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Impact of environmental factors on small mammals and their fleas

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Abstract

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Small mammals in the Horšianska dolina-Valley were researched first in 1984–86 and later in 2016–19. This paper seeks to identify and assess the species composition and dynamics of fleas (Siphonaptera) found in the valley on small mammals of Rodentia and Eulipotyphla and to compare findings from these two periods separated by thirty years. The results indicated deviations in small mammal and flea community similarity as well as in the small mammal indicator species for each habitat and flea indicator species for the small mammal species. A total 12 different species of small mammals were captured, and 12 flea species were collected. Eight flea species were detected in 1984–86 and ten species were found in 2016–19. In both periods *A. penicilliger, C. assimilis, C. solutus, D. dasycnema, N. fasciatus* were captured. The differences were that in the earlier period, the species uncovered were *C. congener, P. bidentata, and P. soricis*, while in the later period they were *C. agyrtes, C. bisoctodentatus, M. turbidus*, and *R. integella*. In the relationship between fleas and small mammals, *C. solutus* was the specific species for *Apodemus flavicollis*, while *A. penicilliger* and *C. agyrtes* were for *Clethrionomys glareolus*, and *C. assimilis* was for *Microtus arvalis*.

Keywords

Eulipotyphla, indicator species, Rodentia, Siphonaptera

Introduction

Horšianska dolina is located in the northern Danube Hills, a part of Slovakia's Danube Lowland, approximately six kilometres to the northeast of Levice. It is a national wilderness area administered by the Ponitrie Protected Landscape Area and located in the cadastral district of Levice. The protected wilderness specifically covers an area around the settlements of Kmeťovce, Žemberovce and Krškany in the municipality of Drženice, which in turn is situated in the District of Levice within Nitra Region. It encompasses a valley deeply cut into the andesite footwall of the Ipeľ Hills with steep slopes and mountain walls at places 20–30 metres high. It is located in Tekov, a part of Nitra Region that lies within the Danube Lowland and Danube Hills. The history of zoological research in Tekov has been described by Dudich (1994), Štollmann and Dudich (1985) studied small mammals in the Burda Mountains and the southern Ipeľ Hills, and small mammals of the Eulipotyphla and Rodentia orders were observed by Bolha (1999).

Fleas native to the Danube Lowland were researched by Cyprich and Kiefer (1984) and by Cyprich et al. (1984, 1987) and Ambros and Dudich (1996). In

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the Danube Lowland were ectoparasitic animals infesting the small mammals studied by Dudich (1986, 1994), while Dudich (1987, 1993a) concentrated on expansion and introgressive hybridisation of *C. agyrtes* there (1987a, 1993a). Ectoparasites (Acarina, Anoplura, Siphonaptera) around the Čenkov Steppe Nature Park within the Danube Lowland were evaluated by Dudich (1993b). Small mammals and their ectoparasites were observed in the southern Danube Lowland by Dudich et al. (1987) and Kováčik and Dudich (1990), while ectoparasites on animal hosts in the riparian forests and wetland habitats of southern Slovakia have been studied by Ambros et al. (1999) and Lengyel et al. (2002). Dudich (1987b) described fleas on small mammals in the Burda Mountains and Ipeľ Hills.

Host specialisation is one of the essential characteristics of any parasitic organism (Krasnov 2008) and each flea species or group of fleas more or less prefers a certain host or group of hosts. Certain hosts or groups of hosts are in turn "bound" to certain flea species with a certain degree of preference, which is also reflected in quantitative values of abundance, frequency and dominance.

This paper seeks to identify and assess 1) the species composition and impact of seasonality on common rodents (Rodentia) and insectivores (Eulipotyphla) found in the region; 2) the species composition and dynamics of fleas (Siphonaptera) on these small mammals over two different periods of time; 3) indicator species of fleas for these small mammal species; and 4) indicator species for the different habitats in selected biotopes of the Horšianska dolina area.

An important aspect of research into the flea communities of small mammals is the expansion of striped field mouse (*Apodemus agrarius*) as a new element in the small mammals native to south-western Slovakia. *A. agrarius* has a preferential ectoparasite, namely fleas of the species *Hystrichopsylla orientalis*, which is broadly distributed throughout continental Europe from Poland and Switzerland eastward. The host first appeared in the region in 2010 and has since been expanding western.

