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Article

Records of Wild Mammals Run over on a Road in Osijek-Baranja County, Croatia

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Abstract: No data on wild mammals run over along the roads in Osijek-Baranja County, in the north-eastern part of Croatia, have been available so far. Mammals run over from 2016 to 2024 on the Zmajevac-Osijek road, 33.4-km long, were recorded using the road sampling method while travelling back and forth from Zmajevac to Osijek. A total of 86 run-over specimens of wild mammals, classified into eight species and one subspecies, were recorded. The northern white-breasted hedgehog, *Erinaceus roumanicus*, topped the list with 38 individuals, followed by the European badger, *Meles meles*, with 23 individuals. Together, these two species amounted to 70.93% of the run-over mammal fauna. Other species and subspecies were recorded in lower numbers. The number of wild mammals run over per kilometer of the observed road section was on the rise from 0.09 to 0.20 in the period from 2016 to 2022, while in 2023 it increased to 0.77 and in 2024 to 0.86. The high proportion of run over wildlife per kilometer is likely due to the high volume of traffic, which disrupts wildlife activities during both day and night.

Keywords: wild mammals; fauna; traffic; roads; mortality; Osijek-Baranja County; Croatia

1. Introduction

Within increasing globalization, the demand for roads to facilitate the fastest and most cost-effective transport of goods has grown. Consequently, collisions between wild animals and vehicles are common, resulting in significant and often serious damage to both wildlife and humans globally [1]. Approximately 80% of the land surface of Earth remains without roads [2] but this area is fragmented into 600,000 zones, more than half of which are smaller than one square km [2]. Only 7% of these zones exceed 100 square km in size [2]. Roads significantly affect habitat fragmentation and are recognized as a major factor contributing to the decline of global animal diversity [3,4]. Unfenced roads in particular can significantly contribute to the mortality of wild mammals due to vehicle collisions [5–7]. Humans are directly responsible for over one-quarter of the global mortality of terrestrial vertebrates [8]. In Europe alone, more than 500,000 vehicle collisions with wild animals are recorded annually [9]. Globally, it is estimated that over 400 million animals are run over each year, but these figures are underestimated because data for many countries are missing [10]. Despite various targeted actions to avoid or reduce wildlife-vehicle collisions—such as green bridges, under-road tunnels, and protective fences—the number of such collisions worldwide has increased significantly [11]. Similarly, in Croatia, numerous wild animal species are frequently run over by vehicles due to increased socio-economic activities, road transport of goods, and heightened passenger traffic, particularly during summer months [11]. In Croatia, a total of 2,333 vehicle collisions with wild animals were recorded in 2014, and this number increased to 3,789 in 2017, with 304 of these occurring in Osijek-Baranja County [12]. Additionally, from June 1, 2020, to May 31, 2021, Croatia recorded 4,048 vehicle collisions with wild animals, with the number rising continuously. By the 2021-2022 period, 5,420 vehicle collisions with wild animals were recorded [13]. The increase in collisions between wild animals and vehicles is attributable not only to factors such as speeding and

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unfenced roads but also to the growing number of cars on the road. In Croatia, the number of registered vehicles rose from 2,261,274 in 2020 to 2,331,034 in 2021, and reached 2,494,208 in 2023 [14–16]. In the first eight months of 2023, 42,485 new passenger vehicles were sold in Croatia, representing a 31.7% increase compared to the same period in 2022 [17]. In terms of number of collisions with wild animals, the Osijek-Baranja County has ranked fourth out of 21 counties in Croatia in 2014 and 2017 [12] and sixth in 2022-2023 [13]. However, accurate records in Croatia mainly focus on large game, and are often aimed to document vehicle damage for insurance compensation purposes [13]. Based on these data, the main purpose of this study is to record run over and killed wild mammals as unintentional traffic casualties on the Zmajevac-Osijek road in the Croatian part of Baranja, covering the period from 2016 to 2024.

