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# Diversity of Flea (Siphonaptera) Parasites on Red Foxes (*Vulpes vulpes*) in Romania

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## Abstract

Red foxes (*Vulpes vulpes* (L.)) are widespread across Europe, tolerant of synanthropic ecosystems, and susceptible to diseases potentially shared with humans and other animals. We describe flea fauna on red foxes in Romania, a large, ecologically diverse country, in part because fleas may serve as an indicator of the risk of spillover of vector-borne disease. We found 912 individual fleas of seven species on the 305 foxes assessed, for an infestation prevalence of 49.5%. Mean flea load per fox was 5.8 (range 0–44 fleas), and flea detections were most abundant in fall and early spring. Fleas included generalists (*Ctenocephalides canis* (Curtis), 32.6% of all fleas), *Ct. felis* (Bouché, 0.1%), and *Pulex irritans* L. (29.9%), the fox specialist *Chaetopsylla globiceps* (Taschenberg, 32.5%), mesocarnivore fleas *Paraceras melis* Walker (3.2%) and *Ch. trichosa* Kohaut (1.5%), and the small mammal flea *Ctenophthalmus assimilis* (Taschenberg, 0.1%), which is rarely or never reported from carnivores. There were significantly more female than male *Ch. globiceps*, *Ct. canis*, and *Pu. irritans*, and these three species were the most broadly distributed geographically. Diversity indices suggested reduced diversity in mountainous areas above 700 m. When compared to other flea studies on foxes in Europe, Romania had flea diversity near the median of reports, which was unexpected given Romania's high ecological diversity. Notably absent prey specialists, compared to other studies, include *Archaeopsylla erinacei* (Bouché) and *Spilopsyllus cuniculi* (Dale). Further studies of possible disease agents in fox fleas could help elucidate possible risks of vector-borne disease in foxes, domestic animals, and humans as well.

**Key words:** *Ctenocephalides*, disease spillover, *Pulex*, sentinel, synanthropy

Red foxes (*Vulpes vulpes*) are among the most widespread wild carnivores in the world and one of the wild species most tolerant of synanthropic ecosystems (Sillero-Zubiri et al. 2004). Although red foxes are native to Europe, boreal North America, and Asia, their ability to disperse into new areas is exceptional, and this species has been listed as one of the 100 most invasive pests in the world (IUCN Species Survival Commission Invasive Species Specialist Group 2010). Numbers of red foxes are reportedly increasing in western Europe (Millán et al. 2007). Native and invasive foxes may be important sources of disease for other wild animals, pets, livestock, and humans, carrying the zoonotic tapeworm *Echinococcus multilocularis*, rabies virus, and *Leptospira interrogans*; and life-threatening pathogens of dogs including the mange mite *Sarcoptes scabiei*, canine distemper virus, and canine parvovirus (Steck and Wandeler 1980, Deplazes and Eckert 2001, Davidson et al. 2008, Slavica et al. 2011, Duarte et al. 2013, Trebbien et al. 2014). Particularly when fox densities are high, disease transmission and spillover risk may be increased (Schweiger et al. 2007). Factors that elevate risk of fox-origin disease affecting dogs and people include the phylogenetic proximity of dogs and foxes (which may increase shared pathogen susceptibility), the fact that foxes often prey on rodents which host a diversity of pathogens and parasites, the close ecological association among some foxes, dogs, and humans, and the connectivity between sylvatic and peridomestic ecosystems resulting from fox movement.

Valuable data could come from further examining foxes for fleas as an indicator of the risk of spillover of vector-borne disease. In addition, a focus on fox disease in countries spanning highly heterogeneous ecosystems, such as Romania, is warranted. Romania is a large country (238,000 km$^2$) in south-eastern Europe, bounded by the Black Sea to the east. Approximately half of Romania remains relatively ecologically intact, with large remaining undisturbed forest inhabited by brown bears (*Ursus arctos*), wolves (*Canis lupus*), and other large mammals. Habitats range from grasslands, to caves, Danube delta, Carpathian Mountain forests, and steppe on the Wallachian Plain. Elevations range from 0–2,500 m above sea level and precipitation averages up to 1,000 mm annually in humid zones to as low as 350 mm annually in the semiarid south. Across this high ecological heterogeneity, one expects high parasite diversity as well.

In this study, we collected fleas from red foxes from sites throughout Romania from various ecosystems and elevations. We provided identities of fleas and ecological metrics of flea species richness, evenness, and diversity which we compared with flea faunas described on foxes in other European countries. By understanding the diversity of red fox fleas, we can infer interactions among foxes and other host species of fleas, suggesting possible disease transmission routes.