Materials and methods

Small mammals were captured at 22 points using the line method (250 traps/nights in the earlier period 1984–1986 and 650 traps/nights in the later period 2016–2019). Fifty live traps were set at ten-metre intervals (see Fig. 1) and left exposed for two or three consecutive nights. The small mammals thus captured (Table 1) were deparasitised and the fleas subsequently identified with a key used to determine the species (Rosický, 1957). The structural and quantitative characteristics of the flea communities found on the small mammals were assessed and the data analysed according to dominance and prevalence of all small mam-

Fig. 1. Locations where small mammals were trapped.

Table 1. Small mammals examined for ectoparasites

Species	Number	%
Apodemus agrarius AAG	4	0.7
Apodemus flavicollis AFL	181	27.9
Apodemus uralensis AUR	16	2.5
Apodemus sylvaticus ASY	97	14.9
Apodemus sp.	11	1.7
Muscardinus avellanarius MAV	9	1.4
Clethrionomys glareolus CGL	191	29.4
Microtus arvalis MAR	102	15.7
Microtus subterraneus MSU	1	0.15
Crocidura leucodon CLE	2	0.3
Neomys anomalus NAN	1	0.15
Sorex araneus SAR	26	4.0
Sorex minutus SMI	8	1.2
Total	649	100

mal individuals and by the prevalence on small mammal species, using a method developed by Schwerdtfeger (1975) and Margolis et al. (1982). Ecological indices of dominance (D%) and prevalence (%) (Bush et al., 1997) were calculated, where %isp equals the number of individuals of a particular infested host species divided by the number of individuals of a particular examined host species and the result multiplied by 100, and %iex equals the number of individuals of a particular infested host species divided by the number of all examined host individuals with the result multiplied by 100. Dominance is a significant relative trait of any zoocenosis. Synusiae are similar associations of organisms with shared life forms inhabiting a unified part of space and generally fulfilling similar ecological roles (Losos et al., 1984).

In order to assess the strength of association between host species abundance and habitats, and between host and flea species, an indicator value analysis (IndVal) (Dufrene and Legendre, 1997) was carried out by us that yielded a percentage indicator value (IndVal) for each species. Small mammal indicator species were established using PAST Version 4.08 (Hammer et al., 2001) for habitats, while the indicator species of fleas for small mammal species were derived from indicator value (IndVal) analysis using the index defined by Dufrene and Legendre (1997). For each species "i" in group "j", specificity is defined as Aij = Nij / Ni, where Nij is the mean number of individuals of species "i" across sites in group "j", and Ni is the sum of the mean numbers of individuals in species "i" over all groups.

Similarly, fidelity was defined as Bij = Nsitesij / Nsitesj, where Nsitesij is the number of sites in the group "j" where species "i" is present, and Nsitesj is the total number of sites in group "j". The indicator value of species "i" in group "j" is then a percentage value from 0 to 100.

Characteristics of the catching points

Small mammals were trapped in Horšianska dolina at five different type habitats whose vegetation varied in nature (David, 2004, Fig. 1):

A. Locations with herbaceous vegetation communities composed of thermophilic shrubs and they were in the overgrowth phase. Fescue grasses produced the habitat's physiognomy, especially *Festuca pseudodalmatica* (related to Balkan fescue), Volga fescue (*Festuca valesiaca*) and shrub stage species such as common hawthorn (*Crataegus monogyna*), blackthorn (*Prunus spinosa*), wild privet (*Ligustrum vulgare*) and dog rose (*Rosa canina*). Aggregate percentage cover never exceeded 50% (Pavlovič, 2011). Catching Points 2, 7, 12.

B. Areas in an advanced stage of overgrowth in herbaceous cenoses with shrubs and trees. The community is typical for the occurrence of thermophilious oak forests whose dominant species are turkey oak (*Quercus cerris*) and downy oak (*Quercus pubescens*). Dense stands of blackthorn (*Prunus spinosa*) and other dominant species covered an average 90% of the locations where samples were taken. Catching Points 4, 10, 14, 16 and 18.

C Age-homogeneous forest growth covering a high proportion of the ground. Samples were taken a) in the riparian zone along the Sikenica, a stream, with a poorer shrub stage dominated by black alder, sessile oak and European hornbeam; and b) in rock debris and on andesite bluffs predominately overgrown with turkey oak and little-leaf linden. Catching Points 3, 5, 8, 9, 13, 15, 17, 19, 21, 23.

D. Areas formerly farmed such as meadows, arable land, and pastures. These habitats were overgrown with ruderal plant species at the time of sampling. Catching Points 6, 20, 22.

