

1 **The late and middle pleniglacial malacofauna of the**
2 **Zemun loess-paleosol sequence**

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18 **Abstract**

19 The aim of our study was to describe the succession of malacological assemblages along the
20 exposed loess profile located in Belgrade, at the Danube river bank (municipality of Zemun).

21 Deposits which belong to the composite loess unit L1 were sampled. Loess unit L1 included
22 two subunits: L1SS1 – the middle pleniglacial subunit with two weakly developed initial
23 pedogenic horizons and L1LL1 – late pleniglacial loess subunit. Three malacological zones
24 were identified. The molluscs indicate the environment with moderate warm and dry climate

25 and mosaic vegetation type composed of grasslands and forest steppe. Gradual cooling was
26 observed towards the end of the upper last glacial period. Our findings concur with results of
27 earlier studies that the Zemun site and the adjacent area served as a transition zone between
28 the refuge areas within the southeastern part of the Carpathian Basin during late Pleistocene.

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30 Key words: loess, malacofauna, Pleistocene, Serbia, Zemun

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32 **1. Introduction**

33

34 Loess deposits cover 10% of the world's continents and even much larger parts of
35 Eurasia (Pécsi, 1990), and represent some of the most important continental climate archives
36 available (Porter, 2001). During the last decade loess-paleosol sequences (LPS) in Vojvodina
37 region (Northern Serbia) have been established as the most complete European continental
38 environmental terrestrial record during the last 1 Ma (Marković et al., 2009, 2011).

39 Previous studies of loess sections at various exposures in Northern Serbia have used
40 lithological, pedogenetic and magnetic susceptibility (χ) data, along with variations in amino
41 acid racemization geochronology (Marković et al. 2004, 2005, 2006, 2007, 2009, 2014), all
42 combined with luminescence dating, as the primary basis for correlation (e.g. Fuchs et al.,
43 2008; Schmidt et al., 2010; Stevens et al. 2011; Murray et al., 2014; Timar-Gabor et al.,
44 2015). The result has been the establishment of a chronostratigraphy for various loess-
45 paleosol units in Vojvodina region, and the southeastern part of the Carpathian Basin.

46 Because mollusc shells are usually well preserved in the loess layers, examination of
47 malacofauna can produce very detailed information about paleoenvironmental and
48 paleoclimatological conditions during Quaternary. Composition of mollusc taxa is influenced
49 by many factors that exist in their habitat, but primarily by macro- and microclimatic

50 conditions and vegetation structure (Sümegei and Krolopp, 2002). Many previous studies
51 indicated that the last glacial land snails assemblages in the LPS in the Vojvodina region
52 provide opportunity for sensitive temporal and spatial paleoenvironmental reconstructions
53 (Marković et al., 2004, 2005, 2006, 2007, 2008, 2013, accepted; Sümegei et al., 2016).

54 In this study we analyzed the late and middle pleniglacial land snails in scope to better
55 understanding of spatial environmental dynamics in southeastern part of the Carpathian Basin
56 during the last glacial period.

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58 **2. Material and methods**

