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PALEOCLIMATIC AND PALEOENVIRONMENTAL RESEARCH FOR THE COMPREHENSION OF THE PRESENT AND FUTURE ENVIRONMENTAL SUSTAINABILITY IN SERBIA

Abstract: Environmental and climate changes are a threat for the survival of global ecosystems and biodiversity. Climate changes can alter rainfall, influence crop fields, affect human health, cause changes to forests and other ecosystems, and impact energy supply. Paleoclimatic research, even not completely analogue, can illustrate how temperatures, precipitation patterns, cryospheric extent, and biospheric adaptations are affected by greenhouse gas emissions. It is the opportunity to observe Earth s system respond to high carbon dioxide, and paleoreconstructions can help us learn how resilient ecosystems become in a time of change. Investigation of small mammal fossils is very useful for Pleistocene terrestrial environment reconstructions. The methods include: Bioclimatic analysis and actualistic methods. Serbia within the Balkan Peninsula, is an interesting place to study the transition between the Late Pleistocene and Holocene and contribute to the knowledge about the formation of the current biodiversity in central Balkan. In the future, Serbia is expected to be especially affected by climate change. Understanding the response of natural systems to changing climate is important for sustainability, and can guide society in adaptation and mitigation, in order to improve present and future resilience of the country.

Key words: PALEOCLIMATE, PALEOENVIRONMENT,
ENVIRONMENTAL SUSTAINABILITY

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Introduction

Our planet is experiencing environmental and climate changes (change in the statistical distribution of weather patterns that persists for an extended period) that are a threat for environment and biodiversity. Climatic variations are influenced by factors that can be both internal (natural to the climatic system) and external. The anthropogenic influences on climate change are considered critical and relevant in the context of environmental policies at both national and global levels. Regional and seasonal shifts in patterns of rainfall and temperature as consequences of climate change are expected to have dramatic consequences for local communities and human society in general.

Although there is no perfect analogue, it is possible to learn from ”paleoclimates” how temperatures, precipitation patterns, cryospheric extent, and biospheric adaptations are affected by greenhouse gas emissions. Paleoclimate research is the only opportunity to observe how the Earth system responds to high carbon dioxide, underlining a fundamental role for paleoclimatology (Tierney, 2020).

In the past, Balkan Peninsula acted as a refugium for the species living in this territory since it was completely isolated from the rest of Europe. The composure of the newly formed terrain with high mountain tops and natural barriers often allowed autochthonous species to find refuge in isolated areas instead of becoming extinct. Balkan Peninsula is located at the crossroads of Europe and represents the connection of several important migration corridors. Rivers such as the Danube make their way through the mountain ranges, forming roads that migrating animals and humans follow (Roksandić, 2016).

To improve our knowledge of the events that shaped natural systems and human evolution over the past 120 thousand years, it is important to focus on two major climatic events that occurred during this time globally and affected the territory of Balkan Peninsula. The first climatic event that is important is the gradual global cooling after the last major interglacial period (MIS 5) before the Holocene. The second event is the eruption of the Campanian Ignimbrite, one of the largest known volcanic eruptions of the Quaternary. The last major interglacial period before the Holocene (MIS 5), is recorded between 124 kya and 119 kya, peaking at 123 kya. Global mean surface temperatures on Earth were at least 2 °C warmer than today, and mean sea level was 4-6 m higher than today as a result of the retreat of the Greenland ice sheet (Rohling et al., 2007). Most widely used age estimate for The Campanian Ignimbrite Volcanic Eruption, based on 40Ar/39Ar dating, is 39,280

± 110 years BP (Bronk Ramsey et al., 2015). Based on sulfate concentrations in the Greenland ice core records, the eruption may have caused global cooling of 1-2 °C (Costa et al., 2012) or 3-4 °C (Fedele et al., 2008) for a period of 2-3 years. The eruption of the Campanian ignimbrite coincided with the onset of Heinrich Event 4 (H4), a cooling period within the milder climate conditions in MIS 3 (Hemming, 2004). The impact of the Campanian Ignimbrite eruption on human populations and the environment have been widely discussed (Costa et al., 2012; Fedele et al., 2008).