E. Ground under high-tension power lines in a band measuring approximately 75 metres wide and associated with the neighbouring agrocenosis. The vegetation underneath the lines is mulched in regular cycles. When the location was sampled, the dominant vegetation was composed of a stand of black locust trees approximately 20–40 centimetres tall. The peripheral parts of the location were composed of an infestation of trees from the surrounding forest cenoses. Two series of sampling took place at this stand. Catching Point 11.

Results

A total of 649 individuals from 12 small mammal species were captured in the traps over the course of the two periods. *Apodemus agrarius* (Pallas, 1771); *Apodemus flavicollis* (Melchior, 1834); *Apodemus uralensis* Kratochvil, Rosicky, 1952; *Apodemus sylvaticus* (Linnaeus, 1758); *Clethrionomys glareolus* (Schreber, 1780); *Microtus arvalis* (Pallas, 1779); *Microtus subterraneus* (de Selys-Longchamps, 1836); *Muscardinus avellanarius* (Linnaeus, 1758); *Crocidura leucodon* (Hermann, 1780); *Neomys anomalus* Cabrera, 1907; *Sorex araneus* Linnaeus, 1758; and *Sorex minutus* Linnaeus, 1766 (eight rodent species and four insectivore species, Table 1). The eudominant species included *Clethrionomys glareolus*, *Apodemus flavicollis*, *Microtus arvalis* and *Apodemus sylvaticus*.

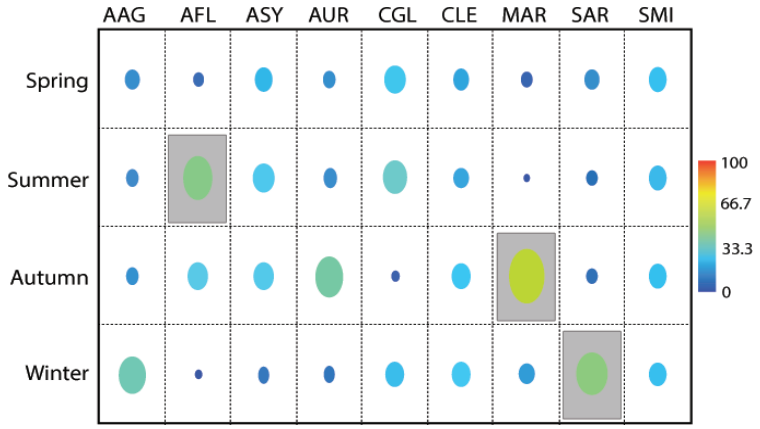

Fig. 2. Indicator species (IndVal) of small mammals for different seasons (AAG – *A. agrarius*, AFL – *A. flavicollis*, ASY – *A. sylvaticus*, AUR – *A. uralensis*, CGL – *C. glareolus*, CLE – *C. leucodon*, MAR – *M. arvalis*, SAR – *S. araneus*, SMI – *S. minutus*, IndVal – shaded boxes indicate statistically significant indicator values).

There were seven species documented in the earlier period (*A. flavicollis*, *C. glareolus*, *M. arvalis*, *M. subterraneus*, *N. anomalus*, *S. araneus*, *S. minutus*), while in the later period the number of species detected had increased to ten (*A. agrarius*, *A. flavicollis*, *A. uralensis*, *A. sylvaticus*, *C. glareolus*, *M. arvalis*, *M. avellanarius*, *S. araneus*, *S. minutus*, *C. leucodon*). The increase in the number of species could be due to greater trapping effort (250 traps/nights in the earlier period and 650 traps/nights in the later period).

Indicator species for the small mammals were established in different seasons from IndVal analysis ($p \leq 0.05$). For autumn it was *M. arvalis*, for summer *A. flavicollis* and for winter *S. araneus* (Fig. 2).

IndVal analysis also determined indicator small mammal species for each habitat. The species *A. flavicollis* and *C. glareolus* were detected in age-homogeneous forest growth, which covers a large proportion of the ground, while *S. araneus* was found in areas that had previously used for agriculture. *A. uralensis* and *M. arvalis* were determined to be the indicator species in the belt of vegetation beneath the overhead high-voltage power lines connected to the surrounding agrocenosis (Fig. 3).