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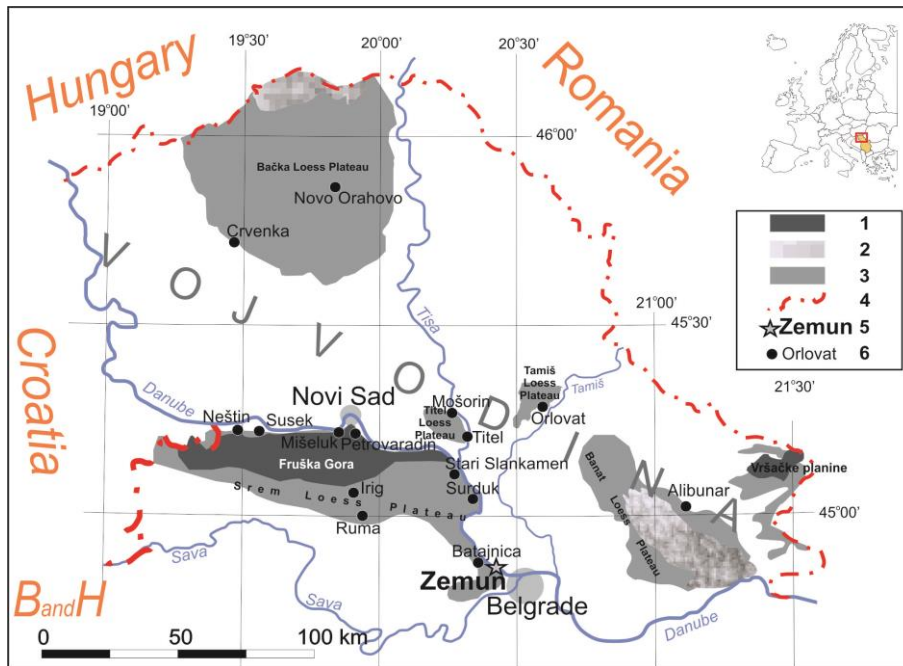
60 LPS near Zemun are nicely exposed along steep cliffs at the Danube river bank (Figure
61 1). The LPS located near the Criminalistic Police Academy (N 44°51'28", E 20°23'13", 105 m
62 a.s.l.), was sampled during 2015. The thickness of the analyzed section was approximately
63 500 cm. Lower part of exposure is completely covered by colluvial material making
64 investigations of older LPS impossible.

65 The nomenclature for chronostratigraphy follows the Chinese loess stratigraphic
66 system, with one exception – we used the prefix "V-" to refer to the standard Pleistocene
67 loess-palaeosol stratigraphy in Vojvodina (Marković et al., 2008). Recently, a Danubian loess
68 stratigraphic model (Marković et al., 2015) has been developed to correlate the loess paleosol
69 units of the Danube Basin with the Chinese loess stratotype sections. Nonetheless, in our
70 paper the use of the Chinese "L and S" labels are applied similarly (e.g. Kukla, 1987) without
71 using any regional prefix.

72 Samples for the low field magnetic susceptibility (χ) variations have been collected
73 over the whole investigated sections with step each 5 cm. Measurements were obtained using

74 a Bartington MS2 susceptibility meter in Laboratory for paleoenvironmental reconstruction,
75 Faculty of Sciences, University of Novi Sad.
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[SP1] megjegyzést írt: paleoenvironmental



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79 Figure 1 Study area. A) Geographic location of the Crvenka brickyard exposure and other
80 relevant sites in the Vojvodinian loess area. Legend: 1. loess plateau; 2. sandy area; 3.
81 mountain; 4; state border; 5. Zemun KPA site; 6. main loess sections.

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85 Samples were taken within the last glacial loess layers (L1), while the top soil cover
86 (S0) was omitted. For the purpose of malacological studies samples of approximately 10 kg
87 were taken continuously at 20 cm intervals. Individual fossils were extracted from loess

88 sediments by washing samples through sieves (0.5–1 mm) in field conditions and then air-
89 dried. Individual shells and shell fragments were further sorted and identified on a dissecting
90 stereo microscope. The abundance was given by the number of complete shells plus the
91 number of apices or apertures which were considered as equivalent to one shell when taken
92 together (Ložek, 1964; Moine et al., 2008; Osipova et al., 2013). Small fragments (lateral
93 shell fragments, collumelae and parts of apertures or apices) were taken into account for
94 counting according to the scheme proposed by Ložek (1964).

95 Identification was done using various malacological literature: Kerney et al. (1983),
96 Pflieger (2000), Fehér et al. (2010), Welter-Schultes (2012) and Nekola et al. (2015).
97 Classification of mollusc taxa according to their ecological preferences (temperature,
98 humidity and vegetation structure) was done by comparison with the interpretations of Ložek
99 (1964), Alexandrowicz (1987), Willis et al. (2000), Sümegi and Krolopp (2002), Sysoev and
100 Shileyko (2009) and Juříčková et al. (2014).