## Materials and Methods

Foxes were collected by the National Sanitary Veterinary Authority during a rabies monitoring program across Romania between June 2010 and April 2012. These convenience samples were not uniformly distributed in time or space, but temporal coverage was good with 82 foxes sampled in winter, 62 in spring, 29 in summer, and 109 in fall (remaining dates were not recorded). All animals that tested negative for rabies were transported individually in sealed plastic bags to the laboratory of the Parasitology Department of the University of Agricultural Sciences and Veterinary Medicine in Cluj-Napoca. The fur on the carcass and any debris remaining in the bag were carefully checked for the presence of ectoparasites which were collected in absolute ethanol. Fleas were cleared by incubating in dilute KOH for 24 h, then dehydrated in an ethanol series (75, 85, 95, and 100% for 30 min each), and mounted in Euparal (BioQuip, Rancho Dominguez, CA). Fleas were identified using keys and published data (Smit 1960, Smit 1966, Steyskal 1988, Beaucournu et al. 1990, Brinck-Lindroth and Smit 2007, Whitaker and Council 2007).

Flea records were archived in Excel (Microsoft, Redmond, WA) and statistical tests were performed using R (R Development Core Team 2008). For statistical tests, a cutoff of $P < 0.05$ was used to infer significance. Prevalence and 95% confidence intervals correcting for continuity were calculated in the R function prop.test. Differences across months in flea numbers were assessed using a chi-square test. Chi-square goodness-of-fit tests were used to detect departure from expected even sex ratio for each flea species. “Preferred hosts” were defined as previously (Suciu 1973). Locations were plotted in ArcGIS 10.2 (ESRI, Redlands, CA). We examined differences in infestation prevalence across three different elevation categories (lowlands <200 m, hilly 200–700 m, and mountains >700 m) using chi-square. Diversity indices calculated for each of the elevation categories were species richness (S, the number of species), the Simpson reciprocal index (D, $1/(\sum(p^2)$ where p is the proportional abundance of each species), and the exponential of the Shannon index ($e^H$) (Krebs 1999). Although H was originally described in $\log_2$, we used the following formula for its updated exponential: $e^H = \exp\ (-\sum p_i \ln(p_i))$. S, D, and $e^H$ have numbers of flea species as units.

Literature on red fox fleas across Europe was compiled systematically using search terms *Vulpes*, flea, Siphonaptera, and parasite on Google Scholar and Pubmed, and from literature cited sections of any paper that reported fox fleas in Europe. We calculated for each European country how many foxes were examined for fleas, how many fleas were found, the intensity (mean number of fleas per fox including uninfested foxes in the denominator), prevalence, and S, D, and $e^H$, where the latter two were calculated from flea prevalences (not numbers of fleas). Studies from Berlin, Germany (Schöffel et al. 1991), and Murcia, Spain (Martínez-Carrasco et al. 2007), did not report flea numbers with sufficient accuracy to calculate intensity and thus these numbers were estimated, while the study from Czech Socialist Republic (as it was then called) did not contain data to calculate prevalence of some fleas (Preisler 1983). We do not report in the table or calculate prevalence of extremely rare flea species in any country (although they are included in the diversity index calculations) unless that species was found in Romania.

## Results

A total of 305 red foxes from 12 Romanian counties in Transylvania and the far southeastern part of the country were examined between June 2010 and April 2012. Examination of these foxes yielded 912 individual fleas in seven flea species, including *Chaetopsylla globiceps* (Taschenberg, 32.5% of all fleas), *Ch. trichosa* Kohaut (1.5%), *Ctenocephalides canis* (Curtis, 32.6%), *Ct. felis* (Bouché, 0.1%), *Ctenophthalmus assimilis* (Taschenberg, 0.1%), *Paraceras melis* Walker (3.2%), and *Pulex irritans* L. (29.9%; Table 1). A single *Chaetopsylla* sp. flea could not be identified to species. The percentage of foxes that were infested was 49.5% (95% C.I. 43.8–52.5), and the flea load per infested fox ranged from 1 to 44 fleas, with a mean load of 5.8 (6.7 standard deviation) fleas per fox. The median load was 3 fleas per fox. Mean loads were highest for *Ch. globiceps*, *Ct. canis*, and *Pu. irritans* (Table 1), with a single highest load of 44 *Ct. canis* fleas. Of foxes for which date of collection was available, total fleas collected peaked significantly in fall and early spring (Fig. 1; $\chi^2 = 62.6$, df = 9, $P < 0.0001$). *Chaetopsylla trichosa* tended to be present year-round including in summer, in contrast to *Ch. globiceps*, which largely disappeared in summer months. *Ctenocephalides canis* levels were steady year-round except for a considerable spike in October, and *P. melis* was always uncommon and only detected in October–January. *Pulex irritans* had fall and spring peaks.

Coinfestations of multiple flea species were common. Among the 151 infested foxes, 76 (50.3%) had a single flea species, 43 (28.5%) had two species, 29 (19.2%) had three, and three (2.0%) had four. For all flea species with sample sizes greater than a single flea, both male and female fleas were found although there were significantly more female *Ch. globiceps* ($\chi^2 = 12.2$, df = 1, $P = 0.0005$), *Ct. canis* ($\chi^2 = 13.6$, df = 1, $P = 0.0002$), and *Pu. irritans* ($\chi^2 = 3.9$, df = 1, $P = 0.047$) than would be expected if sexes were even (Table 1).