Serbian territory is occupying the central and northern part of the Balkan Peninsula. Geographically north Serbia is a large fertile plain (Pannonian Basin), while in the south the landscape is dominated by two main mountain ranges (Carpatho-Balkan belt in the east, and the Dinaric Alps in the west). Because of the difference in landscape, there is also the observable difference in the preservation of the late Pleistocene sediments and fauna. Most Late Pleistocene paleoclimatic reconstructions in Serbia are done by analysing pollen, small vertebrate, and large mammal fauna. These remains are found in cave sediments (Figure 1), as both mountain ranges are very favourable for the creation of limestone caves. Another approach in reconstructing Late Pleistocene climate is analysing malacofauna from loess sequences. Loess is typically found in North Serbia and recently research of these sediments has been attracting more attention (for example, Markovic, 2000) According to these authors loess sediments contain traces of climate changes from Middle Pleistocene to Late Pleistocene (Markovic, 2000). We compare results from these studies with modern methods applicable on rodent remains, in order to reconstruct climatic conditions within the transition between the Late Pleistocene and Holocene and contribute to the knowledge about the formation of the current biodiversity in central Balkan.

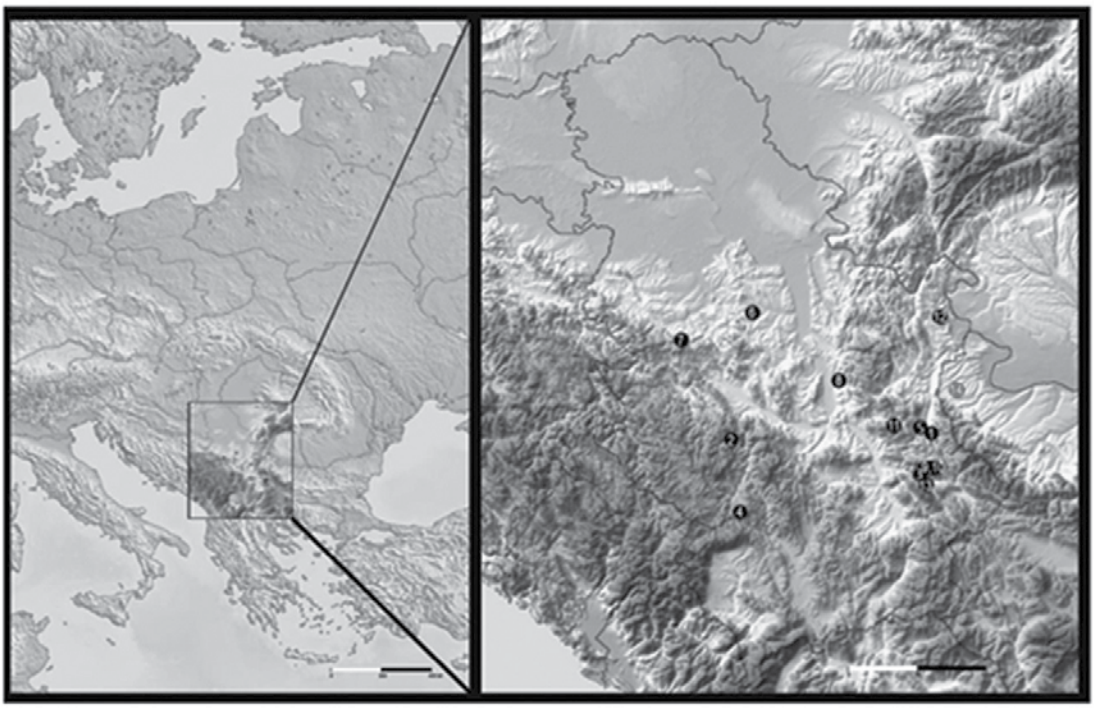

Figure 1: Sites with significant and researched small vertebrate findings. 1, Baranica cave; 2, Hadži Prodanova cave; 3, Pešturina cave; 4, Smolućka cave; 5, Vasiljska cave; 6, Venčac; 7, Petnička cave; 8, Miralovska cave; 9, Velika Balanica cave; 10, Mala Balanica cave; 11, Perućki rock; 12, Canetova cave; 13, Vrelska cave; 14, Magura cave (Bulgaria).