101 Delineation of malacological zones was done using cluster analysis and non-metric
102 multidimensional scaling (NMDS) ordination with PAST software (Hammer et al., 2001).
103 Before Ward's method was selected for clustering, principal coordinates analysis with Bray-
104 Curtis index was performed and original data were replaced with the PCoA scores. The same
105 similarity measure (Bray-Curtis) was chosen for NMDS.

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107 **3. Results**

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109 *3.1 Litho-, pedo-stratigraphy and magnetic susceptibility record*

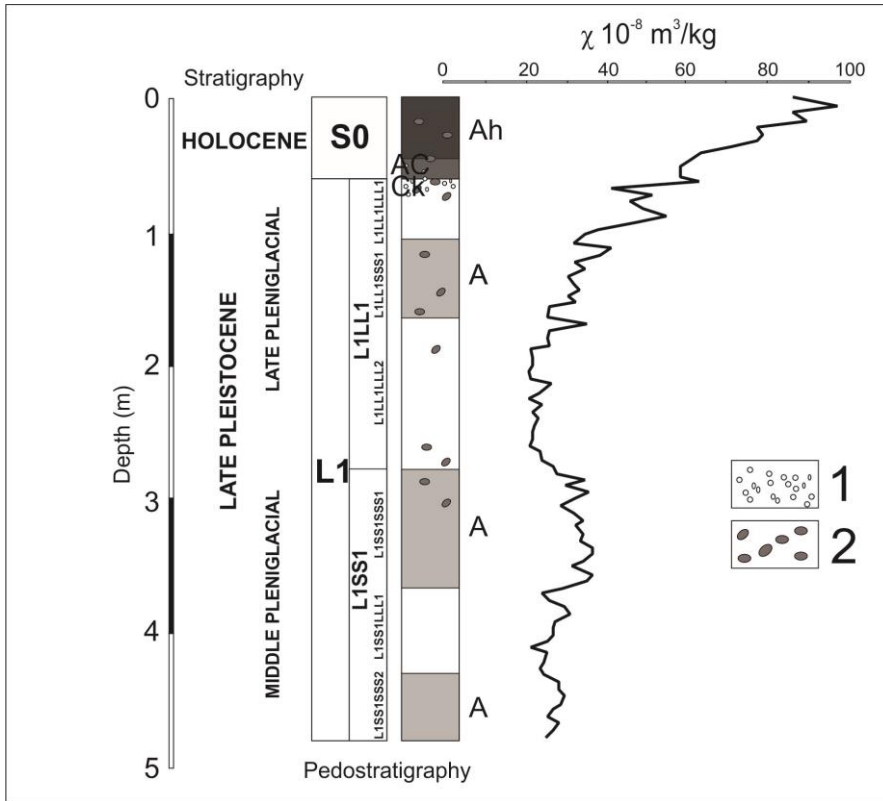
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112 Zemun profile covers the Holocene soil (S0) and the sequence of last glacial units (L1).
113 Two pleniglacial periods were observed within which we characterized three loess and three
114 paleosol layers.

115 The middle pleniglacial period is represented by two weakly developed initial
116 pedogenic horizons L1SS1SSS2 (10 YR 8/2 5/4) and L1SS1SSS1 (10 YR 8/2 5/5) separated
117 by a thin inter loess layer L1SS1LLL1 (10 YR 8/2 5/3). The middle pleniglacial LPS at
118 Zemun site have a typical χ record characterized by two slightly increased magnetic signals
119 approximately $30 \cdot 10^{-8} \text{ m}^3/\text{kg}$, like in many other sections in the Vojvodina region (e.g.
120 Marković et al., 2008, 2009, 2011, 2015; Antoine et al., 2009; Bokhorst et al., 2009),
121 associated with pedogenesis initial interstadial paleosols. Remarkable krotovinas around 3 m
122 of profile depth indicate domination of dry steppic environmental conditions (Fig. 1).

