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DISTRIBUTION OF *IXODES RICINUS* (ARACHNIDA, IXODIDAE) IN UKRAINE IN THE CONTEXT OF TICK HAZARD, AND FACTORS FAVORING ITS PERSISTENCE IN CONDITIONS OF FAST-GOING ENVIRONMENTAL CHANGE

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Distribution of *Ixodes ricinus* (Arachnida, Ixodidae) in Ukraine in the Context of Tick Hazard, and Factors Favoring its Persistence in Conditions of Fast-Going Environmental Change. Akimov, I. A., Nebogatkin, I. V. — Habitat conditions and factors were studied contributing to the spread of *Ixodes ricinus* (Linnaeus, 1758) over vast territories. There are excellent conditions for the existence of the hard ticks in the settlement agglomerations throughout Ukraine: suitable biotopes with expedient litter and a large number of hosts for all stages of development of ticks. The castor bean tick lives in all of Ukraine, adapting its size of idiosome and diapause to changing environmental conditions, and using the ability to parasitize on animals well adapted to urban conditions. *Ixodes ricinus* prefers urban landscapes in areas with unfavorable environmental conditions. The hiatus in the range of the castor bean tick between the southern mainland of Ukraine and the steppe regions of Crimea may be restored due to global climatic changes.
Key words: ticks, *Ixodes ricinus,* distribution, urban landscapes, Ukraine.

Introduction

The castor bean tick *Ixodes ricinus* (Linnaeus, 1758) is the most abundant species of hard ticks in Europe. The southern border of its range is along the borders of Turkey and several northern African countries. The eastern border is in the Russian Federation (Lindquist & Vapalahti, 2008), and the northern one is expanding northward due to climate warming (Medlock et al., 2013). The hiatus (fig. 1) in the range that has been noted on the territory of Ukraine (Akimov & Nebogatkin, 1996) disappeared in 1980–1990s (Akimov & Nebogatkin, 1996). The species now lives throughout the country except for typically arid landscapes (Akimov & Nebogatkin, 2010). As the only common species of the subgenus *Ixodes*, *I. ricinus* is the vector of spirochetes of the genus *Borrelia* (complexes of *B. burgdorferi* s. l. and *B. miyamotoi* s. l.) in Ukraine (Filippova, 1990; Rogovskiy et al., 2018). Hence, it transmits the most common illness in humans and domestic animals, associated with ixodids, Lyme disease (Korenberg et al., 2016; Nebogatkin & Shulhan, 2020). The aims of the present work are to present the distribution of *I. ricinus* in Ukraine in view of tick hazard starting from the beginning of XXI century, to find out the reasons for the "prosperity" of the species under conditions of fast-going environmental change, and to assess the current state of the former hiatus at the territory in Ukraine.

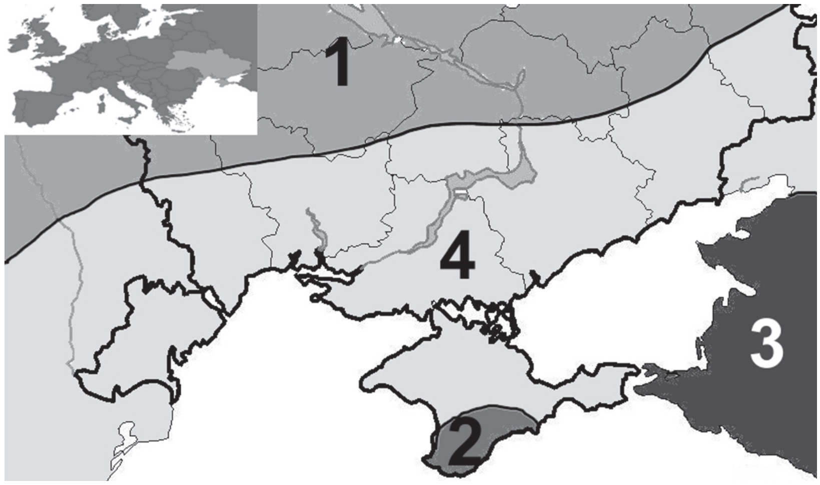

Fig.1. The hiatus in the range that has been noted on the territory of Ukraine: 1 — European area of distribution; 2 — Crimean area of distribution; 3 — Caucasian-Western Asian area of distribution; 4 — zone of disjunction (after fig. 1 Akimov & Nebogatkin, 1996 with changes).