The most broadly spatially distributed fleas were *Ch. globiceps*, *Ct. canis*, and *Pu. irritans* (Table 2; Fig. 2B, D, and E). No or very few fleas were recovered from Harghita, Cluj, and Călărași Counties, while highest prevalence occurred in Bistrița-Năsăud, Constanța, and Alba although sample size in some counties was low. Fleas were collected from low elevation all the way to 1,800 m for the three common and widely distributed fleas. The two species with moderate samples sizes, *Ch. trichosa* and *P. melis*, also had elevation ranges from as low as ~100 m to 900 and 500 m, respectively (Fig. 2F and G). Only a single individual each of *Ct. felis* and *Ct. assimilis* was collected, both at low to moderate elevations (Fig. 2C and A.

**Table 1.** Characteristics of flea infestations on red foxes in Romania

| Species | No. recorded | Percent of all fleas | No. of foxes infested with this species (prevalence) | Mean load (range) among infested foxes | Percent female fleas | Typical host[a] |
|---|---|---|---|---|---|---|
| *Chaetopsylla globiceps* | 296 | 32.5 | 73 (23.9) | 4.0 (1–28) | 64.5 | Fox (*Vulpes vulpes*) |
| *Chaetopsylla trichosa* | 14 | 1.5 | 12 (3.9) | 1.2 (1–2) | 57.1 | Badger (*Meles meles*) |
| *Ctenocephalides canis* | 297 | 23.6 | 79 (25.9) | 3.8 (1–44) | 65.5 | Dogs and cats |
| *Ctenocephalides felis* | 1 | 0.1 | 1 (0.3) | 1 (1–1) | 100 | Dogs and cats |
| *Ctenophthalmus assimilis* | 1 | 0.1 | 1 (0.3) | 1 (1–1) | 100 | Small mammals |
| *Paraceras melis* | 29 | 3.2 | 16 (5.2) | 1.8 (1–6) | 51.7 | Badger |
| *Pulex irritans* | 273 | 29.9 | 84 (27.5) | 3.3 (1–16) | 58.9 | Mesocarnivores |