2. Materials and Methods

2.1. Geographical Description

The Croatian part of Baranja is a distinct geographical region within the eastern Croatian plain. Triangular in shape, it covers an area of 1,147 km² between the Drava and Danube rivers and the land border with Hungary [18]. Administratively, it is part of Osijek-Baranja County, comprising 27.6% of the county total area. The Croatian part of Baranja has a population of 41,700, with an average density of 36 inhabitants per square km [19]. The Baranja region is well-connected to the rest of Croatia through various types of roads. The Corridor Vc highway runs from Budapest (Hungary) through Beli Manastir to Osijek and continues to Ploče in the Mediterranean part of Croatia. Additionally, State Road D-7 crosses the central part of Baranja from the village of Duboševica to the city of Osijek. State Road D-517 connects Beli Manastir, crosses the Drava River, and extends to Belišće. State Road D-212 runs from the settlement of Batina to Karanac, where it intersects with State Road D-7. In addition to the major roads, Baranja has county roads with a total length of 147 km and local roads extending 63.6 km [20]. The region is predominantly lowland, with an absolute elevation not exceeding 243 m [18]. Baranja plain is characterized by homogeneity of climatic conditions without significant microclimate variations [18]. An exception is the Bansko Hill area, where the variety of reliefs favours microclimatic differences. The floodplains along the Danube, Drava, and Karašica rivers cover 63% of the area of Baranja and are characterized by high humidity, mostly in the south-eastern part where the Kopački rit Nature Park is located [18,19]. Overall, Baranja experiences a moderate-continental climate, with an average annual temperature ranging from 10 to 11°C [21], with relatively large annual temperature variations and uneven rainfall distribution. The region receives an average of 600 to 700 mm of precipitation per year [21], making it one of the driest areas in Croatia [18]. The natural vegetation, which previously included oak forests on river terraces and loess plains, as well as steppes on Bansko Hill, has largely disappeared [18]. Currently, only the wettest parts of the floodplain are covered by forest of willow, *Salix spp*. (Malpighiales: Salicaceae), while the higher areas are dominated by white and black poplars, *Populus alba* L., *Populus nigra* L. (Malpighiales: Salicaceae), and common oak, *Quercus robur* L. (Fagales: Fagaceae) [18]. Baranja is a region characterized by intensive agricultural production, which significantly affects the diversity of flora and fauna.

Within a study on the presence of hard ticks (Acarina: Ixodidae) in Croatian part of Baranja and the tick-host relationship in Bansko Hill, Osijek-Baranja County, a study on wild mammals run over along the Zmajevac-Osijek road was conducted. From April 2016 to the end of July 2024, wild mammal mortality was recorded on the Zmajevac-Osijek road during travels from Osijek to Zmajevac and vice versa, crossing nine road sections that pass through eight settlements. The total length of the travel is 33.4 km long and includes the section of State Road D-212 from Zmajevac to Kneževi Vinogradi (8.0 km long), part of County Road 4042 from Kneževi Vinogradi to Bilje (18.1 km long), and part of County Road 4257 from Bilje to Osijek, 7.3 km long [22] (Figure 1). This last stretch is commonly referred to as Biljska Road. Outside the settlements, the studied road primarily crosses agricultural areas with various crops. On the section of State Road D-212 between Zmajevac and Kneževi Vinogradi, vineyards and agricultural fields dominate the landscape, with only small

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fragments of secondary forest stands remaining. Along County Road 4042, near the villages of Lug and Vardarac, there is a 1-km long forest of acacia, *Robinia pseudoacacia* L. (Fabales: Fabaceae), 50 to 100 m wide. The only significant natural forest stand along this road was a belt of white willows, *Salix alba* L. (Malpighiales: Salicaceae) extending from Bilje to Osijek, originally one to two km wide. This willow forest was cleared during 2022 and 2023 and was replaced with a newly planted white willow grove surrounded by a wire fence. On the opposite side of County Road 4257 from this grove there are agricultural areas.

The identification of recorded wild mammals for this study was conducted using the manuals by Garms et al. [23] and Antolović et al. [24]. Differences in the number of run over wild mammals and their species recorded on state roads versus county roads along the travel road were analysed using Chi-square tests with a significance level of $P < 0.05$ [25].