Material and methods

The studies were carried out using a flag or combing from small mammals, or by manual collection from the domestic and agricultural animals according to standard methods (Tularemia, 1954). We used our own data and materials from six-month forecasts and reviews of the Public Health Center of the Ministry of Health of Ukraine, which has previously been known also as Ukrainian Center for Disease Control and Monitoring, Ukrainian Center for State Sanitary and Epidemiological Surveillance, and Republican Sanitary and Epidemiological Station of the Ministry of Health of the Ukrainian SSR.

The territory of Ukraine has been divided into 18 landscape-geographical areas (table 1) according to the boundaries of the administrative regions as of July 17, 2020 (Akimov & Nebogatkin, 2011). The total number of ticks was summed up for the period of 2000–2020 to calculate the index of dominance, ID (Beklemishev,

Table 1. Data used to compile a tick hazard map for humans and animals on the example of *I. ricinus*

No	Plots	Quantity regions	Quantity district	*I. ricinus* feeders	ID	*I. ricinus* flag	ID	AI
1	Eastern Polissia	2	21	83 858	28.53	8636	20.28	3
2	Central Polissia	2	23	28 747	71.15	8402	46.99	5
3	Western Polissia	4	29	44 227	54.59	29 713	28.51	4
4	Eastern Forest-steppe	4	54	67 80	25.71	34 949	46.66	4
5	Central Forest-steppe	4	90	37 107	58.79	40140	58.74	5
6	Western Forest-steppe	7	55	60 360	82.28	49 696	50.91	5
7	Northwestern F-S	2	13	31 860	67.30	23 031	38.94	4
8	Eastern Steppe	4	42	6576	21.98	3696	48.63	3
9	Left Bank Steppe	4	42	9260	62.07	13 778	47.12	4
10	Donets Ridge	2	12	4209	20.58	960	12.32	2
11	Right Bank Steppe	5	66	172 324	62.07	18 424	51.46	5
12	Seaside Steppe	1	2	569	6.77	724	11.93	1
13	Carpathians Mountains	4	16	10 758	70.63	4238	66.10	5
14	Carpathians Foothills	4	14	27 178	60.7	3660	85.16	5
15	Crimea Foothills	1	4	127	2.62	58	30.95	2
16	Crimea Steppe	1	10	36	0.23	56	9.16	1
17	Crimea Kerch	1	1	4	0.17	16	2.59	1
18	Crimea Mountains	1	3	324	11.53	602	53.98	5
Total		53	497	52 4304	37.35	240 779	37.50	64

Note. ID — index of dominance; AI — average indicator.

1961). Based on the index value, tick abundance was scored from 1 to 5 at each landscape-geographical area for the collection from animals and for counts on the flag separately. After that, the results were summarized and averaged.

In order to understand the flourishing of the species under the conditions of the fast environmental changes, we grouped the studied territories of dacha cooperatives, widespread in suburbs of large cities and towns of Ukraine, into settlement agglomerations. We used own data obtained during 16 years starting from 2005 at 3 sites of Kyiv Region, including natural biotopes, part of settlement agglomerations of Kyiv City and Bila Tserkva town.

The maps were made in QGIS 3.16. The statistical processing was performed in the programs R-statistics i386 3.5.1 and Past 3.2.

Results and discussion

We analyzed the distribution of 524 304 *I. ricinus* ticks collected from hosts, and 240 779 ticks caught on the flag. In total, 765 083 pieces were analyzed according to the summarized data taken from six-month forecasts and our own data since 2000 (table 1).

The percentage of ticks collected by authors to the total number varied depending on the site from 0.3 % (Carpathian Mountains) to 45 % (central Forest-steppe and Polissia).

Three sites were found with a very low abundance (1 point), two sites with a low (2 points) and with an average abundance (3 points), 4 sites with normal abundance (4 points) and 7 sites (5 points) with a lot of castor bean ticks.

The optimum (4 and 5 points) of the abundance of *I. ricinus* in Ukraine was found on the territory of 11 areas of 20 regions (fig. 2), or 61.11 %.

Thus, the distribution of the castor bean tick at the territory of Ukraine differs in terms of abundance, the level of dominance, and the presence of foci of mass tick emergence, i. e. in terms of tick hazard.

