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UTILIZAREA METODELOR DE ANALIZĂ DATELOR MARI ÎN STUDII BIOGEOGRAFICE: EXEMPLUL CERBILOR FOSILI DIN ZONA PALEARCTICĂ DE VEST

IMPLICATION OF DATA ANALYTIC METHODS IN BIOGEOGRAPHIC RESEARCH: THE CASE OF FOSSIL DEER FROM WESTERN PALEARCTIC

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Rezumat. *Aplicarea metodelor de analiză a datelor la letopisețul paleontologic a cerbilor de tip modern din zona vestică a Palearcticii oferă o perspectivă mai largă asupra biodiversității cerbilor şi pune în lumină istoria evolutivă a familiei Cervidae din această regiune. Miocenul târziu a fost marcat de o bogată radiație evolutivă a subfamiliei Capreolinae, în timp ce etapa pliocenă a fost caracterizată de primele răspândiri a reprezentanților subfamiliei Cervinae și dispariția majorității capreolinelor arhaice. Etapa pleistocenă este caracterizată de o mare diversitate taxonomică și ecomorfologică a subfamiliei Cervinae, datorată dispersărilor multiple din zona est-palearctică și proceselor evolutive locale. În același timp, etapa Pleistocenului din zona vest-palearctică se caracterizează prin prezența a doar câtorva reprezentanți puternic specializați ai subfamiliei Capreolinae, care ocupau nișe ecologice marginale pentru cervide.*
Cuvinte cheie: *Cervidae, biogeografie, biogeografie, Miocen târziu – Pleistocen*

Abstract. *The application of data analytics methods to the paleontological record of fossil crown deer from the western Palearctic area provides a broader perspective on the biodiversity of deer and sheds light on the evolutionary history of the family Cervidae in this region. The late Miocene was marked by a rich evolutionary radiation of the subfamily Capreolinae, whereas the Pliocene stage was characterized by the first dispersals of representatives of the subfamily Cervinae and the disappearance of most of the archaic Capreolinae. The Pleistocene stage in the western Palearctic region is characterized by the significant taxonomical and ecomorphological diversity of Cervinae, along with the presence of a few highly specialized representatives from the subfamily Capreolinae, which occupied marginal ecological niches for cervids.*
Keywords: *Cervidae, biogeography, biogeography, Late Miocene – Pleistocene*

Introduction

Biogeographic research is essential to understanding the past and present distribution of species and the processes that shape them. Fossil records play a critical role in reconstructing biogeographic histories, and data analytic methods are becoming increasingly important for analyzing and interpreting this data. Deer of the modern subfamilies Cervinae and Capreolinae, also known as "crown deer", are a dominant group of herbivores in the Palearctic region, known for their evolutionary plasticity and ecological opportunism [1] that reflect the climate changes that have occurred in the western Palearctic area over the last approximately 10 million years. Body mass and shape of antlers (number of tines and development of palmations) are selected as the primary ecophysiological and ecomorphological features that define a species' ecological niche and reflect the evolutionary radiation of cervids [1, 2]. Data on the geochronological distribution of cervid species,

their body mass estimations, and bibliographic sources are available as supplementary material for the paleobiogeographic study of cervids [3]. The database includes only continental forms of fossil and modern deer and does not takes in consideration insular endemics. The data are treated in Jupyter Notebook (Anaconda3) using Python-3 programming language..

Results and discussion

The geochronological distribution of deer species in the western Palearctic area indicates that only representatives of the subfamily Caprolinae (telemetacarpal deer) were present during the Late Miocene (Fig. 1).