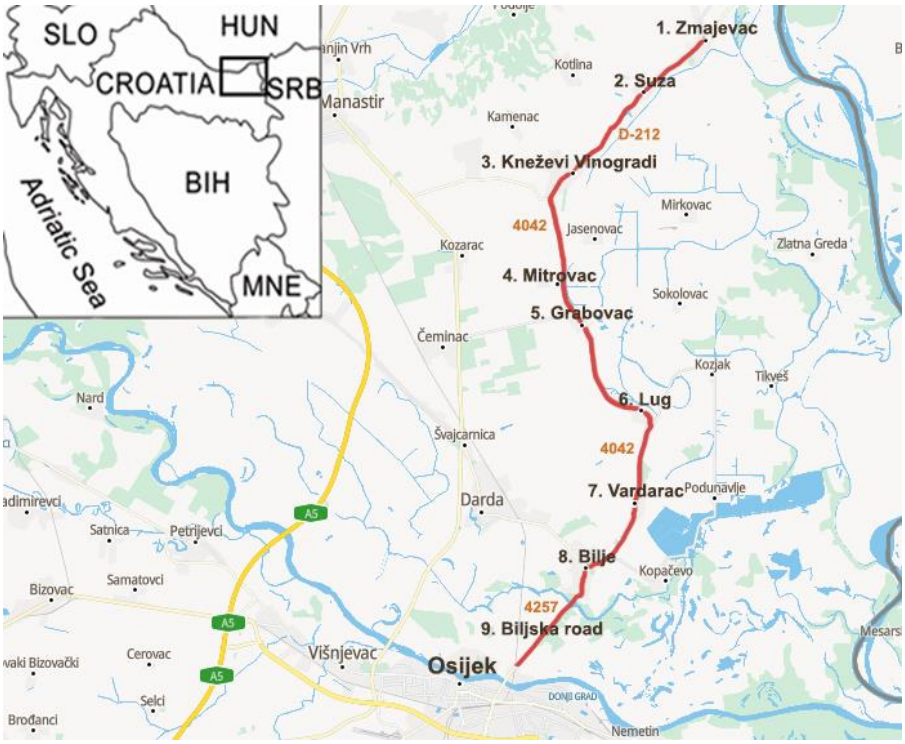

Figure 1. Sampling sites for run over mammals along the Zmajevac-Osijek road (red line) in Croatian part of Baranja (downloaded from Google Maps and modified according to atlas of Croatia [19,26]).

3. Results

On the 33.4-km long Zmajevac-Osijek road, from April 2016 to the end of July 2024, 86 run-over individuals of wild mammals, classified into eight species and one subspecies, were recorded using the road sampling method (Table 1). The most numerous individuals belonged to the northern white-breasted hedgehog, *Erinaceus roumanicus* Barrett-Hamilton, 1900 (Eulipotyphla: Erinaceidae), with 38 individuals recorded in eight road sections crossing seven settlements (Table 1), followed by the European badger, *Meles meles* (L., 1758) (Carnivora: Mustelidae) with 23 individuals from seven road sections crossing seven settlements, the red fox, *Vulpes vulpes* L., 1758 (Carnivora: Canidae) with 13 individuals from five road sections crossing five settlements, and the stone marten, *Martes foina* Erxleben, 1777 (Carnivora: Mustelidae), with four individuals from four road sections crossing three settlements. The pine marten, *Martes martes* L., 1758 (Carnivora: Mustelidae) was recorded with three individuals in two road sections, and the European wildcat, *Felis silvestris silvestris* Schreber, 1777 (Carnivora: Felidae) with two individuals in two road sections crossing two settlements. Additionally, the red squirrel, *Sciurus vulgaris* L., 1758 (Rodentia: Sciuridae), the wild boar, *Sus scrofa* L., 1758 (Artiodactyla: Suidae), and the red deer, *Cervus elaphus* L., 1758 (Artiodactyla: Cervidae) were each recorded with one individual in one road section crossing one settlement (Table 1). All road

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sections and all settlements along the Zmajevac-Osijek road had at least one wild mammal species recorded as run over (Table 1).

Table 1. Number of recorded individuals of different taxa of run over wild mammals in the study area from 2016 to 2024. 1. Zmajevac, State Road D-212; 2. Suza, State Road D-212; 3. Kn. Vinogradi, State Road D-212; 4. Mitrovac, County Road 4042; 5. Grabovac, County Road 4042; 6. Lug, County Road 4042; 7. Vardarac, County Road 4042; 8. Bilje, County Road 4042; 9. Biljska Road, County Road 4257. See Figure 1.