Season has no impact on the similarity of small animal guilds (two-way PERMANOVA [permutational multivariate analysis of variance] df = 3, F = 1.6795, p = 0.125, while habitat does have a significant effect on the similarity of species composition among small mammal communities (two-way PERMANOVA df = 4, F = 2.27, p = 0.037). However, no significant interaction of the two

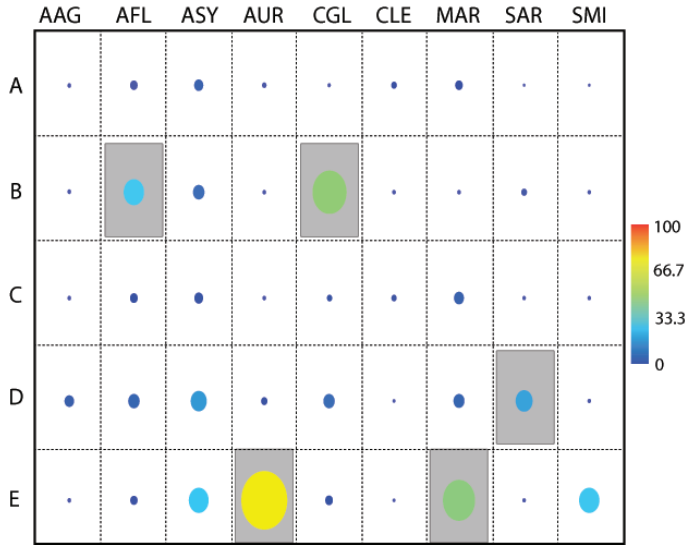

Fig. 3. Indicator species (IndVal) of small mammals for different habitats (AAG – *A. agrarius*, AFL – *A. flavicollis*, ASY – *A. sylvaticus*, AUR – *A. uralensis*, CGL – *C. glareolus*, CLE – *C. leucodon*, MAR – *M. arvalis*, SAR – *S. araneus*, SMI – *S. minutus*, A – grass-herb communities overgrown with thermophilic shrubs, B – an advanced stage of overgrowth of digestive herbaceous coenoses by shrubs and trees, C – connected, age-homogeneous, forest stands, D – in the past, it was used economically – mowed meadows, arable land, pastures, E – a strip of vegetation under high-voltagelines, IndVal – shaded boxes indicate statistically significant indicator values).

Table 2. Quantitative structure of small mammals and their fleas obtained in 1984-86

	A. flavicollis	*C. glareolus*	*M. arvalis*	*M. subterraneus*	*S. araneus*	Total
NEx	28	30	4	1	16	79
NInf	15	9	3	1	11	39
%isp	53.6	30	75	100	68.8	49.4
%iex	19	11.4	3.8	1.3	13.9	
Amalaraeus penicilliger	–	15	10	–	–	25
Ctenophthalmus agyrtes	37	11	4		4	56
Ctenophthalmus congener	–	–	–	1	–	1
Ctenophthalmus assimilis	–	–	1	–	–	1
Peromyscopsylla bidentata	–	1	–	–	–	1
Ctenophthalmus solutus	37	2	–	–	1	40
Doratopsylla dasycnema	2	–	–	–	21	23
Palaeopsylla soricis	–	–	–	–	17	17
Palaeopsylla similis					1	1
Nosopsyllus fasciatus	6	–	–	–	–	6
Total	82	29	15	1	44	171

NInf – number of positive findings of fleas on small mammals; NEx – number of examined specimens of small mammals; %isp, number of individuals of particular infested host species / number of individuals of a particular examined host species × 100; %iex – number of individuals of particular infested host species / number of all examined host individuals × 100

environmental variables was observed by us (two-way PERMANOVA df = 12, F = 0.45, p = 0.78).

A total of 372 individuals covering 13 flea species were recovered from the captured mammal species: *Amalaraeus penicilliger* (Grube, 1851); *Megabothris turbidus* (Rothschild, 1909); *Nosopsyllus fasciatus* (Bosc, 1800); *Peromyscopsylla bidentata* (Kolenati, 1863); *Ctenophthalmus agyrtes* (Heller, 1896); *Ctenophthalmus bisoctodentatus* Kolenati, 1863; *Ctenophthalmus solutus* (Rothschild, 1920); *Ctenophthalmus E. assimilis* (Taschenberg, 1880); *Ctenophthalmus E. congener* Rothschild, 1907; *Doratopsylla dasycnema* (Rothschild, 1897); *Palaeopsylla soricis* (Dale, 1878); *Palaeopsylla similis* Dampf 1910; and *Rhadinopsylla integella* Jordan, Rothschild, 1921. In 1984–86 (during spring and autumn), ten flea species were determined (Table 2), while in 2016-19 (during all seasons) it was nine (Table 3). In both periods, there were occurrences of *A. penicilliger*, *C. assimilis*, *C. solutus*, *D. dasycnema*, and *N. fasciatus*. Differences in species between the two periods were that in the earlier period, *C. congener*, *P. bidentata*, and *P. soricis* were observed, while in the later period *C. agyrtes*, *C. bisoctodentatus*, *M. turbidus*, and *R. integella* were present. The prevalence rate in the earlier period was 49.4% and in the later period 14.8%.

