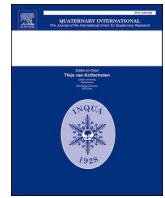


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## *Stephanorhinus kirchbergensis* (Jäger, 1839) (Mammalia, Rhinocerotidae) from the Po valley (Lombardia, Northern Italy): possible diet/nutrition and living conditions

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### ABSTRACT

In July 2013, a *Stephanorhinus kirchbergensis* (Jäger, 1839) skull was found along the Po River near Spinadesco (Cremona, Lombardia, Northern Italy). It was found in an excellent preservation status even if without the lower jaw as well as the third left upper molar. At that time, a certain amount of plant remains was found inside the dental fossettae. Later pollen analyses on this material were carried out in order to hypothesize the possible diet/nutrition as well as the related living conditions of *S. kirchbergensis* on that territory.

These analyses revealed that the material consists of peat containing an amount of 496 pollen and spores. This assemblage allows to assume that *S. kirchbergensis* from Spinadesco lived in interglacial periods within the MIS 19–MIS 5 time span (late Middle Pleistocene). The pollen complex is suggesting a palaeoenvironmental landscape like a grassy vast alluvial plain above which there were mesophilic forests dominated by beeches, therefore in a moderately humid climate. *S. kirchbergensis* from Spinadesco probably consumed twigs of the sea buckhorn (*Hippophae rhamnoides* L.) and Rosaceae shrubs as well as Asteraceae. Finally, the most probable time of its death and its relative burial was in a spring or in a summer period coinciding with blossom period for sea buckhorn.

Up to now as few *S. kirchbergensis* remains were found in a relatively limited number of localities on the vast Eurasian landmass, it still appears to be a rare species. Furthermore, no chrono- or biostratigraphic data are available in most of the cases. The *S. kirchbergensis* skull from Spinadesco represents one of these cases.

### 1. Introduction

In July 2013, an extraordinary well-preserved skull of *Stephanorhinus kirchbergensis* (Jäger, 1839) (also known as “Merck’s rhinoceros” or “nosorog Merka” in Russia) was recovered on an alluvial bar of the Po river not far from the small town of Spinadesco (Cremona, Lombardia, Northern Italy) (Persico et al., 2015).

This present study focused on the analysis of pollen within the peaty residues found in the teeth presenting – for the first time in the Po Valley – a palynological association capable of reconstructing diet, palaeoenvironment and death season of the specimen under study. The absence of a stratigraphic order and consequently of relative dating as well as radiometric ones relating to the fossils from the Po prevents studies carried out with the criteria adopted by Asperen and Kahlke

(2015) as well as Rivals and Ziegler (2018). In fact, in these studies the reconstruction of ecosystems was performed by the study of the fauna associations found in situ and by morphometrics and mesowear analyses. In the work of Asperen and Kahlke (2015) deductions are made on the *S. kirchbergensis* diet thanks to the observation of sympatric distributions of this species and of *S. hemitoechus* evaluating this overlap of areas as a low variability or, conversely, as a high environmental variability. In archaeological sites with high-resolution stratigraphic records, the combined use of tooth mesowear and microwear permitted the identification of seasonality in the accumulation remains (Rivals and Ziegler, 2018). This ordered stratigraphic condition is not compatible with the present case.

The skull – found without its mandible – preserves all the teeth, the third left upper molar apart. At that time, a certain amount (about 3.4 g)

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of plant remains was found into the dental fossettae. Some time later it was decided to carry out pollen analyses on this plant detritus in order to hypothesize the possible diet/nutrition as well as the related living conditions of the species in that specific area.

In literature, some previous studies concerning *S. kirchbergensis* diet are already known.

By way of example, recent investigations by some authors are taken into consideration here. In accordance with the Van der Made and Grube (2010) reports, in Western Europe the *S. kirchbergensis* diet was probably made up of foliage and bushes.

In more recent times, a similar investigation performed on the *S. kirchbergensis* from the Chondon River valley (Arctic Yakutya, Russia) (Kirillova et al., 2016; Kirillova et al., 2017) revealed that the *S. kirchbergensis* diet included grasses (Poaceae), herbs (Dicotyledones), mosses (*Aulacomnium* sp., *Polytrichum* sp.), trees (*Salix* sp., *Betula* sp., *Larix* sp. as well as Pinaceae), heather (Ericaceae as *Vaccinium*), foliage, and shrubs. These results suggest a mixed feeder's diet for the Chondon River *S. kirchbergensis*. In particular, the results achieved lead Kirillova et al. (2017) to believe that – during the last months of its life – the specimen of the Chondon River fed predominantly on leaves and twigs. The habitat of the Chondon River comprised grassland and open woodland that were characterised by moist and cold climate conditions similar to those in the region today.