Taxon/ road sections	**1.**	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**	**8.**	**9.**	**Total**
Erinaceus roumanicus	2	2	6	-	7	9	6	3	3	38
Meles meles	2	2	3	2	5	6	-	3	-	23
Vulpes vulpes	2	2	4	-	2	3	-	-	-	13
Martes foina	-	-	-	-	1	-	1	1	1	4
Martes martes	-	-	2	-	-	1	-	-	-	3
Felis silvestris silvestris	-	-	-	-	1	-	-	1	-	2
Sciurus vulgaris	-	-	-	-	-	-	-	1	-	1
Cervus elaphus	-	-	-	-	-	-	-	-	1	1
Sus scrofa	-	-	-	1	-	-	-	-	-	1
Number of individuals	6	6	15	3	16	19	7	9	5	86
Number of taxa	3	3	4	2	5	4	2	5	3	

The highest number of individuals of run over wild mammals was observed on the sixth road section that crosses the Lug settlement, namely 19 individuals classified into four species (Table 1). This was followed by the fifth road section that crosses the Grabovac settlement with 16 run over individuals classified into four species and one subspecies. In the third road section that crosses the Kneževi Vinogradi settlement 15 individuals of run over wild mammals classified into four species were recorded (Table 1). On the remaining six road sections crossing five settlements, 36 run over wild mammals were recorded, classified into eight species (Table 1). During 2024, the highest number of run over wild mammals was recorded on the Zmajevac-Osijek road, totalling 29 individuals, which represented 33.72% of the overall number of run over wild mammals, classified into six species. The fewest run over wild mammals, with only three specimens (3.48% of the total), were recorded in 2020 and 2021, likely due to the significant reduction in traffic intensity during the COVID-19 pandemic. The highest number of run over wild mammals, totalling 59 and classified into nine taxa, was observed on the County Road 4042 segment from Kneževi Vinogradi to Bilje, and Biljska Road (4257). On State Road D-212, from first to third road sections, 27 run over wild mammals were recorded, classified into four species. The majority of run over wild animals, 50 (58.13%), were recorded in June, July, and August. On the contrary, only 6 (6.97%) of run over occurred during the winter months in February. Among the run over wild mammals, three species (the European badger, the northern white-breasted hedgehog, and the red fox) were the most frequently recorded, accounting for 86.04% of the total. The European badger had the highest number of incidents in February and March, accounting for 52.17% of the total European badger cases. The northern white-breasted hedgehog was most frequently run over in June and July, with 78.94% of its total run over cases occurring in these months. Run over of the red fox was mostly recorded in October, amounting to 30.76% of the total of run over red fox cases. Chi-square analysis showed a significant difference in the number of run over individuals between county and state roads ($\chi^2 = 11.9$, $P < 0.05$). However, the number of different species recorded did not significantly differ between these two types of roads ($\chi^2 = 1.92$, $P > 0.05$). In this study, the nine taxa (eight species and one subspecies) of run over wild mammals belong to four orders within the class Mammalia. The most represented order is Carnivora, with three families and five taxa, followed by Artiodactyla, with two families and two species. Insectivora and Rodentia each have one family and one species represented.

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4. Discussion

The investigated road (Zmajevac-Osijek), which is 33.4 km long, represents only 1.96% of the total road network in Osijek-Baranja County, which spans approximately 1,700 km [13]. The mammal fauna in Baranja exhibits a remarkable biodiversity, with most species recorded in protected areas like nature parks or in forested habitats along the Danube and Drava rivers. For instance, 54 mammal species have been documented in Kopački rit Nature Park [27]. On the contrary, habitats such as agricultural lands, vineyards, orchards, fragmented forest remnants along roads, and human settlements show a much lower diversity of mammal species. This is in agreement with the data from this study, which recorded nine taxa (species and subspecies) of run over wild mammals, accounting for 16.66% of mammal fauna of Kopački rit Nature Park.

