the same time.

A new enhancement in fire activity is observed during the last 500 years in and at the upper limit of conifer forests (Rodna and Bucovina Mountains), but also in other mountain areas of the northern and northwestern Romania (according to published information). This intensification shows general common trends and corresponds to a synchronous increase in human impact on the landscape, overlapped on the similarities in the overall vegetation dynamics.

6. ORIGINAL CONTRIBUTIONS TO THE PRESENT STATE OF KNOWLEDGE IN THE FIELD OF THE THESIS

Research activities carried out within our doctoral studies, and the results detailed in this thesis have been obtained by applying new methods, some of them used for the first time in the study region and even at the national level. We summarize below the main original contributions brought by the thesis:

- This thesis is - according to our current state of knowledge - the first integrated paleolimnological approach addressed in the framework of doctoral studies and defended at a Romanian university;

- We investigate key aspects of the climate-vegetation-environment-humans dynamics in an area less studied and highly vulnerable to current and projected anthropogenic pressure and climate change;

- For the first time we place the eastern extremity of the northern Romanian Carpathians, namely Bucovina Mountains, on the paleoenvironmental reconstructions map, by producing detailed, interdisciplinary results spanning the last millennium; we hence illustrate the complexity of relationships that are built both within the system consisting of the lake and its catchment and at the upper level, the interaction of the main environmental factors and reflection of this interaction in sediment dynamics at catchment level;

- We develop age-depth models which display and calculate the evolution of the Holocene sedimentation rates (mid and late Holocene in Rodna Mountains and last millennium in Bucovina Mountains); assessment of sedimentation rates is a topical issue in Romanian geomorphology, and therefore our contribution in this field, particularly through the long-term perspective offered, is important and useful;

- Moreover, we use for the first time modern statistical methods to derive semi-quantitative information concerning reconstruction of fire frequency, magnitude and fire return interval in the last ca. 9000 years in the Carpathian mountain region; the first and only attempt of this kind at national level has been developed by Feurdean et al (2013) for Lake Ştiucile, northern Transylvania.

- We perform at national level the first comparison between macrocharcoal accumulation in recent sediments and variation in main climatic parameters (temperature, precipitation) for the last ca. 150 years; the aim is to analyze in detail fire activity in modern and contemporary periods in relation to natural factors (climate, vegetation, topography morphometry) and anthropogenic drivers (human activities, changing socio-political regimes etc.).

- We construct for the first time at national level a review and assessment of paleolimnological research results published for the Romanian territory; our approach develops regionally towards an integrated perspective; such an approach is highly useful in any paleoclimate study conducted in the Central - Eastern Europe.

The results of this doctoral thesis are important both scientifically and socially, because they refer to the sensitive issue of the past dynamics of natural and anthropogenic factors and the effects of this dynamics on the current state of the environment and the so-called natural landscapes. Our doctoral thesis, through the research methodology used and the interpretation of results obtained can be viewed as a model of interdisciplinary, integrated paleolimnological study, which can also be applied for other study areas. Moreover, chosing within this research a previously less studied area in terms of paleoenvironmental evolution, together with preliminary results obtained, represent a first step in developing and implementing a sustainable local and regional management.

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