[a] Typical hosts following **Suciu, M. 1973.**

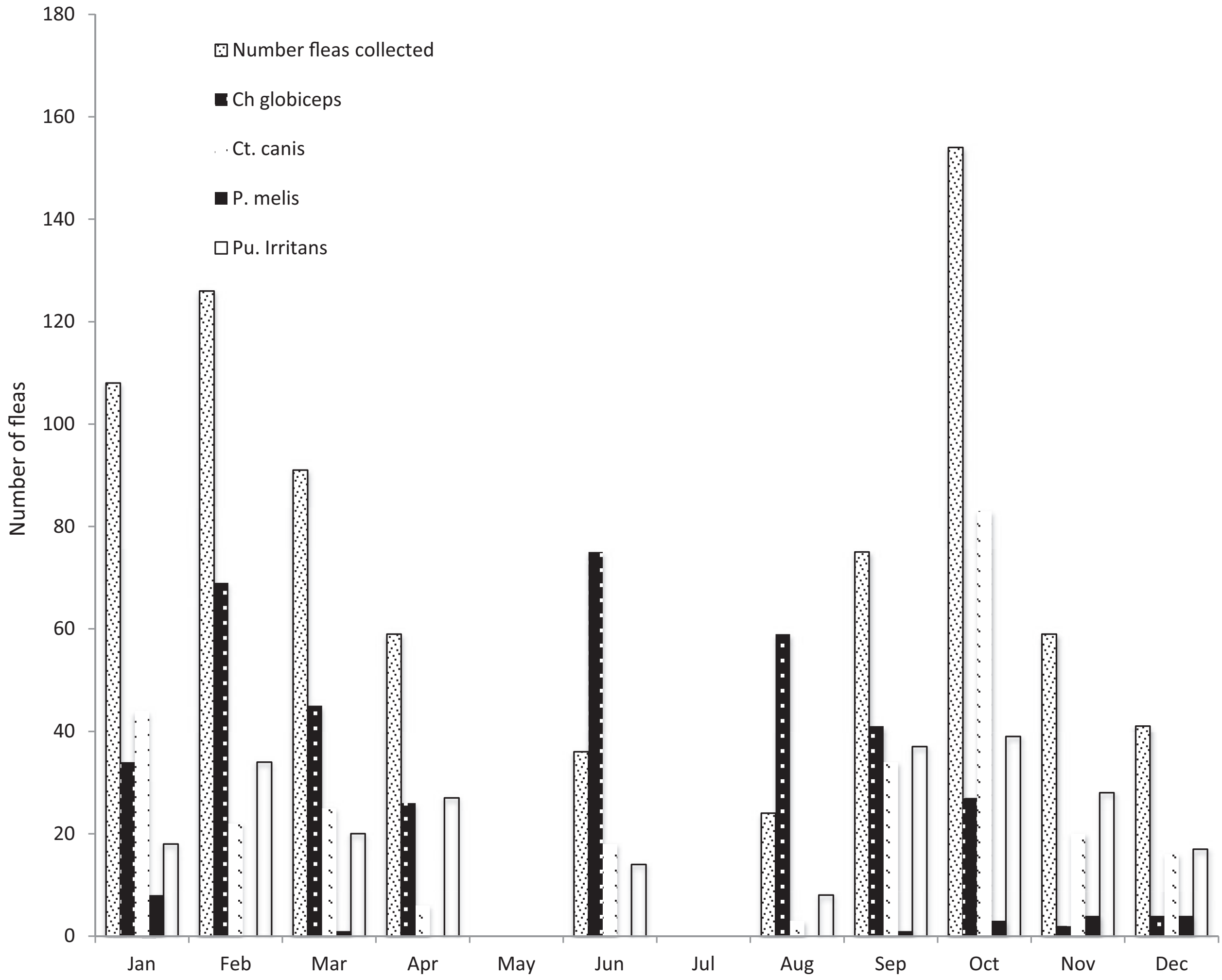


**Fig. 1.** Monthly numbers of abundant species of red fox fleas collected in Romania.

Across the three elevation categories, infestation prevalence, intensity S, D, and $e^H$ are summarized in Table 3. In the lowlands, we saw the highest infestation prevalence (57%) and high intensity of 3 fleas per fox. Although $e^H$ and D showed relatively high diversity, those values were slightly higher in hilly areas, where prevalence and per-fox intensity were reduced. The reductions in diversity in mountainous areas were associated with the presence of far fewer *Ct. canis* and *Pu. irritans* in this region and absence of *P. melis*.

We compared fox flea reports across Europe (Table 4), although we consider that differences in collection practices and sample size may have strongly biased these richness and infestation intensity, while diversity indices $e^H$ and D would be less biased. Romania's D of 3.66 and $e^H$ of 4.11 are near Europe's overall median of 3.96 and 4.46, respectively. *Pulex irritans* is often the most prevalent species, as occurred in Romania, France (except in northeast), Hungary, and Spain. *Ctenocephalides felis* and *Ct. canis* vary from having far greater numbers of *Ct. canis* than *Ct. felis* as was seen in Romania, France, Hungary, Slovakia, and Burgos, Spain, while more equal numbers or an excess of cat fleas were seen in British Isles, Murcia, Spain, and Austria. Although *Sp. cuniculi* and *Ar. erinacei* are

**Table 2.** Characteristics of spatial distribution of fleas on Romanian red foxes

| | *Ch. globiceps* | *Ch. trichosa* | *Ct. canis* | *Ct. felis* | *Ct. assimilis* | *P. melis* | *Pu. irritans* | Overall prevalence of infested foxes |
|---|---|---|---|---|---|---|---|---|
| Elevation range | 40–931 | 103–931 | 40–1004 | N/A[a] | N/A[a] | 114–509 | 40–1799 | |
| Mean elevation | 364.9 | 355.2 | 302.5 | 173 | 529 | 345.3 | 230.7 | |
| Prevalence by county (no. of foxes per county)[b] | | | | | | | | |
| Alba (14) | 21.4 | 14.3 | 50.0 | 0 | 0 | 7.1 | 64.3 | 85.7 |
| Bihor (84) | 32.1 | 3.6 | 38.1 | 0 | 0 | 10.7 | 39.2 | 64.3 |
| Bistrița-Năsăud (1) | 100 | 0 | 0 | 0 | 0 | 0 | 100 | 100 |
| Brașov (7) | 42.9 | 0 | 0 | 0 | 0 | 0 | 28.6 | 42.9 |
| Cluj (8) | 0 | 0 | 12.5 | 0 | 0 | 0 | 12.5 | 12.5 |
| Călărași (2) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Constanța (1) | 100 | 0 | 100 | 0 | 0 | 0 | 100 | 100 |
| Covasna (65) | 20.0 | 3.1 | 18.5 | 0 | 1.5 | 3.1 | 16.9 | 43.1 |
| Hunedoara (48) | 16.7 | 2.1 | 14.6 | 2.1 | 0 | 2.1 | 16.7 | 29.2 |
| Harghita (1) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Mureș (37) | 37.8 | 0 | 8.1 | 0 | 0 | 0 | 24.3 | 40.5 |
| Satu Mare (37) | 5.4 | 8.1 | 37.8 | 0 | 0 | 5.4 | 21.6 | 56.8 |

[a] No elevation range is specified because there was only a single flea in this species.

[b] Percentage of foxes in each county infested with fleas of each species.

Names of fleas are *Chaetopsylla globiceps* (*Ch. globiceps*), *Chaetopsylla trichosa* (*Ch. trichosa*), *Ctenocephalides canis* (*Ct. canis*), *Ctenocephalides felis* (*Ct. felis*), *Ctenophthalmus assimilis* (*Ct. assimilis*), *Paraceras melis* (*P. melis*), and *Pulex irritans* (*Pu. irritans*).

common in many countries, they were not detected in Romania. The fox specialist *Ch. globiceps* was seen at high prevalence and across many countries including Romania.