Further previous works discuss the possible *S. kirchbergensis* diet through palaeoenvironmental assessments and comparison with the data of the coeval herbivorous fauna association, however without objectively listing the plant species consumed by *S. kirckbergensis* (Rivals and Lister, 2016; Rivals et al., 2009). The indications of nutritional behavior of the species are used for palaeoecological and vegetable reconstructions (Rivals and Ziegler, 2018).

The aim of this study is to identify in detail the botanical taxa constituting the *S. kirckbergensis* diet deducing the palaeoecological and seasonal conditions at the time of the death of the only specimen found in Italy certainly belonging to this species.

## 2. Material and methods

As normally happens in the case of fossils from the Po floods, the skull was found disjointed and in an allochthonous position. Therefore, no stratigraphic references are available in this regard. Despite this find situation – which is certainly characterized by a very low river transport – peat remains strongly compacted and different from the sandy and clayey sediments abundant in the river bed have been preserved in the dental fossettae.

The sediment sampling took place, following its discovery during the palaeontological analysis of the fossil, in the laboratory of the Museo Paleontologico del Po of San Daniele Po (CR).

The pollen analyses were carried out on a sample of plant detritus with sand and clay particles (total weight ca. 3.4 g) which was collected from the teeth cavities of the *S. kirchbergensis* skull from Spinadesco.

The compacted peat found in the teeth has no sedimentological analogies with other sediments that constitute the Po river bar mainly consisting of sand, gravel and silt. Peat sediments similar to those sampled were also found in outcropping layers in the Adda river (Persico et al., 2012), 10–15 km at north of the area where the fossil under examination was found. There is no stratigraphic correlation between the levels of peat found and the samples recovered from the teeth, but the facies – in context of river sedimentation – are compatible and reflect the same, repeated, sedimentary conditions.

The sample was treated with NaOH (20%), HCl (10%) HF (40%) and HCl (10%) according to the standard procedures (Methodical recommendations for the technique of processing sedimentary rocks during spore-pollen analysis. All-Union Geological Research Institute, Leningrad, 1986). The extraction of pollen and spores was done by gravitation separation using K–Cd liquid mixture (density 2.2 g/cm<sup>3</sup>) without acetylation treatment. The pollen were identified and counted using light

microscope Leica DM 1000 with magnifications of ×400, ×630, and ×1000. The identification of pollen was conducted with the help of published atlases and other sources as well as the comparative collection of the Laboratory of the Mesozoic and Cenozoic Continental Ecosystems of the Tomsk State University (Siberia, Russia). The percentage sum is based on ratios of terrestrial angiosperm pollen (excluding the aquatic palynomorphs), the spores of vascular plants, and non-pollen forms.

## 3. Results

The results of the analyses are in Table 1, while the percentage diagram of the pollen taxa is showing in Fig. 1. In total, 496 grains were found including non-classified pollen of angiosperms. Besides pollen and spores, the remains of the diatoms (*Pennatophyceae*), fragments of plant macrofossils, rare fungal remains (hyphae and fruiting bodies), mineral grains, and rare charcoal particles were also identified. Tree pollen constitute around 50% of the total amount of pollen (Table 1). Dominant pollen types (ca. 43.2%) are: *Fagus* sp., *Quercus* sp., *Betula* sp., *Ulmus* sp., *Carpinus* sp., *Fraxinus* sp., and coastal taxa of *Alnus* sp. and *Salix* sp. Conifer pollen (8%) belongs to *Pinus* sp. and *Abies* sp. The most numerous taxa of tree pollen are *Alnus* sp. and *Fagus* sp. while *Abies* sp., *Carpinus* sp. and *Fraxinus* sp. are very rare. The characteristic feature of the pollen spectrum is a significant percentage of shrub pollen (17.3%) with sea buckhorn (*Hippophae rhamnoides* L.) as dominant species. Terrestrial herb pollen (31.6% of the total amount) belongs to 16 taxa with domination of Asteraceae (*Cirsium*-type), Fabaceae and Rosaceae. The pollen amount of *Artemisia* sp. and Chenopodiaceae does not exceed 1.5%. Pollen of aquatic and coastal herbs belongs to Cyperaceae, *Potamogeton* sp., and *Myriophyllum* sp. Rare spores are assigned to four taxa with *Lycopodium inundatum* L. as the most typical species. Hence, upon completed the pollen analysis 496 grains were identified overall (Fig. 2).