123 The uppermost late pleniglacial loess subunit L1LL1 (10 YR 8/2 4/4) is less cemented
124 and very porous. This loess stratigraphic subunit at Zemun loess section is separated by a thin
125 initial weakly developed paleosol L1LL1SSS1 (10 YR 8/2 5/3). The lowest values of
126 magnetic susceptibility (MS) is observed in subunit L1LL2LLL2 about $20 \cdot 10^{-8} \text{ m}^3/\text{kg}$.
127 However, MS values gradually increase from paleosol L1LL1SSS1 towards modern soil.
128 Presence of many bioturbations in the uppermost part of L1LL1LLL1 loess layer, close to
129 contact with modern soil (S0), indicate strong impact of post depositional process and more
130 visible variations of MS (Fig. 1).



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132 Figure 2 Litho- and pedostratigraphy of the Zemun loess section related to general
 133 stratigraphic interpretations and magnetic susceptibility record. Legend: 1 – Krotovinas; 2 –
 134 Carbonate concretions.

135

136 At the top of the investigated section, the modern soil is a 60 cm thick carbonate
 137 chernozem. The lower Ck horizon contains many CaCO_3 nodules of 1 to 3 cm in diameter,
 138 numerous krotovinas and root channels filled with humic material. A transitional AC horizon
 139 (10 YR 5/1 3/3) is a 15 cm thick, very porous, silty loam with fine granular structure. The
 140 uppermost Ah horizon (10 YR 6/3 3/3) is a 40 cm thick silty loam with typical granular

141 structure and some carbonate pseudomycelia. Magnetic susceptibility values gradually in
142 increase in modern soil S0 from 40 to almost 100 30 10⁻⁸ m³/kg.

[SP2] megjegyzést írt: I think here something miss

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144 3.2 Malacofaunistical investigations

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146 Twenty two samples of the Zemun loess profile were taken for malacological analyses.
147 A total of 3684 whole fossil shells of adult individuals were extracted from the sediment,
148 together with 3757 apertures, 2969 apices and 2843 various small fragments. Complete and
149 reconstructed shells (combined apertures and apices, together with calculated number of
150 whole shells based on small fragments) produced 8846 identifiable mollusc shells. Eighteen
151 species from 14 genera were identified. Rudimental slug shells (163 shells) could not be
152 identified but belonged to species of Milacidae, Limacidae or Agriolimacidae. Shells of
153 *Cecilioides acicula* (O. F. Müller, 1774) were omitted from analyses. This recent species is
154 subterranean and can bury themselves 20–40 cm (up to 2 m) into the sediment (Welter-
155 Schultes, 2012). Furthermore specimens of this species can also be secondarily deposited in
156 the loess material by the process of bioturbation (Ložek, 1985). Only one shell of the juvenile
157 individual that appeared to be *Quickella arenaria* was found and was excluded from analysis
158 as well.

159 The loess sequence at Zemun contained terrestrial mollusc assemblages that share
160 relatively high abundance of *Pupilla triplicata* and *Vallonia costata*, but differed in the
161 presence of other species with vast range of ecological preferences. Based on changes in
162 species richness and abundance (Fig. 2), as well as on the results of cluster and ordination
163 analyses (Fig. 3, 4) three malacological zones can be distinguished. Snail fauna of each of
164 these zones have a specific set of ecological preferences (Fig. 5).