## Discussion

Red foxes in Romania host a diverse set of fleas, including species that are host specialists, likely shared with other carnivores, and zoonotic. In this study, we found that about half of all red foxes hosted fleas, that numbers of fleas tended to be relatively low but that some foxes had dozens of fleas, that coinfestation with multiple flea species was common, and that there were temporal and spatial patterns that distinguished flea infestations. The skew toward female fleas is a common pattern with ectoparasitic insects, possibly because males have shorter life spans and are not as involved in egg production as females (Marshall and Adrian 1981). Preisler (1983) also found skew toward females in Czech *Ch. globiceps* and *P. melis*, as occurred in Irish fox fleas including *P. melis* (Ross and Fairley 1969). Although phenological data should be interpreted with caution as effort was not consistent year-round in ours or other studies, our findings of *Ch. globiceps* mostly in Romania and *Ch. trichosa* in Czech Republic in winter, contrasting with observations of most fleas in late summer in London (Buckle and Harris 1980, Preisler 1983) is likely associated with lower summer temperatures and higher humidity in England compared with Romania.

Our infestation prevalence of ~50% compares with levels from as low as 25–34% in London and Ireland to as high as 60 and 86% in foxes in Spain and Hungary (Ross and Fairley 1969, Buckle and Harris 1980, Sréter et al. 2003, Millán et al. 2007). In a very small dataset from France, flea loads ranged from 0–12 fleas per fox (Marié et al. 2012) while foxes in London had only 2 fleas per fox (Buckle and Harris 1980), compared with our mean of 6. The most infested fox in Romania had 44 fleas, compared with a Czech fox with 237 *Ct. globiceps* (Preisler 1983).

In ranked order, our most abundant fleas were *Ct. globiceps* with 4 fleas per fox, *Ct. canis* with 3.8, and *Pu. irritans* with 3.3, whereas in Hungary, loads were 2.1 *Pu. irritans* per fox, 2.0 *Ct. globiceps* per fox, 0.2 *Ct. trichosa* per fox, 0.3 *Ct. canis* per fox, and 0.04 *P. melis* per fox (Sréter et al. 2003). *Chaetopsylla globiceps* is a fox specialist and abundant on foxes in the wild (Hinaidy 1976, Beaucournu et al. 1990, Schöffel et al. 1991, Sréter et al. 2003). *Pulex irritans* is often regarded as a human flea, but its common occurrence on wildlife and dogs in some parts of Europe including foxes suggests that it in reality it has low host specificity, often maintained on peridomestic species such as foxes, and readily infesting wildlife and humans (Beugnet et al. 2014). In Spain, its presence on foxes and Eurasian badgers (*Meles meles* (L.)) could be considered evidence for disease threat on the endangered Iberian lynx (*Lynx pardinus* (Temminck)) which also was infested with *Pu. irritans* (Millán et al. 2007). The dog and cat fleas, *Ct. canis* and *Ct. felis*, respectively, occur worldwide and are typically the most common fleas on pet cats and dogs interchangeably, despite their misleading specific epithets (Lawrence et al. 2015). In many regions, *Ct. felis* is more abundant on pet animals although some data indicate that *Ct. canis* predominates in eastern Europe (Beugnet et al. 2014, Lawrence et al. 2015). Both species, as well as *Ch. globiceps* and *Pu. irritans*, have been found on red foxes in Turkey (Aydin et al. 2011), while *Ct. felis* fell out of the fauna in Hungary (Sréter et al. 2003). *Paraceras melis* and *Ct. trichosa* are occasionally reported on foxes but some authors regard both of them as fleas of badgers (Suciu 1973). In most literature where a similar assemblage of fleas has been observed as this study, *P. melis* and *Ct. trichosa* have been less common than *Ct. canis*, *Ch. globiceps*, and *Pu. irritans*, including in Hungary, Austria, and France (Hinaidy 1976, Beaucournu et al. 1990, Sréter et al. 2003). There is a relatively meager literature on *Ct. assimilis* which is a small mammal flea found in eastern Europe. To our knowledge, it has not been reported on a carnivore previously. Among fleas commonly found on European foxes, we did not see the flea *Spilopsyllus cuniculi* which prefers lagomorph hosts, the hedgehog flea, *Archaeopsylla erinacei* (Beaucournu et al. 1990,