## 4. Interpretation and discussion

The dietary spectrum of a herbivorous community would suggest as a whole our understanding of the vegetation environments in a given location, especially where direct palaeobotanical evidence is limited or lacking (Rivals and Lister, 2016). In the current case, this role is played by the sole pollen spectrum coming from *S. kirckbergensis* hitherto known.

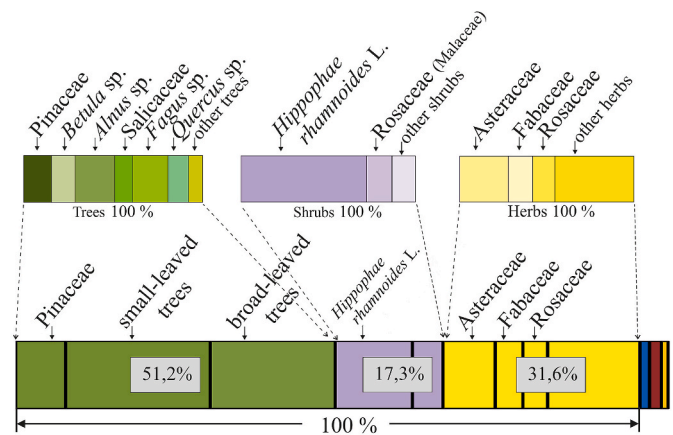
The composition and ratios in the pollen-and-spore spectrum reflect the landscapes occupied by various plant assemblages. Concentrations of tree pollen exceed threshold values (Table 1) which points to the regional presence of the trees around the locality (Lisitsyna et al., 2011). An exception is represented by the pollen of *Abies* sp. and *Fraxinus* sp., but it can be considered as transported from far away by wind. Therefore, despite relatively low ratio of tree pollen (51.2% of total pollen-and-spores), it is possible to assume the presence of deciduous forests with admixture of pine. The dominant species were mesophilic moisture-loving species such as *Alnus* sp. and *Fagus* sp.

The coastal and aquatic vegetation (*Alnus* sp., *Salix* sp., *Cyperaceae*, *Potamogeton* sp., *Myriophyllum* sp., *Lycopodium inundatum* L.) is well-represented, and this can testify in favour of coastal environment around the fossil locality. Domination of *Alnus* sp. (31%) witnesses the presence of the well-developed coastal forest. At the same time, a large amount of pollen of terrestrial herbs and their taxonomic diversity suggest the presence of vast and fertile meadows. Rare pollen grains of xerophytic herbs give us ground to suggest the mesophytic-type vegetation. Probably, the high amount of sea buckhorn pollen testify the presence of sandy soils on the river terraces in the surroundings of the fossil locality.

The composition of the spore-and-pollen spectrum derived from the sediments found in the *S. kirchbergensis* from Spinadesco dental fossettae reflects the grassy floodplain with patches of nearby forest. On the river terraces above the floodplain, the broad-leaved forest dominated by *Fagus* sp. with admixture of pine existed.