The territory of Ukraine is divided into four following zones according to the distribution of *I. ricinus*:

- zone of dominance of the castor bean tick by abundance factor over other ixodid species, ID more than 50 %;

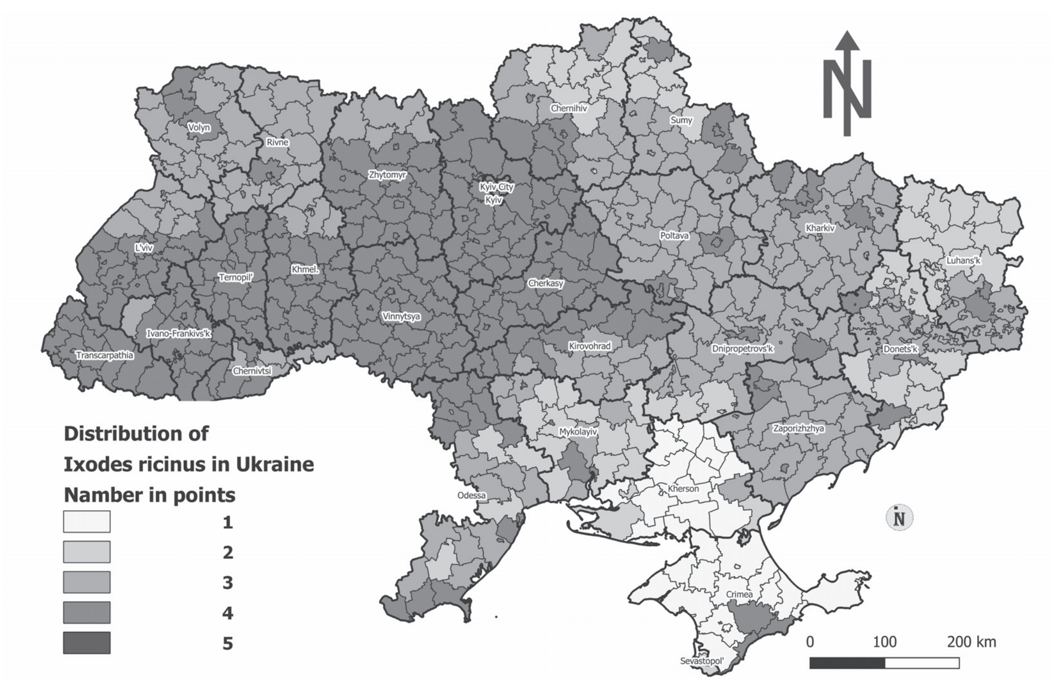

Fig. 2. Distribution of *I. ricinus* on the territory of Ukraine, from the point of view of tick-borne danger.

- zone of regularly occurring mass emergence, once in three years;
- zone of periodically occurring mass emergence;
- zone of mosaic foci of emergence due to unfavorable environmental conditions.

To study the ecology of ixodid ticks in the settlement agglomerations, more than 300 field trips were carried out, about 20 thousand ixodid ticks of 3 species were captured, 345 Gero traps were placed, and 67 small mammals of 4 species were caught in Kyiv Region (table 2). A paired two-sample t-test for averages in pairwise comparison of the results for areas with a normal distribution showed a significant difference by more than 95 % between natural biotopes, Kyiv and Bila Tserkva agglomerations.

The abundance of *I. ricinus* in the Bila Tserkva agglomeration is more than twice higher ($P > 0.05$) than that in natural biotopes, and more than in the Kyiv agglomeration. The finds of *I. hexagonus* Leach, 1815 indicate the existence of Southern white-breasted hedgehogs (*Erinaceus concolor* Martin, 1838) in these territories, and their abundance is apparently higher in the human-altered landscapes. Among small mammals in settlement agglomerations *Apodemus agrarius* (Pallas, 1771) are dominant, amounting to 6.67 per 100 п/с (ID is 62.16) and house mice (*Mus musculus* Linnaeus, 1758), amounting to 2.32 п/с (ID is 21.62). Single specimen's genus of *Sylvaemus* Ognev, and common shrews (*Sorex araneus* Linnaeus, 1758) were recorded in the catches: 0.87 per 100 trap-days. One of the three wood mouse (*Sylvaemus sylvaticus* (Linnaeus, 1758)) was a host of one non-feeding and two feeding nymphs of *I. ricinus*.

Thus, there are excellent conditions for the existence of ixodid ticks at the settlement agglomerations of Ukraine, there are suitable biotopes with expedient litter, varying grasses and thickets of ruderal plant species, a lot of hosts of all stages of tick development, including stray and domestic dogs and cats, large and small ruminants, horses, various species of mice and shrew hosts of immature ticks.