The stratigraphic composition intended for this research ranges from an interglacial period MIS 5 (marine isotope stage with climate on average similar or warmer than today), which is an interesting period in the evolution of climate, because it represents an example of an ecosystem that thrives in conditions warmer than today, and can possibly project to an event of global warming in the future. Certain stratigraphic layers in Serbian caves also recorded various scenarios that happened in the past and may happen again in the future. In a cultural context, the layers were deposited during the Mousterian-Aurignacian-Gravettian succession which is another interesting change in the history of mankind, namely the arrival of Anatomically modern humans.

Neanderthals and anatomically modern humans overlapped in the Balkans for several thousand years (Alex, 2016). During this period of overlap they inhabited different geographic zones, consistent with models of prolonged coexistence through displacement or avoidance. The period of overlap ended by the time of the Campanian Ignimbrite eruption (dated at around 39 kya) and the onset of the Heinrich Event 4 cold phase (Alex, 2016). There is no physical evidence found of Neanderthals living in

Serbia after 44 kya (Mihailović, personal communication). Recent tendency in science to apply multidisciplinary approach on archaeological data showed that Neandertals persisted in Europe longer than previously thought (Carrión et al., 2008; Finlayson et al. 2008), and Balkans could prove to be home of last surviving Neandertals or paleoreconstructions can pinpoint the time and cause of their disappearance, using state of the art methods. The Balkans, as well as the rest of the world, was subjected to several climatic changes during this period. Climatic and environmental changes are recorded by changes in the composition of small vertebrate remains in the strata from caves in Serbia. Fossil small vertebrate assemblages are commonly used as a proxy for the reconstruction of Pleistocene terrestrial environments and climates. Previous research included materials from archaeological sites in Serbia, since researchers had adequate access to only this material.

Material and methods

Rodent remains used in this research have been collected from numerous archeological excavations. Descriptions of the material have been published in various publications (Dimitrijevic, 1995; Bogicevic, 2008; etc). Most data have been collected from previous publications, checked, and updated in the purpose of this research. Other data is still preliminary but can be used in the analysis.

Bioclimatic analysis

The bioclimatic model postulates that there is significant correlation between the climate and mammal communities. According to Hernández-Fernández (2001a, b), Hernández-Fernández and Peláez-Campomanes (2005), and Hernández-Fernández et al. (2007), any mammal assemblages can be included within ten climate types, which can been distributed using the Climatic Restriction Index (CRIi = 1/n, where “n” is the number of climate zones where the species is represented and “i” is the climate zone where the species appears): I Equatorial; II Tropical with summer rains; II/III Transition tropical semiarid; III Subtropical arid; IV Subtropical with winter rains and summer droughts; V Warm-temperate; VI Typical temperate; VII Arid-temperate; VIII Cold-temperate (boreal); and IX Arctic. After obtaining the distribution of a small mammal fossil assemblage according to each climate group, the bioclimatic component (BC; representation by level of each of the available climates) can be calculated using the following formula:

$BCi = (\Sigma\ CRIi)\ x100/S,$

where S is the number of species per unit. From the BC, a mathematical model has been elaborated using a multiple linear regression (Hernández-Fernandez and Peláez-Campomanes, 2005) which allows, by means of a series of functions, various climate

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parameters to be estimated. Based on this method, two climate factors have been estimated: the mean annual temperature (MAT) and the mean annual precipitation (MAP).

Results

The stratigraphical position (Figure 2) of the layers we have studied represents an interesting change in human history. In cultural context layers described are deposited during the Mousterian-Aurignacian-Gravettian succession. The chronology and faunal findings from Baranica, Hadži Prodanova cave, and Pešturina have been thoroughly discussed in Jovanovic et al. 2020.