**Table 1**  
The composition and the ratio of taxa.

	The amount of pollen and spores	The composition of the spore-pollen spectrum	The ratio of taxa in the group
<i>Abies</i> sp.	1	0,2	0,4
Pinaceae	21	4,4	8,6
<i>Piceae</i> sp.	2	0,4	0,8
<i>Pinus</i> s/g Dyploxylon	6	1,3	2,5
<i>Pinus</i> s/g Haploxylon	8	1,7	3,3
<b>Total Pinaceae:</b>	<b>38</b>	<b>8,0</b>	<b>15,6</b>
<i>Alnus</i> sp.	54	11,4	22,2
Salicaceae	24	5,1	9,9
<i>Betula</i> sp.	32	6,7	13,2
<b>Total small-leaved trees:</b>	<b>110</b>	<b>23,2</b>	<b>45,3</b>
<i>Carpinus</i> sp.	6	1,3	2,5
<i>Fagus</i> sp.	48	10,1	19,8
<i>Fraxinus</i> sp.	1	0,2	0,4
<i>Quercus</i> sp.	28	5,9	11,5
<i>Ulmus</i> sp.	12	2,5	4,9
<b>Total broad-leaved trees:</b>	<b>95</b>	<b>20,0</b>	<b>39,1</b>
<b>Total trees:</b>	<b>243</b>	<b>51,2</b>	<b>100,0</b>
Cornaceae (Cornus)	2	0,4	2,4
<i>Corylus</i> sp.	7	1,5	8,5
Elaeagnaceae	2	0,4	2,4
<i>Hippophae rhamnoides</i> L.	59	12,4	72,0
Rosaceae (shrubs)	12	2,5	14,6
<b>Total shrub pollen:</b>	<b>82</b>	<b>17,3</b>	<b>100,0</b>
Apiaceae	6	1,3	4,0
Asteraceae	7	1,5	4,7
Asteraceae (Cirsium-typ)	29	6,1	19,3
Asteraceae	4	0,8	2,7
<i>Artemisia</i> sp.	2	0,4	1,3
Caryophyllaceae	1	0,2	0,7
Cichoriaceae	2	0,4	1,3
Chenopodiaceae	5	1,1	3,3
Fabaceae	21	4,4	14,0
Onagraceae	1	0,2	0,7
Poaceae	7	1,5	4,7
Ranunculaceae	8	1,7	5,3
Polygonaceae	6	1,3	4,0
Rosaceae	19	4,0	12,7
Solonaceae	1	0,2	0,7
Valerianaceae	3	0,6	2,0
Triporopollenites	2	0,4	1,3
Tricolpopollenites	8	1,7	5,3
Tricolporopollenites	18	3,8	12,0
<b>Total herbs:</b>	<b>150</b>	<b>31,6</b>	<b>100</b>
<b>Total land plants</b>	<b>475</b>	<b>100,0</b>	
Cyperaceae	2	0,4	
<i>Potamogeton</i> sp.	1	0,2	
<i>Myriophyllum</i> sp.	4	0,8	
<b>Total aquatic and wetland plants:</b>	<b>7</b>	<b>1,5</b>	
<i>Equisetum</i> sp.	4	0,8	
Monoletes	2	0,4	
<i>Botrychium</i> sp.	1	0,2	
<i>Lycopodium inundatum</i> L.	1	0,2	
<b>Total spores:</b>	<b>9</b>	<b>1,9</b>	
Angiospermae	5	1,1	
<b>Total:</b>	<b>496</b>	<b>104,4</b>	



**Fig. 1.** The total composition of the spore-pollen spectrum, group: Trees, Shrubs, Herbs, aquatic and wetland plants (blue), Spores (red) and Angiospermae (orange). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