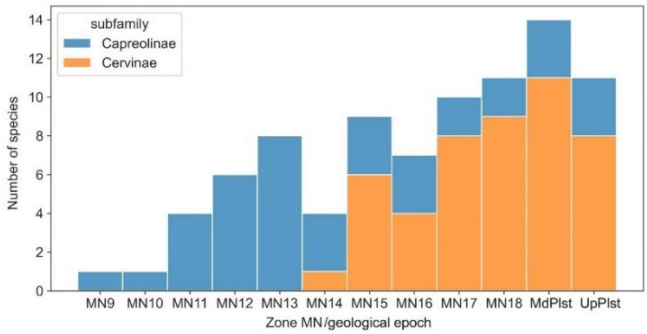

Fig. 1. Geoghronological distribution of crown deer species (subfamilies Cervinae and Capreolinae) from Late Miocene to Upper Pleistocene

The gradual increase in the number of Capreolinae species during the late Miocene (MN 9-13) represents a local evolutionary radiation of telemetacarpal deer [4, 5]. The beginning of the Pliocene (MN 14) is marked by the extinction of most genera of telemetacarpal deer [4]. The extinctions of archaic capreolines were followed in the western Palearctic by the first appearance of early representatives of plesiometacarpal deer (subfamily Cervinae) that dispersed from the biogeographic center of their evolutionary radiation in southeastern Asia [6]. Although the early evolution of telemetacarpal deer led to a certain diversity of antler shapes, Late Miocene capreolines showed a relatively consistent pattern of body mass diversification, suggesting limited eco-physiological adaptations (Fig. 2). However, the idea that the subfamily Capreolinae is evolutionarily conservative may be oversimplified. The lack of body size diversity in Late Miocene capreolines could be attributed to the limited time frame and geographic area of their evolutionary radiation, which may have restricted their eco-morphological diversification. Therefore, the observed low diversity of adaptations could reflect a limited number of available adaptation zones.

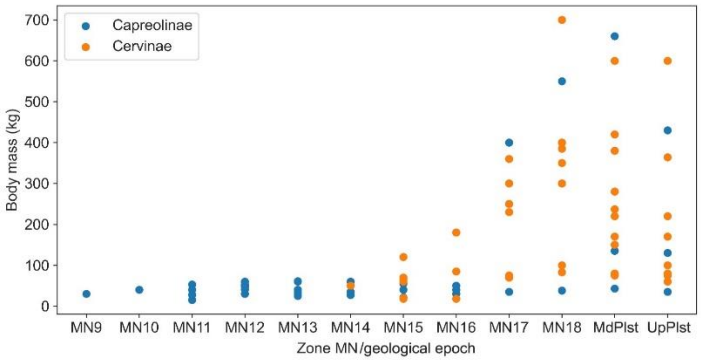

Fig. 2. Geoghronological distribution of crown deer species from western Palearctic plotted against their body mass

Plio-Pleistocene representatives of the subfamily Cervinae are characterized by a broader diversity of body mass, signaling a wider range of ecological niches occupied by Cervinae in comparison to Capreolinae. The high diversity of eco-morphological forms in plesiometacarpal deer is likely due to the fact that all cervines in the western Palearctic region are already specialized forms that originated from the evolutionary radiation in Southeast Asia. These cervines dispersed throughout the entire Palearctic realm and subsequently developed local adaptations in the western Palearctic region. In the early Pleistocene, a significant gap can be observed in the body masses of small-sized deer that predominantly evolved in the western Palearctic area and rather large-sized deer that are new faunal elements dispersed from the eastern Paleartic. However, during the Middle Pleistocene, this gap in body mass distribution among cervid species disappeared, suggesting that cervids became the dominant taxonomic group in the community of middle Pleistocene ruminants and occupied most of the available ecological niches. This period witnessed the highest systematic diversity of cervids in the western Palearctic [7, 8].

There is no evidence to suggest that the dispersal of plesiometacarpal deer caused the extinction of archaic capreolines in western Eurasia. This is because during the transitional period (MN14), the fauna of western Eurasia only includes one small-sized species ("*Cervus*" *ruscinensis*), which is closely related to the evolutionary lineage of plesiometacarpal deer. When comparing the frequency of body sizes within each of the crown deer subfamilies, it becomes clear that the body size similar to that of modern roe deer is most commonly found within the subfamily Caprelinae, whereas species with a body mass between 200 and 400 kg are absent. In contrast, among Cervinae, a body mass of around 100 kg is the most frequently observed, but there is also a high frequency of species with a body mass between 200 and 400 kg (Fig. 3).