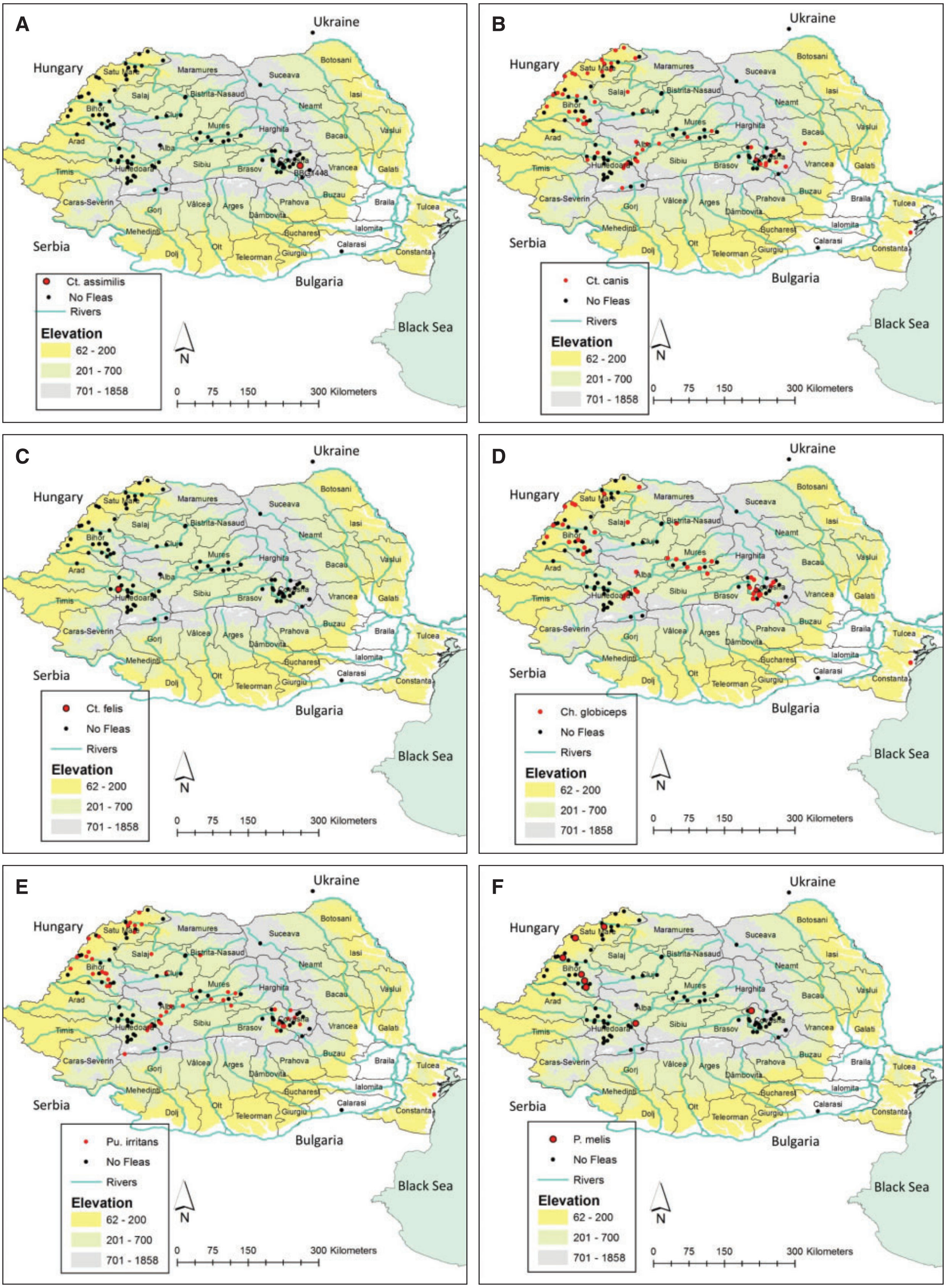


**Fig. 2.** Maps of detections on foxes in Romania of fleas of each species, according to three elevation categories (62–200 m above sea level, 201–700 m, and >700 m). The set of foxes from which no fleas were found is also plotted on each map to provide context. Map A: *Ctenophthalmus assimilis*, Map B: *Ctenocephalides canis*, Map C: *Ct. felis*, Map D: *Chaetopsylla globiceps*, Map E: *Pulex irritans*, Map F: *Paraceras melis*, Map G: *Ch. trichosa.*

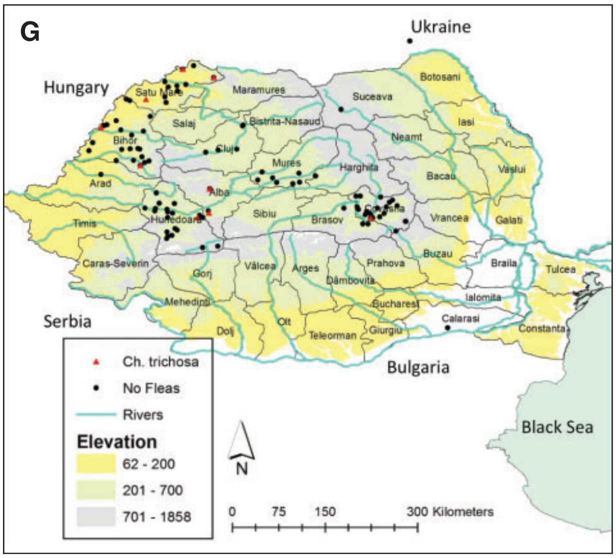


**Fig. 2.** Continued.

**Table 3.** Overall (all flea species) infestation prevalence (%) of foxes, intensity (average fleas per fox), and diversity indices for flea species according to elevation

| Elevation category | No. of foxes assessed | Flea infestation prevalence (95% C.I.) | Intensity | S | $e^H$ | D |
|---|---|---|---|---|---|---|
| Low (62–200 m) | 78 | 56.6 (44.7–67.7) | 3.01 | 5 | 3.49 | 3.13 |
| Mid (201–700 m) | 175 | 38.8 (31.7–46.4) | 2.49 | 6 | 3.58 | 3.24 |
| Mountainous (>700m) | 23 | 41.7 (22.8–63.1) | 3.04 | 4 | 1.99 | 31.55 |

Lowland is <200 m, hilly is 200–700 m, and mountainous is >700 m. Diversity index calculations are by flea number, not prevalence, and are described in the text.