Indicator flea species were determined for the small animal species from the IndVal analysis. *C. solutus* was found to be the indicator species for *A. flavicollis*, *A. penicilliger* and *C. agyrtes* were the indicator species for *C. glareolus* and *C. assimilis* was the indicator species for *M. arvalis* (Fig. 4).

Discussion

There have been changes in environmental conditions, suc-

Table 3. Quantitative structure of small mammals obtained in 2016–19

	A. agrarius	*A. flavicollis*	*A. sylvaticus*	*C. glareolus*	*M. arvalis*	Total
NEx	4	97	73	126	65	365
NInf	1	11	10	23	9	54
%isp	25	11.3	13.7	18.3	13.8	14.8
%iex	0.3	3	2.7	6.3	2.5	
Amalaraeus penicilliger	–	–	–	39	3	42
Ctenophthalmus agyrtes	–	4	5	31	7	47
Ctenophthalmus assimilis	–	–	2	8	12	22
Ctenophthalmus bisoctodentatus	–	–	2	–	–	2
Ctenophthalmus solutus	1	25	13	11	3	53
Doratopsylla dasycnema	–	–	–	–	2	2
Megabothris turbidus	–	2	1	12	4	19
Nosopsyllus fasciatus	–	4	5	4	–	13
Rhadinopsylla integella	–	–	–	1	–	1
Total	1	35	28	106	31	201

NInf – number of positive findings of fleas on small mammals; NEx – number of examined specimens of small mammals; %isp, number of individuals of particular infested host species / number of individuals of a particular examined host species × 100; %iex – number of individuals of particular infested host species / number of all examined host individuals × 100.

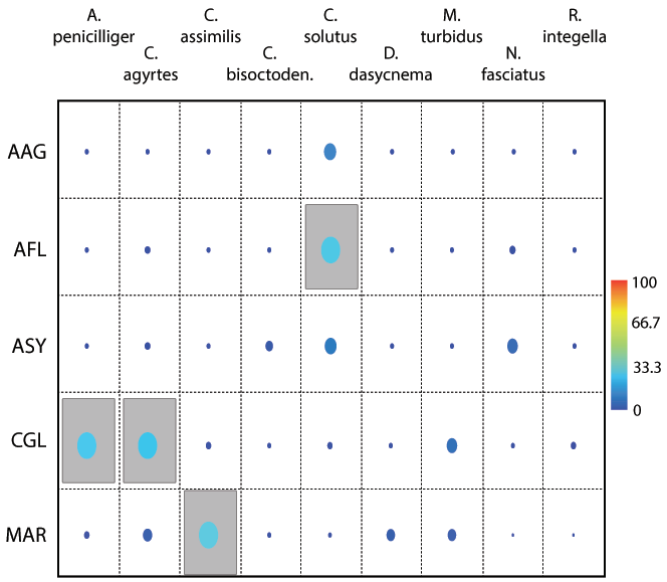

Fig. 4. Indicator flea species (IndVal) for small mammal species (AAG – *A. agrarius,* AFL – *A. flavicollis*, ASY – *A. sylvaticus*, CGL – *C. glareolus*, MAR – *M. arvalis*, IndVal – shaded boxes indicate statistically significant indicator values).

cession, and a noticeable expansion in vegetation over the thirty years between the earlier and later periods of small mammal research. More hygrophilous species (*M. subterraneus, N. anomalus*) had retreated and species typical of successional, overgrown, drier areas like *A. agrarius*, *A. uralensis*, *A. sylvaticus*, and *C. leucodon* appeared. Forest species (*A. flavicollis*, *C. glareolus*, *S. araneus*, *S. minutus*) still persisted (Baláž et al., 2013) as some parts from the earlier study had became more forested by the later study.