In Ukraine, the number of castor bean ticks is higher in urban landscapes than in natural ones, even higher than in settlement agglomerations. One of the reasons for this fact can be elimination of roe deer in many habitats except for hunting grounds.

Thus, the most important factors that determine the prosperity of *I. ricinus* in most of its range are, in our opinion:

1. The size of the idiosomes of mature and immature ticks are 3–4 mm. That allows inhabiting the biotopes with relatively low humidity (up to 75 %) due to the ability of litter to adsorb water vapor above the soil surface. To accumulate water, the mature *I. ricinus* ticks enter the litter on soil surface, from 1 to 8 times, depending on microclimate (Gigon, 1985). The tick salivary glands produce hyperosmotic saliva in alveoli of the 1st order (Needham et al., 1990). This saliva actively collects water vapor from the air. The vapor is adsorbed in the preoral cavity. Droplets of the hygroscopic saliva are then swallowed back or adsorbed in certain cuticle areas inside the oral cavity (Rudolph, Knulle, 1978). Also, ticks can exist in small islands of natural and artificial landscapes, including urban, scattered mosaically, on a wide range of hosts of various sizes.

2. Using diapause, the castor bean tick can complete its full life cycle in 1.5 to 5–10 years, allowing for significant individual longevity (Balashov, 1998). During this time, they avoid elimination by possible acaricidal treatments or several consequent dry years in a row,

Table 2. Abundance indices of ixodid ticks and the sampling effort in three areas of Kyiv Region

Plots	Sections	Number of ticks	Species		
			IR	DR	IH
Vasilkovsky District, natural biotopes	77	8298	4,44	5,03	not differ
Kyiv-Sviatoshyn agglomeration	125	9554	6,60	5,10	0,01
Bilotserkivsky agglomeration	59	8895	10,38	11,73	0,03

Note. IR — *I. ricinus*; DR — *D. reticulates*; IH — *I. hexagonus*.

and survive in conditions of newly developed areas and otherwise changing environment (Akimov & Nebogatkin, 2016).

3. The ability of ticks at all stages of development to parasitize on animals that are most adapted to urban and anthropogenic landscapes. These hosts include the field and house mice, the brown rat (small mammals); foxes (carnivores); cats and dogs, including stray; domestic and agricultural cattle (goats, cows, horses).

4. Parasitizing birds, including common passerines, provides access to new territories. Adults of *Parus major* Linnaeus, 1758 and, more often, the younger birds of this species fly hundreds of kilometers away for wintering. Those birds migrate mainly from west to east than from north to south and back (Poluda, 2011). In such areas, ixodid ticks can create spontaneous foci (Nebogatkin, 1996), which either become permanent or decline.

5. Ticks inhabit the relatively new conditions of settlement agglomerations, which are spreading, including on the territories which ixodid ticks did not previously live due to low moisture.

Natural warming of the planet's climate, on the one hand, ensures that several species of ixodid ticks expand northward, such as *Ixodes persulcatus* Schulze, 1930 (Uspensky et al., 2003), and *Ixodes ricinus* (Medlock et al., 2013). On the other hand, the warming induces unfavorable conditions associated with the loss of moisture in habitats in parts of the species ranges located closer to the equator. Hence, a natural interest arose in the areas of the former hiatus of this species on the territory of Ukraine (Nebogatkin, 2018). Findings the castor tick in the southern regions of Ukraine confirm the existence of local foci of reproduction of the species. The index of dominance ranged from 0.06 to 14.7 (table 1). The presence of this species is indirectly confirmed by human cases of Lyme disease (Rogovskiy et al., 2020). In 2009–2019, the number of cases of Lyme disease in Kherson region was 12 times less than in Kyiv Region. In the southern regions of Ukraine, *I. ricinus* is inhabiting local areas, urban territories, and settlement agglomerations near large and medium-sized cities. However, due to climate change, conditions for the hiatus in the range of *I. ricinus* in Ukraine may reappear.

Conclusions

The castor bean tick (*Ixodes ricinus*) lives everywhere in Ukraine, adapting to changing environmental conditions based on the size of its idiosome, diapause, the ability to parasitize on mammals and birds well adapted to urban conditions, especially in settlement agglomerations.

In areas with unfavorable environmental conditions, *I. ricinus* tends to inhabit urban landscapes.

Continuous ranges of ixodid ticks should be modeled as separate zones based on the level of tick hazard, taking into account dominance, the possibility of regular, periodic mass foci of reproduction, and mosaic habitats.

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