Heptner 1998), or the oriental rat flea *Xenopsylla cheopis* (Rothschild) found to be the most abundant flea on foxes in Sicily (Torina et al. 2013). Lagomorphs are geographically very restricted in Romania and more evaluation of foxes near lagomorph-occupied areas could still yield the rabbit flea. However, hedgehogs (*Erinaceus roumanicus* Barrett-Hamilton) are abundant and the lack of *Archaeopsylla* is enigmatic.

While the data in this study are extensive, lack of samples from some regions in Romania preclude creation of definitive rule-sets for abiotic and biotic conditions where the various flea species are most likely to occur. Overall flea diversity in Romania was near the median for Europe. We were wary of direct comparisons of intensity per host and believe that some studies may have failed to find rare flea species if carcasses weren't sampled promptly (and few papers addressed that in their methods provided) because fleas often abandon cooling carcasses. Sample handling in Romania was as expeditious as possible but not always immediate after fatality and we don't have records as to which foxes may have been processed more slowly. Nevertheless, the diversity indices we employ are less biased by sample size. For example, a study with a very large flea sample size in CSR (Preisler 1983) had a very high S value while D and $e^H$ were not remarkably high relative to other countries. It was surprising that Romanian flea diversity wasn't higher and in fact even lower than reported for London (Buckle and Harris 1980).

Fleas can be vectors of disease or an indicator for cross-species interactions that could allow nonflea transmitted diseases to spread. Likely disease spillover patterns from our data are fox to fox via *Ch. globiceps*, among a mesocarnivore guild, and zoonoses via *Ctenocephalides* spp. and *Pu. irritans*. We found limited support for amplification of rodent-borne zoonoses via fox fleas although other studies found more rodent fleas than occurred in Romania, e.g., in London (Buckle and Harris 1980). Red foxes are native in Romania and are expected to compete and share disease with dogs, among other animals. When foxes live in peridomestic communities, disease dynamics in those communities are influenced by fox density, which can become high seasonally (Bartoń and Zalewski 2007). Other contributors to dynamics include spatial distribution and movement, interaction rates among foxes and other species, especially dogs, and host affinities of pathogens and parasites. Foxes are territorial although subadults or displaced individuals may be itinerant (Macdonald and Reynolds 2008). In Canada, average dispersal was 19 km but distances as high as 48 km were recorded as well (Rosatte and Allan 2009). Foxes dispersing from within London tended to go towards rural areas and as far as 7.9 km for males (Page 1981), revealing that dispersal, and possible long-distance movement of infection, could vary with habitat type, fox density, and other factors. Although red foxes may live in the open outside of breeding season (Harris and Yalden 2008), burrowing foxes may accumulate ectoparasites.

Our study did not include testing the foxes or fleas for vector-borne pathogens, but one that might be expected is *Rickettsia felis* which has been found in *Ct. felis* fleas of red foxes in Sicily (Torina et al. 2013), both *Ct. felis* and *Ct. canis* on domestic animals in the Czech Republic (Lawrence et al. 2015), and *A. erinacei* in France (Marié et al. 2012, Lawrence et al. 2015). While *Bartonella rochalimae* and *B. vinsonii* subsp. *berkhoffii* occurred in *Pu. simulans* from gray foxes (*Urocyon cinereoargenteus* (Schreber)) in northern California (Gabriel et al. 2009), no *Ctenocephalides* spp. from foxes in Romania or Czech Republic or *A. erinacei* from France were PCR-positive for this pathogen (Marié et al. 2012, Lawrence et al. 2015). Fleas are vectors of the agent of flea-borne typhus, *R. typhi*, although we are not aware of this agent being found in foxes or fox fleas. Although no longer present in most of Europe, plague caused by *Yersinia pestis* has been reported in foxes (Heptner 1998); indeed, the most implicated vector for *Y. pestis* is *X. cheopis* which we did not observe on Romanian foxes but was abundant on Sicilian foxes (Torina et al. 2013). More data on pathogens in fleas in Romania can help evaluate whether fleas on foxes could serve as a risk for pathogens to domestic animals and people.