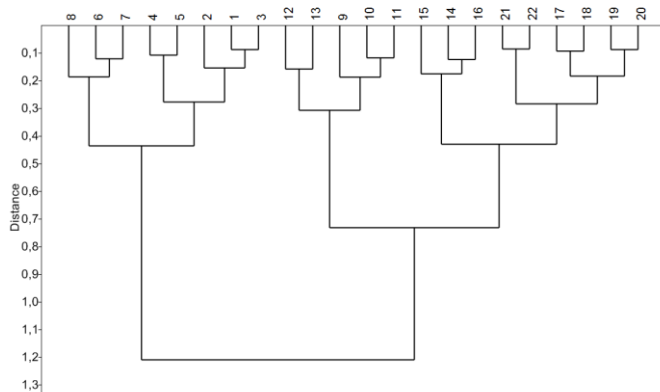
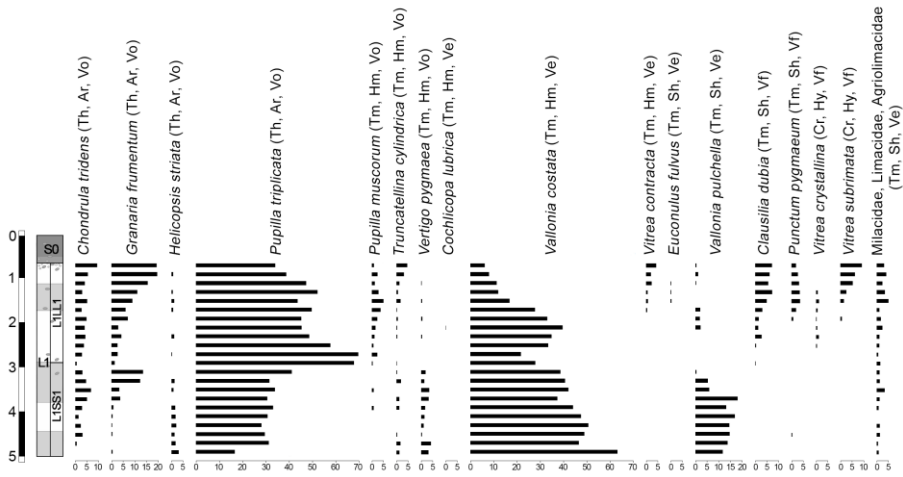
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168 Fig. 2. Species abundance diagram of the loess section. The values represent the percentages
 169 of total number of taxa found in a sample. Abbreviations in parentheses are as follows:
 170 Temperature: thermophilous – Th, mesophilous – Tm, cold resistant – Cr; Humidity: aridity
 171 resistant – Ar, mesophilous – Hm, Subhygrophilous – Sh, Hygrophilous – Hy; Vegetation:
 172 open vegetation – Vo; ecotone vegetation – Ve; forest – Vf.

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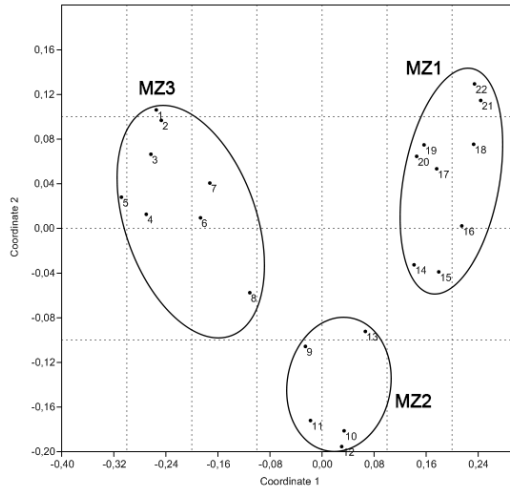


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176 Fig. 3. The results of the cluster analysis of the malacocoenosis from the Zemun loess profile.

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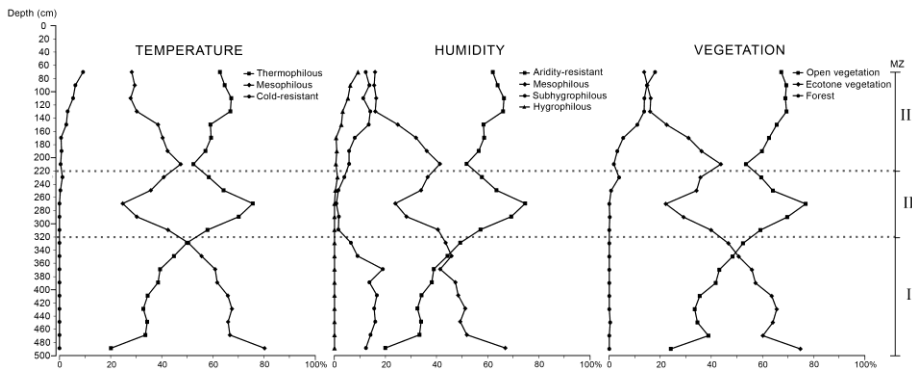