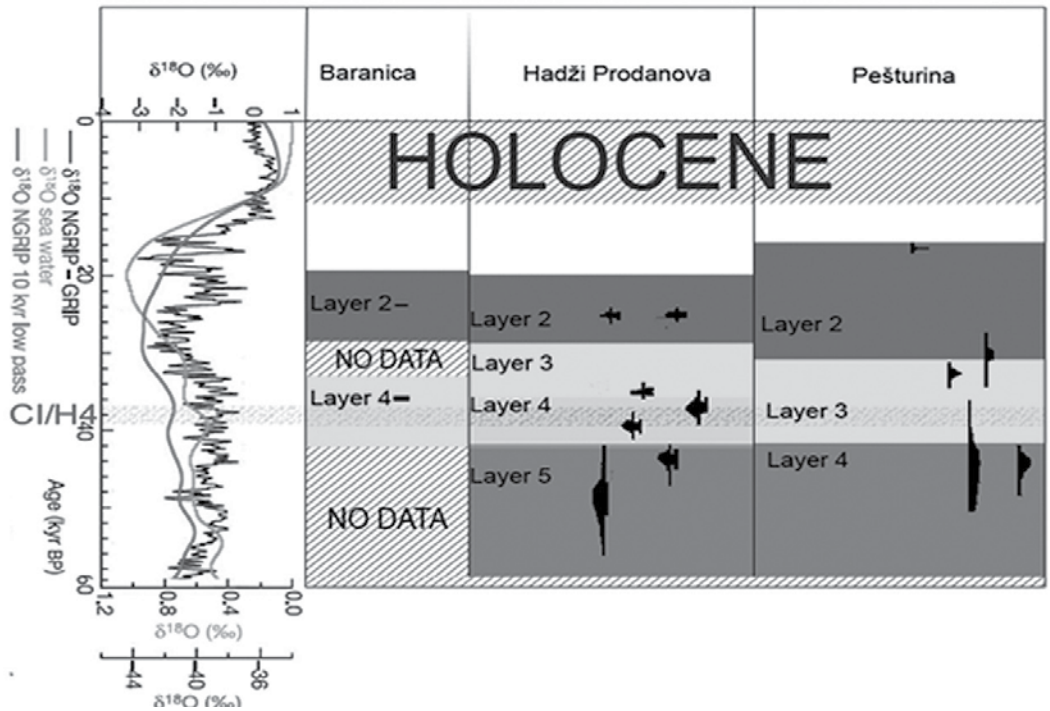

Figure 2 - showing age of chosen samples dated by various authors (explained in the text). Colors are associated with plausible human cultural context: Mousterian (dark green), Aurignacian (light green), Gravettian (blue), and modern (red). In Hadži Prodanova layer 4, human cultural context could not be determined and it is assigned to (Musterian- Aurignacian). Temperature deviation curve has been adapted from Andersen et al. 2004.

Fossiliferous layers containing small-vertebrates have been organized chronologically using numeric datings. Datings in Serbian caves have been collected and adapted for this purpose (Figure 2, Figure 3). Dating procedures have been explained in various publications (most importantly: Alex, 2016).

LAYERS:	PES-L4	HPP/L5	PES/L3	BAR/L4	HPP/L4	BAR/L3	PES/L2	HHP/L3	BAR/L2	SMP/L6	SMP/L5	SMP/L4	SMP/L3z	SMP/L3
MAT (in °C)	8.2	6.0	6.9	8.7	8.0	10.5	7.5	7.8	6.7	10.5	12.0	7.9	9.6	9.1
Today	11.7	10.0	11.7	11.2	10.0	11.2	11.7	10.0	11.2	7.8	7.8	7.8	7.8	7.8
Delta	-3.5	-4.0	-4.8	-2.5	-2.0	-0.7	-4.2	-2.2	-4.5	2.7	4.2	0.1	1.8	1.3
MAP (in mm)	1305.9	1106.1	1052.4	993.7	861.6	824.8	1328.041	1225.1	811.2	1247.5	1430.9	924.2	1178.5	1276.9
Today	595.0	897.0	595.0	605.0	897.0	605.0	595.0	897.0	605.0	610	610	610	610	610
Delta	710.9	209.1	457.4	388.7	-35.4	219.8	733.0	328.1	206.2	637.5	820.9	314.2	568.5	666.9

Figure 3: Bioclimatic analysis results, Mean annual temperature (MAT) in Celsius degrees (°C) and Mean annual precipitation (MAP) in millimetres (mm).