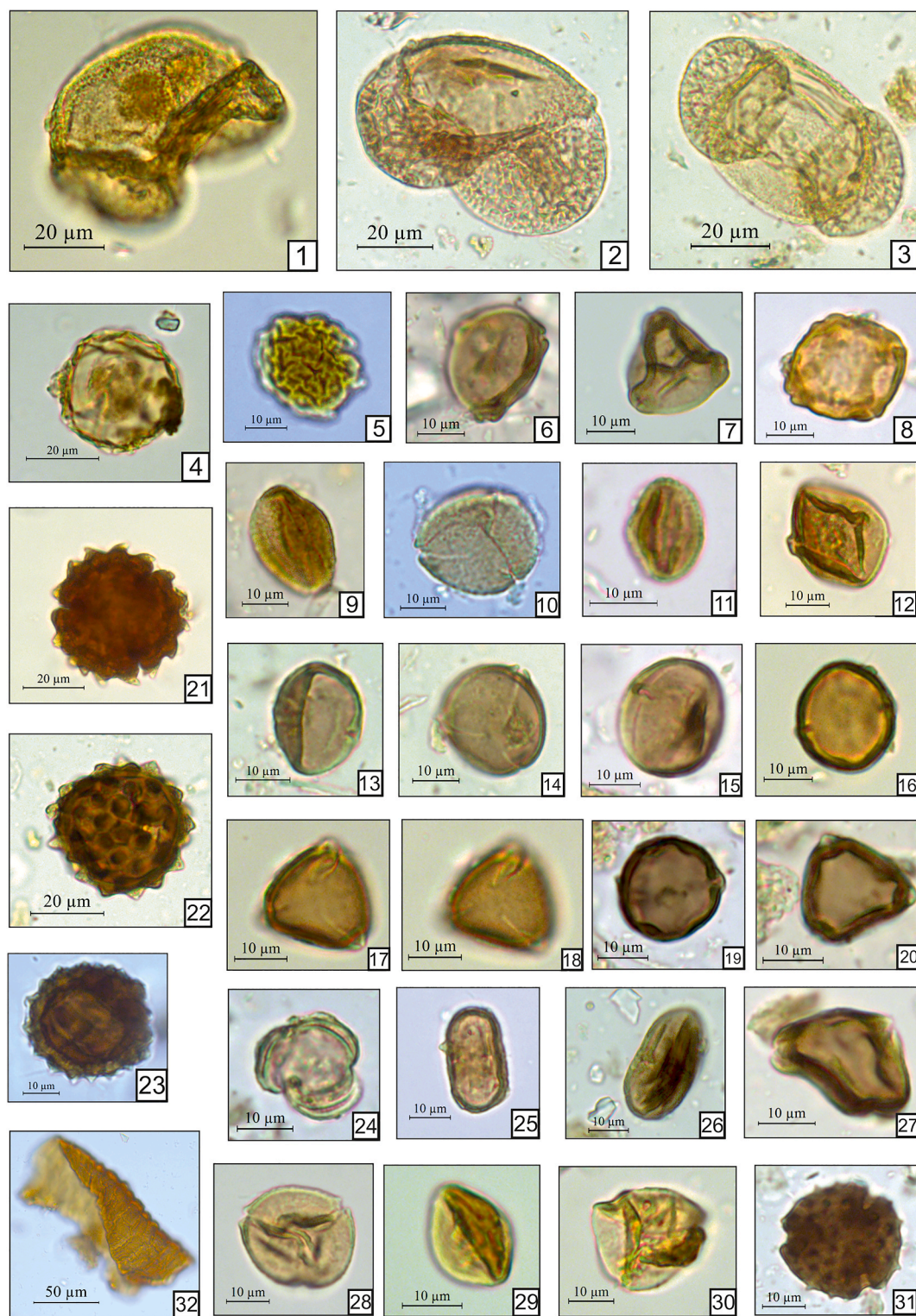
Assuming the accumulation of the studied sediments while the animal was still alive, the anomalously high content of pollen of the sea buckhorn, Rosaceae (shrubs and herbs), Fabaceae and Asteraceae (*Cirsium*-type) may have showed a food preference of *S. kirchbergensis* from Spinadesco. In such case, abundant pollen of sea buckhorn indicates that the animal died in spring or summer. The available data from another source – those regarding the *S. kirchbergensis* from the Chondon River – suggest that the main food types of these species were mixtures of twigs, leaves, and herbs (Kirillova et al., 2017).

Like the Chondon River specimens, the plant remains recognised in the peat show that the specimen fed on both grass and shrubs confirming the Kirilova's dietary deductions, i.e. a mixed feeder's diet. These results are in accord to same conclusions by Van Asperen and Kahlke (2015) and Rivals and Lister (2016) based on mesowear and microwear analyses.

The spore-and-pollen spectrum studied by us indicates that the vegetation reconstructed from the sediments found in the *S. kirchbergensis* from Spinadesco dental fossettae is different if compared with the modern one. The Spinadesco area as well as its surroundings appears currently to be one of the areas with the greatest floristic diversity in the Cremona province (Bonali et al., 2006). Represented by an open flood plain, the present Spinadesco area is mainly vegetated by macrothermal species prevalent on mesotherms. Microtherms species are present in lower percentages. The prevailing arboreal species are *Acer campestre* L., 1753, *Acer pseudoplatanus* L., 1753, *Populus alba* L., 1753, *Populus nigra* L., 1753, *Quercus robur* L., 1753, *Alnus glutinosa* (L.) Gaertn., 1790, *Salix* spp., *Prunus* sp. The herbaceous flora is indistinguishable from that which characterizes the floodplain of the middle Po and consists predominantly of grasses belonging to the families of Poaceae, Rosaceae, Cyperaceae, Brassicaceae, Euphorbiaceae, Liliaceae, Caryophyllaceae, and Solanaceae.