Data on wild mammals run over along roads in Osijek–Baranja County and much of eastern Croatia have not been available so far. Accurate records of roadkill in Croatia have been available only for large carnivores such as the brown bear, *Ursus arctos* L., 1758 (Carnivora: Ursidae), the grey wolf, *Canis lupus* L. 1758 (Carnivora: Canidae) and the Eurasian lynx, *Lynx lynx* (L., 1758) (Carnivora: Felidae) [3,5–7]. More recent data include the roe deer, *Capreolus capreolus* L., 1758 (Artiodactyla: Cervidae) and *S. scrofa* in the Dinaric area [28]. There were no accurate records of other run over mammals in Croatia until 2017 [13]. Accurate records in Croatia mainly focus on large game and often aim to document vehicle damage for compensation purposes. The Road Traffic Safety Bulletin of the Ministry of the Interior of the Republic of Croatia only recorded incidents of vehicle collisions with animals without specifying if they were wild or domestic [13]. Since 2017, due to no institution in Croatia keeping records of collisions with wild game, the Croatian Hunting Association has begun collecting data in this field [13]. Despite this effort, county-specific records of vehicle collisions with wild game remain sparse, with detailed species records only starting from June 1, 2022 [13]. These detailed records from 2022 exist because the Croatian Hunting Association took over the payment of compensation for damage to vehicles in the event of a collision with wild game [13]. In Osijek-Baranja County, from June 1, 2022, to May 31, 2023, there were 302 recorded vehicle collisions with wild game [13]. The roe deer was the most frequently involved, followed by the wild boar and the red deer, which together amounted to 78.80% of all wild game run over [13]. However, according to our data, on the Zmajevac-Osijek road during the same period, only 2.32% of the run over animals were large game. Also, on the same road (Zmajevac–Osijek) and during the same period (June 1, 2022 to May 31, 2023), six European badgers and one red fox were run over. The Croatian Hunting Association data for Osijek-Baranja County during this period shows run overs of nine European badgers and nine red foxes [13]. Thus, the Zmajevac-Osijek road accounted for 66.66% of all European badgers and 11.11% of all red foxes run over in the county, despite the road representing only 1.96% of the total road network. This high proportion of European badgers relative to the small percentage of road sections belonging to the Zmajevac-Osijek road suggests deficiencies in the records maintained by the Croatian Hunting Association. Notably, while roe deer are the most frequently involved large wild game animals in vehicle collisions in Croatia [11,29], no collisions with roe deer were recorded on the Zmajevac-Osijek road between 2016 and 2024. Roe deer is the most numerous species of large game in Croatia [30]. However, in the area of Slavonia and Baranja the roe deer population has been considerably reduced due to the invasion of the large American liver fluke, *Fascioloides magna* Bassi, 1875 (Plagiorchiida: Fasciolidae [30]. Sometimes, discrepancies arise between the data reported by the Ministry of the Interior Republic of Croatia and the Croatian Hunting Association regarding the number of recorded run over animals. For example, the Ministry of the Interior recorded 684 vehicle collisions with animals in 2020 and 717 in 2021 [14,15]. On the contrary, the Croatian Hunting Association recorded 4,048 run-over animals on Croatian roads for the same period [13]. Collisions involving smaller wild animals (European badger, red fox, stone marten, pine marten, European wildcat) typically result in minimal material damage to vehicles, which may lead to these incidents being recorded sporadically. This discrepancy could be a primary reason for the variation in annual run over animal counts reported. Comparing data from the Zmajevac-Osijek road with similar data from other Croatian counties is challenging, as reports usually focus on large game, with other animals mentioned less frequently. Comprehensive data on wild animals run over on the section of