Discussion

Although layers from Smolućka cave have not been successfully dated there have been hypotheses of thair age established on other indicators. Based on analysis of the fauna Dimitrijevic 1991 concludes that layers SMP/L3 and SMP/L3z definitely belong to Late Pleistocene, and theorizes that they might have been deposited simultaneously, which is completely in accordance to our results, as they show that although there is a significant change in habitat ratio between SMP/L3 and SMP/L3z, there are no significant temperature oscillations. Layer 4 is without pottery fragments but with osteological material and chipped stone artifacts, the chronology of this layer remained insufficiently defined. According to Dimitrijević (1991), Layer 4 probably belongs to the second Wurmian stadial stage. The most important findings of the chipped stone artifacts in this layer also confirm Middle Paleolithic age of this layer. When all facts are taken into account we reach the conclusion that this layer could have been deposited during the MIS 4 and possibly late MIS 5. Sedimentological features and mammalian remains of layer 5 indicate interstadial character of this layer. According to the Dimitrijević (1991), this layer is deposited after the first Wurmian stadial, when warmclimate species disappeared from central Europe, and probably the Balkans. The results of the Bioclimatic analysis of the rodent fauna also suggest a warm humid climate indicative for the MIS 5. The proposed age of layer 6 according to its superposition corresponds to the first Wurmian stadial (Dimitrijević, 1991). Layer 6 did not provide identifiable material except a small number of osteological finds. The Bioclimatic analysis shows that Layer 6 is the only layer completely absent of cold elements in rodent fauna, therefore it was probably deposited during the early MIS 5. The chronology and faunal findings from Smolućka cave have also been thoroughly discussed in Jovanovic 2021, and Jovanovic et al. 2022.

The Mousterian-Aurignacian transition is not observable among Smolućka layers, as due to lack of datings it's chronostratigraphical position is uncertain. Among other sites, it is observable between HPP/L5 and PES/L3 (Figure 3). The Bioclimatic analysis shows that there were no dramatic climatic oscillations between within the

MIS 3, while there is a notable drop in temperature in MIS 2 (Figure 3). This proposal is in coincidence with the conclusions drawn for Western Europe. However, in Western Europe, the timing and nature of the overlap have been studied more intensively. Neanderthals are thought to have survived longest in southern European regions, such as the Balkans, Italy, and Iberia.

Conclusions

Overall, there were no important ecological changes during the transition between Mousterian and Aurignacian, i.e. between Neanderthals and Modern Humans. This conclusion is in line with the common opinion that climate change was not a crucial factor in Neanderthal extinction in the Balkans. Nevertheless, it had an effect similar to Iberian and Apennine Peninsulas, where milder climate allowed Neanderthals to find refuge and survive longer than in the rest of Europe.

This paper presents a multidisciplinary approach to the complex problem of climate change with aim to contribute to the understanding of the past events and their effects on the societies and nature. Understanding the response of natural systems to changing climate at local level is important for sustainable development and can guide society in steps towards adaptation and mitigation, in order to improve present and future resilience. It could be very important for Serbia which is in the vicinity of Mediterranean and is expected to be especially affected by climate change even in the near future.

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ПАЛЕОКЛИМАТСКЕ И ПАЛЕОЕКОЛОШКЕ РЕКОНСТРУКЦИЈЕ У СВРХУ РАЗУМЕВАЊА ОДРЖИВЕ ЖИВОТНЕ СРЕДИНЕ У СРБИЈИ

Апстракт: Промене климе и животне средине представљају претњу за опстанак глобалног екосистема и биодиверзитета. Климатске промене могу променити количину падавина, утицати на поља усева, утицати на здравље људи, изазивају промене у шумама и другим екосистемима и утичу на снабдевање енергијом. Палеоклиматска истраживања, чак и не потпуно аналогна, могу да илуструју како промене температуре, количине падавина, површине леда и други фактори утичу на адаптације биосфере која је под утицајем ефекта стаклене баште због емисије гасова. То је прилика да се посматра како Земљин систем реагује на повећање угљен-диоксида. Палеореконструкције нам омогућавају да разумемо процесе формирања отпорних екосистема у време промена. У овом истраживању коришћене су методе које се примењују на фосилима ситних сисара. Методе обухватају: Биоклиматску анализу и актуалистичке методе. Србија у оквиру Балканског полуострва, представља занимљиво место за проучавање прелаза између касног плеистоцена и холоцена, и доприносе сазнањима о формирању биодиверзитета на централном Балкану. У будућности се очекује да ће Србија бити посебно погођена климатским променама, због тога је важно разумети на који начин природни системи реагују на промене. Боље разумевање начина на који се промене дешавају би створило отпорније друштвене системе који су боље припремљени на предстојеће промене.

Кључне речи: ПАЛЕОКЛИМА, ПАЛЕОЕКОЛОГИЈА,
ОДРЖИВОСТ ЖИВОТНЕ СРЕДИНЕ