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180 Fig. 4. The results of the NMS analysis of the fossile mollusc fauna from the Zemun loess
181 profile.

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185 Fig. 5. Ecological preferences of the loess malacofauna.

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187 Paleoenvironment as recorded at Zemun LPS is characterized by the continuous
188 presence of two mollusc species – *Valonia costata* and *Pupilla triplicata*. Although their
189 numbers fluctuated, they remained dominant elements that shaped the assemblage.

190 First mollusc zone (MZ1) is placed between 500 and 320 cm, into the middle
191 pleniglacial period. High presence of *V. costata* in this zone indicates a mesophilous open or
192 semiopen environment, such as a forest steppe ecotone. *Vertigo pygmaea* that is typical for
193 low grassland areas was also commonly found in this zone. Thermophilous and xerophilous
194 species remained at low numbers throughout MZ1, which also point to mesophilous
195 conditions.

196 Second mollusc zone (MZ2) developed between 320 and 220 cm. It includes parts of
197 the middle and late pleniglacials. The most important change is a drastic increase in the
198 proportions of *Pupilla triplicata*. *P. triplicata* is dry open vegetation preferring species that is
199 representative of steppe environment. An increase in the abundance of the xerophilous and
200 open habitat species *Chondrula tridens* was also noted. The faunal change in MZ2 point to a
201 transition from mild humid to drier conditions. Low grasslands were the prevailing type of
202 vegetation during this period.

203 Third malacological zone (MZ3) is located between 220 and 60 cm, and stretches all
204 the way to the top layer of the Holocene soil (S0). This zone is placed in the late pleniglacial
205 period. A pronounced faunal change can be observed in this zone. The ratio of thermophilous
206 and xerophilous species decreased, while cold-loving species, characteristic for more humid
207 habitats, started to increase in number. Mollusc fauna of this zone is considerably more
208 diverse, however only a few species achieved dominance in the assemblage. The appearance
209 of *Vitrea subrimata* and *V. crystallina* indicate forest and ecotone environment. Other shade-
210 loving species, such as *Vitrea contracta*, *Truncatellina cylindrica* and *Clausilia dubia* also

211 increased in abundance. The faunistic change of MZ3 suggest an increase of vegetation cover
212 and an onset of colder climatic period in the study area.

213

214 **4 Discussion**

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216 Due to climatic fluctuations during late Pleistocene the structure of the last glacial loess
217 (L1) varies in different loess localities across the Vojvodina region (Marković *et al.*, 2008).
218 Nevertheless, stratigraphy of the Zemun LPS show close similarities with the Batajnica loess
219 profile, probably because sites are spatially close to each other and both are positioned at the
220 Danube river bank (Marković *et al.*, 2008; Osipova *et al.*, 2013). We observed similar
221 magnetic susceptibility (MS) pattern in L1 of the Zemun and Batajnica sections. MS values
222 are related to marine isotope stages (MIS) 3 to 1. Both sections are characterized with two
223 weakly developed interstadial paleosols that formed within L1SS1 during the middle
224 pleniglacial interval. MS values of those pedocomplexes are only slightly higher than loess.
225 The youngest loess layer L1LL1 accumulated during dry and temperate stadial in the late
226 pleniglacial. Sedimentary proxies also suggest that conditions at Zemun site were similar to
227 Batajnica (Marković *et al.*, 2008; Osipova *et al.*, 2013).