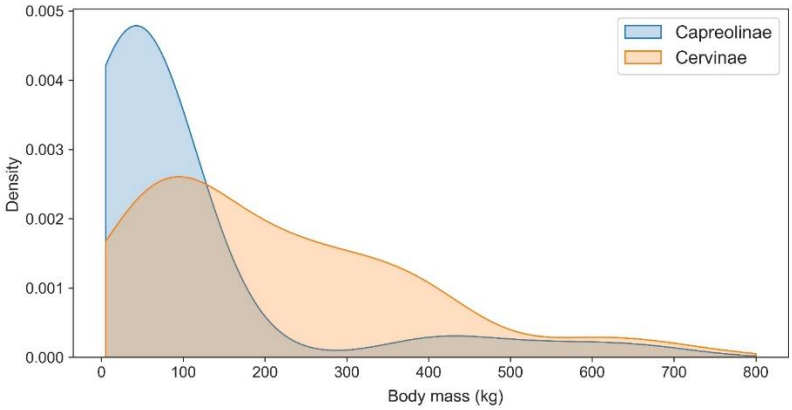

Fig. 3. Body mass distribution within subfamilies Capreolinae and Cervinae from western Palearctic

Available data suggest that antler palmations are more frequent among species of the subfamily Capreolinae, accounting for 28.1% of the total number of recognized telemetacarpal deer species in the world. The point-biserial correlation coefficient of 0.566 in the subfamily Capreolinae from the western Palearctic zone indicates a moderate positive correlation between palmation development and an increase in body mass. The extremely low p-value indicates that the obtained correlation coefficient is statistically significant. This correlation is stronger than that in the subfamily Cervinae, whose point-biserial correlation coefficient is only 0.277, and this result is not statistically robust. In general, the subfamily Cervinae has a lower relative number of species that evolved antler palmations (15.7%) due to more complex, diversified, and longer evolutionary processes, resulting in a greater number of eco-evolutionary forms, many of which evolved in tropical latitudes and exhibit

adaptations to forest biomes. This fact explains the low number of species with palmated antlers that serve as an organ of visual communication in open landscapes. Several examples of secondary body size reduction in Cervinae with palmed antlers exist, such as in *Praemegaceros dawkinsi* and *Megaceroides algericus*. The general evolutionary trend of the subfamily Cervinae indicates a moderate and statistically significant correlation between body mass and the number of antler tines (Pearson correlation coefficient is 0.68), which is higher than that of the subfamily Capreolinae (Pearson coefficient is 0.59). Thus, it is difficult to describe the diversified evolution of Cervinae from the western Palearctic by a simple correlation between body mass and the development of antler palmation.

During the Pleistocene, the subfamily Capreolinae was presented by few survived lineages that occupied marginal ecological niches for Palearctic cervids, including the ecological niche of a small-sized forest/woodland dweller (*Capreolus*), the specific ecological niche of gregarious periglacial open-landscape (tundra and dundra-steppe) dweller (*Rangifer*), and the niche of an open wetland giant (*Alces*). These extreme specializations allowed capreolines to avoid direct ecological competition with representatives of the subfamily Cervinae in the Palearctic realm.

Conclusions

The application of data analytics methods to the paleontological record of fossil crown deer from the western Palearctic area allows for a broader view of the biodiversity of deer and reveals the general pattern of the evolution of the Cervidae family in this region. There are three main stages of deer evolution in the study area: 1) the early evolutionary radiation of the subfamily Capreolinae during the Late Miocene (MN 9-13); 2) the Pliocene stage (MN 14-16) marked by the disappearance of most archaic Capreolinae and the arrival of the first lineages of the subfamily Cervinae from the southeast of Eurasia; and 3) the Pleistocene stage characterized by the great ecomorphological diversification of the subfamily Cervinae due to multiple dispersals from the eastern Palearctic area and local evolutionary processes. During the Pleistocene, Capreolinae occupied ecological niches that were marginal for other Cervidae, indicating their extreme specialization and ability to avoid direct ecological competition with representatives of the subfamily Cervinae.

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