The study of Romanian fleas offers valuable opportunities to understand impacts of high ecological diversity on an obligate arthropod parasite and potentially to understand vector-borne diseases of wildlife, domestic animals, and humans. Here and in the literature, individual foxes often host multiple different flea species (Buckle and Harris 1980, Preisler 1983). It has been proposed that fox interactions with humans (and also with our domestic animals), increased synanthropy of red foxes, and urbanization of Europe could account for the finding of common peridomestic fleas often outnumbering specialist fox fleas (Sréter et al. 2003) although unlike in the Hungarian study, fox specialist fleas were still the most abundant in Romania possibly because so much of Romania remains wild. A complementary hypothesis is that *Ctenocephalides* and *Pulex* are truly cosmopolitan but have been thought to have peridomestic ecologies because of attention bias. Further examining flea faunal assemblages as Europe continues to experience anthropogenic influences will help clarify patterns of parasite disease risk for wildlife and humans as well.

**Table 4.** Fox flea diversity and prevalence (%) across Europe

| | Fox *N* | Flea *N* | Intensity | D | $e^H$ | S | *Pu. irritans* | *Ct. canis* | *Ct. felis* | *Sp. cuniculi* | *Ar. erinacei* | *Ch. globiceps* | *Ch. trichosa* | *Ch. matina* | *Ch. rothschildii* | *P. melis* | *Ce. gallinae* | *No. fasciatus* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Prevalence | | | | | | | | | | | |
| Romania (this paper) | 305 | 912 | 2.99 | 3.66 | 4.11 | 7 | 27.54 | 25.9 | 0.3 | | | 23.9 | 3.9 | | | 5.2 | | |
| France (Beaucournu 1973) | 80 | 1,497 | 18.71 | 5.41 | 6.17 | 9 | 51.25 | 25 | 1.3 | | | 2.5 | 21.3 | 1.25 | 15 | 23.8 | | |
| NE France (Aubert and Beaucournu 1976) | 206 | 804 | 3.90 | 5.97 | 7.49 | 14 | 4.37 | 15.53 | 2.43 | 13.59 | 25.24 | 5.34 | 5.83 | | | 15.53 | 0.49 | 0.97 |
| North Ireland (Ross and Fairley 1969) | 453 | 161 | 0.35 | 2.01 | 2.6 | 6 | | 0.22 | | 7.95 | 0.4 | | | | | 3.1 | 0.22 | 0.22 |
| London (Buckle and Harris 1980) | 252 | 513 | 2.04 | 4.73 | 5.89 | 8 | 1.59 | 3.57 | 3.6 | 4.76 | 15.1 | | | | | 6 | | 0.4 |
| Hungary (Sréter et al. 2003) | 100 | 62 | 0.62 | 4.27 | 4.8 | 6 | 43 | 11 | | | 30 | 37 | 12 | | | 4 | | |
| CSR (Preisler 1983) | 7,783 | 6,205 | 0.80 | 4.8 | 5.9 | 21 | 0.09 | 0.46 | * | 0.9 | 0.9 | 2.4 | 1.3 | 0.14 | 0.01 | 0.6 | * | * |
| Slovakia (Kočišová et al. 2006) | 78 | 1,925 | 24.68 | 1.44 | 1.62 | 2 | | 15.4 | | | | 67 | | | | | | |
| Berlin (Schöffel et al. 1991) | 100 | ~400 | ~4 | 3.44 | 4.11 | 7 | | 1 | 2 | 14 | 30 | 31 | | | | 1 | | 6 |
| Murcia, Spain (Martínez-Carrasco et al. 2007) | 55 | ~482 | ~8.8 | 1.92 | 2.24 | 3 | 90.1 | | 9.1 | 36 | | | | | | | | |
| Burgos, Spain (Dominguez 2004) | 26 | 13 | 0.5 | 3.28 | 3.83 | 5 | 30.77 | 26.92 | 7.7 | | | | 3.8 | | | 7.7 | | |
| Austria (Hinaidy 1976, Lassnig et al. 1998) | 295 | | | 4.26 | 5.31 | 8 | 5 | 3 | 1 | 0.3 | 6 | 18 | 11 | | | 3 | | |

The columns show total number of foxes examined, total number of fleas retrieved, mean number of fleas per fox (intensity) calculated from both infested and uninfested foxes, three measures of flea diversity (S, D, and $e^H$), and prevalences for each flea species at each location as described in text. Flea biodiversity as represented in this table is truncated to remove very rare species for northeastern France and Czech Socialist Republic (CSR), except that rare species are used in calculations of diversity. Because of missing data, exact total numbers and intensity of fleas are not available for Austria (designated with ~) and prevalences of some CSR fleas cannot be calculated (indicated by *).

Not shown in this table: a prevalence of 38% for *Chaetopsylla homoea* reported from France (Beaucournu 1973); a prevalence of 0.33% for *Ctenophthalmus assimilis* observed in this paper from Romania; a prevalence of 5.2% for *Orchopeas howardi* from London; and a prevalence of 0.01% for *Dasypsyllus gallinulae* in CSR. Names of fleas are *Chaetopsylla globiceps* (*Ch. globiceps*), *Chaetopsylla trichosa* (*Ch. trichosa*), *Ctenocephalides canis* (*Ct. canis*), *Ctenocephalides felis* (*Ct. felis*), *Ctenophthalmus assimilis* (*Ct. assimilis*), *Paraceras melis* (*P. melis*), and *Pulex irritans* (*Pu. irritans*).

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