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State Road D1 from Klinča Sela to Karlovac, offering a basis for comparison, were reported in 2016 [31]. According to these data, on this 25 km section, the northern white-breasted hedgehog ranked first with 60 run-over specimens (45.80% of the total), while the red fox was third with 13 specimens (9.92%) [31]. These figures closely align with those recorded in our study on the Zmajevac-Osijek road, where the northern white-breasted hedgehog is also the most frequently run over species (45.24%), and the red fox ranks third (14.28%). Similarly, the northern white-breasted hedgehog is the most frequently run over species on roads in Hungary [32]. For the European hedgehog, *Erinaceus europaeus* L. 1758 (Eulipotyphla: Erinaceidae), which is widespread in northern and western Europe, there is significantly more literature available compared to *E. roumanicus*. The European hedgehog inhabits similar environments and exhibits comparable behaviours. It ranks highest for road mortality in Vienna, Austria [4], second in southern Ireland [33] and in the Campania region of southern Italy [34]. In the Netherlands, road traffic is estimated to reduce the density of *E. europaeus* by about 30%, affecting local population survival [35]. Similarly, in southern Sweden, traffic accidents are a major cause of death for *E. europaeus* [36]. This species is among the most frequent road casualties wherever its populations intersect road networks [37]. Data on run over E. *roumanicus* are scarce. In Croatia, information on road mortality for *E. roumanicus* is limited, partly because collisions with these small mammals rarely cause significant vehicle damage or pose a threat to drivers. Across Europe, road collisions with large game (wild boar, roe deer, and red deer) are more commonly recorded due to their potential for severe vehicle damage and associated risks to human life [38]. Although Croatia has a lower incidence of ungulate road collisions compared to other European countries [39], on the Zmajevac-Osijek road the number of run over wild mammals per km was 0.77 in 2023 and 0.86 in 2024. Despite being the most frequently run over species on this road, *E. roumanicus* was not recorded during the species hibernation period in late autumn and winter months (November through March). Similarly, run over of European badgers, *M. meles*, were not observed in November, December, and January, because the species also hibernates during this period. The mortality data for European badgers in this study show a unimodal peak in spring, which contrasts with the bimodal peak observed in southern England during spring and late summer [40]. In this study, European badgers rank second in mortality, consistent with findings from the Po-Veneto plain in Italy [41], but at odds with earlier studies where the percentage of run over European badgers in Croatia was below 3% [11,12,27,31]. In Britain, road traffic is the leading cause of European badger deaths, indicating that road traffic significantly affects badger populations through habitat fragmentation at the local level [42]. The red fox, *V. vulpes*, ranks third among run-over species on the Zmajevac-Osijek road in Osijek-Baranja County. It is the most frequently run over small mammal in the Campania region of southern Italy and in northern Poland [34,43], and second in south-western Germany [44]. In our study on the area of Osijek-Baranja County, the majority of run over red foxes were recorded in October, showing a unimodal seasonal mortality pattern. These data are not in agreement with those of UK, where no significant seasonality was observed [45]. Collisions involving small to medium-sized vertebrates and carnivores are often linked to roadside vegetation [46], which may explain the high number of run over mammals recorded on the sixth section of the road through the Lug settlement in this study. During the COVID-19 pandemic, run over rates dropped considerably to 3.48%, similar to reduced mortality observed for European badgers and red foxes in the UK in the same period [47].

5. Conclusions

Nine taxa (species and subspecies) of run over wild mammals were recorded in Osijek-Baranja County, located in north-eastern Croatia, along the 33.4 km Zmajevac-Osijek road. These taxa are classified into seven families and four orders within the class Mammalia. The northern white-breasted hedgehog, *Erinaceus roumanicus*, the European badger, *Meles meles*, and the red fox, *Vulpes vulpes*, represented 86.04% of the run over wild mammals in the study area. All nine taxa are listed in the IUCN Red list of threatened species as least concern (LC) [48–56]. The European badger was most frequently run over in February and March. The northern white-breasted hedgehog was most commonly run over in June and July, while the red fox was most frequently run over in October.

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During the COVID-19 pandemic, which led to reduced traffic and lockdowns, only 3.48% of run over mammals were recorded, supporting the hypothesis that increased traffic correlates with a higher proportion of roadkill. Chi-square analysis showed that the number of run over mammals differed significantly between county and state roads ($\chi^2 = 11.9$, $P < 0.05$). On the Zmajevac-Osijek road, the number of run over wild mammals per km was 0.77 in 2023 and 0.86 in 2024. These data highlight the need for protective measures on state and county roads similar to those implemented on highways.

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Institutional Review Board Statement: The animal study protocol was approved by the Ethic Committee of the Department of Biology, Josip Juraj Strossmayer University of Osijek (Approval Code: 011-01/22-02/04; Approval Date: 29 September 2022).

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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