In both periods of research into small mammals, there were five different flea species (*A. penicilliger*, *C. assimilis*, *C. solutus*, *D. dasycnema*, *N. fasciatus*) found hosting on them. Some were pleioxenous parasites, with no specific host or several hosts during its life cycle, while others were oligoxenous, adapted to life in only a few species of hosts. The flea species detected are themselves cosmopolitan, and in terms of seasonality they develop predominantly throughout the year with *N. fasciatus* flourishing in autumn and winter. The species *P. bidentata* detected during the earlier research period is similarly predominant in autumn and winter, while *R. integella* is considered a winter species (Bartkowska, 1973) and *M. turbidus* predominant in the summer and autumn (Rosický, 1957). These last two species were detected in the later period of research.

C. solutus is a species occurring mostly in the fur of its host (Beaucournu and Launay, 1990). A flea species inhabiting the lower vegetation zone of the Carpathian foothills prefers to host on field mice of the genus *Apodemus*, and mainly *A. flavicollis*. The optimal occurrence of *C. solutus* has been noted in forest steppe formations and debris communities of natural vegetation formations, while reaching an even higher abundance on field and wood mice in the replacement tree formations of deforested landscapes (Dudich and Ambros, 1984).

A. penicilliger is a burrow species occurring predominantly in the foothills and higher elevations of mountains (Skuratowicz, 1967). In exceptional cases, it will descend from hilly regions, but only as far as areas directly connected to the larger mountain massif. Despite the occurrence of this species in all seasons of the year, it is more abundant in colder periods (Rosický, 1957; Dudich, 1995). The interface of planar and colline zones in Slovakia was first documented in the fragments of oak forests found at elevations of 250 metres in the Danube Hills surrounding the Hron River (Dudich and Ambros, 1984). The species is bound to hosts of the vole family, in particular *C. glareolus*, *M. tatricus* a *M. agrestis* (Dudich, 1995) although Skuratowicz (1967) reported the most species most commonly captured to be *C. glareolus*.

C. assimilis is predominantly a nesting species (Beauournu and Launay, 1990) whose original ranging was the Eurasian forest steppes (Dudich, 1995). The chief host is the common vole (*M. arvalis*), which is widely distributed in steppes and forest steppes. The species penetrates with its main host along roads, railways and through logging sites into more wooded areas where it also successfully survives on secondary hosts. It is most abundant in open habitats, making up the vast majority of fleas found on common voles (Dudich and Ambros, 1985).

D. dasycnema is a species that parasitises on the fur of its host (Brinck-Lindroth and Smit, 2007) and is specific to shrews of the family Soricidae like the genera *Sorex*, *Neomys* and *Crocidura* (Dudich and Ambros, 1984). It only occurs randomly and apparently transiently on other host species. It is widespread and in forest formations the dominant species (Dudich, 1991), avoiding large riverbeds that periodically flood (Dudich, 1995). The species reaches its highest abundance during warm months. It has also been recorded on a wide range of other small mammal species in the genera *Talpa*, *Apodemus*, *Clethrionomys*, *Microtus*, *Micromys* and *Mus* (Rosický, 1957). Skuratowicz (1967), Brinck-Lindroth and Smit (2007) consider its occurrence on voles and mice to be co-

incidental.

N. fasciatus is a cosmopolitan, nesting species (Skuratowicz, 1967) and a parasite of synanthropic rodents (*M. musculus, R. rattus*). Exoanthropic flea populations occur in the warmer lowland regions of Slovakia, mainly on field and wood mice (*Apodemus*). Although it favours suburban and urban habitats and livestock production facilities (Dudich and Ambros, 1984), it likewise occurs in the wild. The species prefers drier, open and well-lit habitats and is rarely found in humid environments. It does not ascend to higher elevations and its maximum distribution is in hilly regions. It reaches its highest abundance from late summer until February. Apart from rats, they mainly parasitise in species of the subfamily Murinae (composed mainly of species of the genus *Apodemus* and the species *M. musculus*), even though it has also been found on various other species of small mammals such as the genera *Talpa, Clethrionomys, Microtus, Micromys, Sorex* (Rosický, 1957; Skuratowicz, 1967), as well as on bird species and people (Brinck-Lindroth and Smit, 2007).

Ethics statement

The study was approved by the institutional research ethics committee (The Ethics Committee of the Constantine the Philosopher University in Nitra) and certify that the study was performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. Trapping of small mammals was approved by the Ministry of Environment of the Slovak Republic in accordance with permission MŽP SR no. 4850/2019-6.3.

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