228 Malacological results imply a change in climatic conditions and subsequently in
229 vegetation structure. Relatively monotonous and poorly diversified malacocoenosis of the
230 mollusc zone 1 (MZ1) was characterized by the paleoassociation of *Vallonia costata* and
231 *Vertigo pygmaea*. Mesic elements are replaced by xeric associations of *Pupilla triplicata* and
232 *Chondrula tridens* in MZ2. Following gradual cooling, open vegetation (steppe) that
233 extended during mild climatic periods was partially replaced with closed vegetation cover
234 (forest). The vegetation structure was probably mosaic, with grasslands and patches of
235 forested areas (forest steppe). In the southern part of the Great Hungarian Plain similar

236 change was observed under arid local conditions, where short-grassed steppe vegetation
237 developed during the interstadials of the last glacial, while during cold periods, vegetation
238 density increased and forest steppe (mosaic-like vegetation) and long-grassed steppe became
239 dominant (Sümegei *et al.*, 2016). It is known that the mosaic-like vegetation is capable of
240 supporting high faunal diversity (Olf *et al.*, 1999; Adler *et al.*, 2001). Our observation of the
241 increase in the number of species in the MZ3 (upper last glacial) is also in compliance with
242 this statement.

243 Mollusc assemblage of the Zemun LPS show a constant presence of certain warm
244 loving and xerophilic species (*Pupilla triplicata*, *Granaria frumentum*, *Chondrula tridens*).
245 Even though their abundance is higher during interstadials, and is generally lower toward the
246 end of the late pleniglacial, they maintained high presence. This suggests that the late
247 Pleistocene climate in the analyzed region was dry and relatively warm. The cooling that
248 started towards the end of the upper last glacial period was not as intense at the Zemun
249 locality compared with glacial periods at other sites in Central Europe. Paleoclimatic and
250 paleoenvironmental reconstructions indicate that the Vojvodina region was located at the
251 northern edge of a southeastern European "warm" glacial province and was under
252 Submediterranean influence (Marković, 2007). Therefore, continental climatic conditions
253 were somewhat mitigated.

254 The most significant change in mollusc fauna occurred at the end of the glacial (in
255 MZ3). Species associated with an increased vegetation cover and elevated levels of humidity
256 appeared. Forest steppe vegetation existed during this period. It is believed that grassland and
257 forest steppe mosaics that existed in the Vojvodina region served as a transition zone that
258 mollusc species used while seeking refuges in nearby areas (Sümegei *et al.*, 2016).

259

260 **5 Conclusions**

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262 Investigations of the loess-paleosol sequence at Zemun have established the importance
263 of this site as a record of late Pleistocene paleoclimate and paleoenvironment in Serbia.
264 Sedimentological, pedological, magnetic, and malacological evidence suggest a relatively
265 dry and warm conditions in this region. Gradual cooling was observed toward the end of the
266 late pleniglacial period, however it was less pronounced than in other parts of Central Europe.

267 Identified malacofauna revealed important paleoclimatic and paleoenvironmental
268 interpretations: 1) loess of MZ1 formed in a mild forest steppe environment; 2) loess of MZ2
269 formed in a typical dry and temperate steppe environment; 3) loess of MZ3 formed in a
270 cooler and more humid forest steppe environment with a denser vegetation cover. During the
271 last glacial Zemun and other adjacent localities probably served as a transition zone used by
272 molluscs during their migrations between refuge areas. We can speculate that one such
273 migration route led towards the Fruška Gora mountain which sheltered terrestrial snails
274 from unfavorable conditions at the end of the Pleistocene.

275

276 **Acknowledgements**

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278 This study is financed by Serbian Ministry of Education, Science and Technological
279 development grants 176020 and 47007. Logistical support during the fieldwork was provided
280 by Belgrade Fire Service Rescue unit of Serbian Ministry of Interior. We thank Miloš Ostojić
281 and Daniela Constantin for their help with sampling.

282

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