Overall, it resembles the composition of the mixed forest with a high or dominant role of the deciduous trees reconstructed for warm interglacial periods of the Ionian–early Tarantian time (0.781–0.0117 Ma) (late Middle Pleistocene, (Moscariello et al., 2000; Magri et al., 2015; Cacciari et al., 2018). During the Gelasian (2.588–1.806 Ma) and Calabrian stages (1.806–0.781 Ma) in forest formations of northern Italy conifers (*Sciadopitys* sp., *Tsuga* sp., *Cedrus* sp., *Taxodium* sp., *Picea* sp., and *Abies* sp.) were dominant along with Juglandaceae (*Carya* sp., *Pterocarya* sp., and *Juglans* sp.) (Bertini, 2010; Magri et al., 2017). The Ionian stage (0.78 Ma near MIS 19) is characterized by significant changes marked by the gradual extinction of these taxa and the development of modern vegetation. At that time, deciduous and broadleaf taxa, such as *Quercus* sp., *Fagus* sp., *Carpinus* sp., and conifers of the Pinaceae family were the most dominant kinds of vegetation. At the





**Fig. 2.** Spores and pollen found in the sample: 1. Pinaceae; 2. *Piceae* sp.; 3. *Pinus* s/g *Dyploxylon*; 4. *Equisetum* sp.; 5. *Lycopodium inundatum* L.; 6, 7. *Betula* sp.; 8. *Alnus* sp.; 9, 10. *Quercus* sp.; 11. Salicaceae; 12. Rosaceae (shrubs); 13–15. *Fagus* sp.; 16–20. *Hippophaë rhamnoides* L.; 21, 22. Asteraceae (Cirsium-tyt); 23. Asteraceae; 24. *Artemisia* sp.; 25. Apiaceae; 26. Fabaceae; 27. Onagraceae; 28, 29. Rosaceae; 30. Poaceae; 31. Valerianaceae; 32. Plant tissue.

same time, the small amount and rare presence of taxa such as *Pterocarya* sp. and *Zelkova* sp. have been recognised in palynological records up to the beginning of the Tarantian stage (Bertini, 2010; Magri et al., 2017; Di Rita and Sottili, 2019).

The analysis of the sample from *S. kirchbergensis* found at Spinadesco points to the absence of the pollen of thermophilic or moderately

thermophilic plants (Table 1). This indicates that the age of the sample is not older than the early Ionian. For the MIS 4–2 stages in this region, dry and cool climatic conditions were reconstructed. At that time, *Pinus* spp. prevailed in vegetation cover accompanied by significant amount of xerophytic elements (Kaniewski et al., 2005; Monegato et al., 2015; Ravazzi et al., 2014; Ravazzi et al., 2018). As we noted earlier, the data

obtained show a rather wet and moderately warm (interglacial-type) environment. Therefore, the upper boundary of the *S. kirchbergensis* death is not later than the early Tarantian stage (MIS 5).

## 5. Conclusions

The data obtained allow to reach the conclusions regarding the period in which *S. kirchbergensis* from Spinadesco lived, the climate, its ecology, its diet, the season in which it could have died.

The age of *S. kirchbergensis* from Spinadesco coincides with interglacial periods during Ionian–early Tarantian stages (MIS 19 – MIS 5). It seems likely that *S. kirchbergensis* from Spinadesco inhabited a broad grassy floodplain above which (on the terraces) mesophilic beech-dominated forests were grown. This indicates moderate, humid climate. It is quite possible that *S. kirchbergensis* from Spinadesco consumed twigs of the sea buckthorn (*Hippophae rhamnoides* L.) and Rosaceae shrubs as well as Asteraceae data confirming a mixed feeder's diet.

The typology of the peat remains found in its dental fossettae lead us to believe that the most probable time of the *S. kirchbergensis* from Spinadesco death and its relative burial was a spring or a summer period coincided with blossom period for sea buckthorn.

Finally, we already had other opportunities to emphasize the rarity of the *S. kirchbergensis* species as well as its mostly unavailable chrono- or biostratigraphic data (Billia, 2008, 2011a; 2011b, 2014; Billia and Petronio, 2009; Billia and Zervanová, 2014, 2015; 2016; Persico et al., 2015).

## Author contribution

The author collective conceived and designed the study. All authors have read and approved the final manuscript. E.M. Burkanova developed the methodology performing the pollen analyses, collecting and processing the data on the whole. E.M.E. Billia devoted himself to the original draft writing and preparation of the article. Davide Persico was responsible for the discovery and sampling of peat and took care of the taphonomic parts, the supervision and validation of the manuscript.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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