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Long-Term Monitoring of the Numbers of Ixodid Ticks (Acari: Ixodinae) in St. Petersburg and Leningrad Province

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Abstract—Changes in the distribution and abundance of ixodid ticks *Ixodes persulcatus* and *I. ricinus* in St. Petersburg and Leningrad Province over the period of 1970–2018 are analyzed. As compared with the data of the 1970s, the abundance of ticks has decreased by 6–9 times in the city parks and suburbs and by 1.5–10 times in Leningrad Province. With the increasing anthropogenic impact caused by the population growth and seasonal migration of people in the territories of Leningrad Province bordering the city, contacts of people with ixodid ticks have become more frequent, increasing the number of tick bites and complicating the epidemic situation of tick-borne infections.

Keywords: *Ixodes persulcatus*, *I. ricinus*, St. Petersburg, Leningrad Province

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Ixodid ticks are part of the fauna of cities and suburbs (Dautel and Kahl, 1999; Uspensky, 2008, 2017; Medvedev et al., 2016; Klitgaard et al., 2019) located under suitable natural and climatic conditions. These arthropods have an epidemic significance since they form a component of the parasitic environment of natural ecosystems in which they act as vectors of transmissible infections (Daniel and Cerný, 1990; Gern et al., 1997; Romanenko, 2002). Observations of the ixodid tick abundance in the territories of St. Petersburg (formerly Leningrad) and Leningrad Province started in the 1960s, but regular annual surveys were performed from the early 1970s to the 1980s (Zolotov et al., 1974; Vansulin et al., 1981). The fauna of ixodid ticks of St. Petersburg and Leningrad Province comprises five species of the subfamily Ixodinae, among which the taiga tick *Ixodes persulcatus* Schulze, 1930 and the wood tick *I. ricinus* Linnaeus, 1758 can attack humans for blood feeding and live in anthropogenically transformed biotopes. In the territories of St. Petersburg and Leningrad Province these ticks can transmit tick-borne encephalitis, ixodid tick-borne borrelioses, granulocytic anaplasmosis, monocytic ehrlichiosis, tularemia, and Q fever (Tokarevich, 2008; Grigoryeva et al., 2019; Tokarevich et al., 2019). *Ixodes trianguliceps* Bir., *I. apronophorus* P. Sch., and *I. lividus* Koch inhabit natural biotopes and cannot feed on humans (Zolotov et al., 1974; Filippova, 1977). One more species, *Dermacentor pictus* Herm. (Amblyomminae), was recorded for the study region by Zolotov and co-authors (1974) but not found in the subsequent collections (Tretyakov et al., 2012).

Natural and climatic conditions. The city of St. Petersburg (with an area of over 1 300 km^2) and Leningrad Province (83 908 km^2) lie in the Northwest of European Russia within the taiga zone (with a small part of the

province extending into the mixed forest zone), under the conditions suitable for completion of the life cycles of *I. ricinus* and *I. persulcatus*. The mean temperature of January is −8…−11°C, that of July is +16…+18°C. The annual precipitation is 600–700 mm. The period of stable snow cover lasts from the second half of November or the first half of December to the second half of April. The predominant soils are of the podzolic type. A considerable part of Leningrad Province is occupied by bogs, while forests cover 55.5% of its territory. Anthropogenic and transformed natural biotopes occupy over 330 km^2, of 25% of the territory of St. Petersburg; they include residual forest stands, forest parks, cemeteries, coppice and shrubs near gardening communities and cluster home settlements.

Hosts of ixodid ticks. The fauna of Leningrad Province mainly includes forest-dwelling animals, of which 68 species of mammals are known as potential hosts of ixodid ticks. The principal hosts are red squirrels, polecats, baum martens, European moles, mountain and brown hares, hedgehogs, and various small mammals, such as common voles, striped and yellow-necked field mice, rats, etc. Besides, there are gray wolves, wild boars, roe deer, red foxes, elk, brown bears, lynx, weasels, river otters, spotted deer, beavers, minks, and raccoon dogs.

Life cycle and phenology of ixodid ticks. The abiotic and biotic factors mentioned above determine the non-uniform distribution of ixodid ticks over St. Petersburg and Leningrad Province. Both species of epidemic significance are present in St. Petersburg, with prevalence of *I. persulcatus* (Zolotov et al., 1974; Vansulin et al., 1981; Tretyakov et al., 2012). *Ixodes ricinus* occurs in Kurortny District, to the north of Solnechnoe (Grigoryeva et al., 2019), with single records also known from the southwestern districts of the city. The activity of this species starts in the middle or last third of April, and its abundance reaches a peak in the beginning third of May. The activity season of *I. persulcatus* continues to the end of June, less often to the beginning of July. Its life cycle takes 3 years but may be extended to 4 or even 5 years in no more than 10% of the population (Grigoryeva, 2015; Grigoryeva and Stanyukovich, 2016). The activity of *I. ricinus* continues from April to October, with the highest abundance in July–August. During the whole activity season most of the ticks belong to the generation which reached the adult stage in August and early September of the preceding year. At the beginning of the activity season (April–June) the populations may include up to 17% of ticks of the previous generation which were active in the preceding year (Grigoryeva, 2017); samples collected at the end of the activity season include from 30 to 60% of ticks of the new generation. Similar to adult ticks, nymphs of two successive generations coexist during the activity season (Grigoryeva et al., 2019). The whole life cycle of *I. ricinus* may take from 3 to 7 years (Grigoryeva, 2017; Grigoryeva and Shatrov, 2018).

In this paper we summarize our data and information provided by epidemiological surveillance officials on the abundance and ecology of ixodid ticks in St. Petersburg and Leningrad Province over the period of 1970–2018.

MATERIALS AND METHODS

Observations of the epidemically significant species of ixodid ticks, *I. persulcatus* and *I. ricinus*, were carried out in St. Petersburg and Leningrad Province during the past 60 years by researchers from the Hygienic and Epidemiological Centers for St. Petersburg and Leningrad Province, the Northwestern Antiplague Station of Rospotrebnadzor, and the Zoological Institute of the Russian Academy of Sciences. This work is based on estimates of tick abundance from more than 430 localities, including 25 localities in which regular seasonal surveys were carried out using standard techniques: counting the number of ticks per 1 flag-hour and collecting ticks off small mammals captured in snap traps.

RESULTS AND DISCUSSION

The results are summarized in the tables and illustrated with maps (Fig. 1; Fig. 2). Under the conditions of St. Petersburg megalopolis, the most suitable territories for ixodid ticks are city parks, forest parks, and cemeteries; however, their stable populations occur in the territories adjoining the forested areas of Leningrad Province, where they are supported by actively migrating hosts (Table 1; Fig. 1). Following the construction of the Ring Road freeway encircling St. Petersburg, which started in 1998, the peripheral forest parks in Primorsky and Kurortny districts became less accessible to large and medium-sized mammal hosts, so that the tick abundance in these biotopes decreased. The same effect was observed in Kurortny District after the construction of the Western High-Speed Diameter toll road. This is evi-

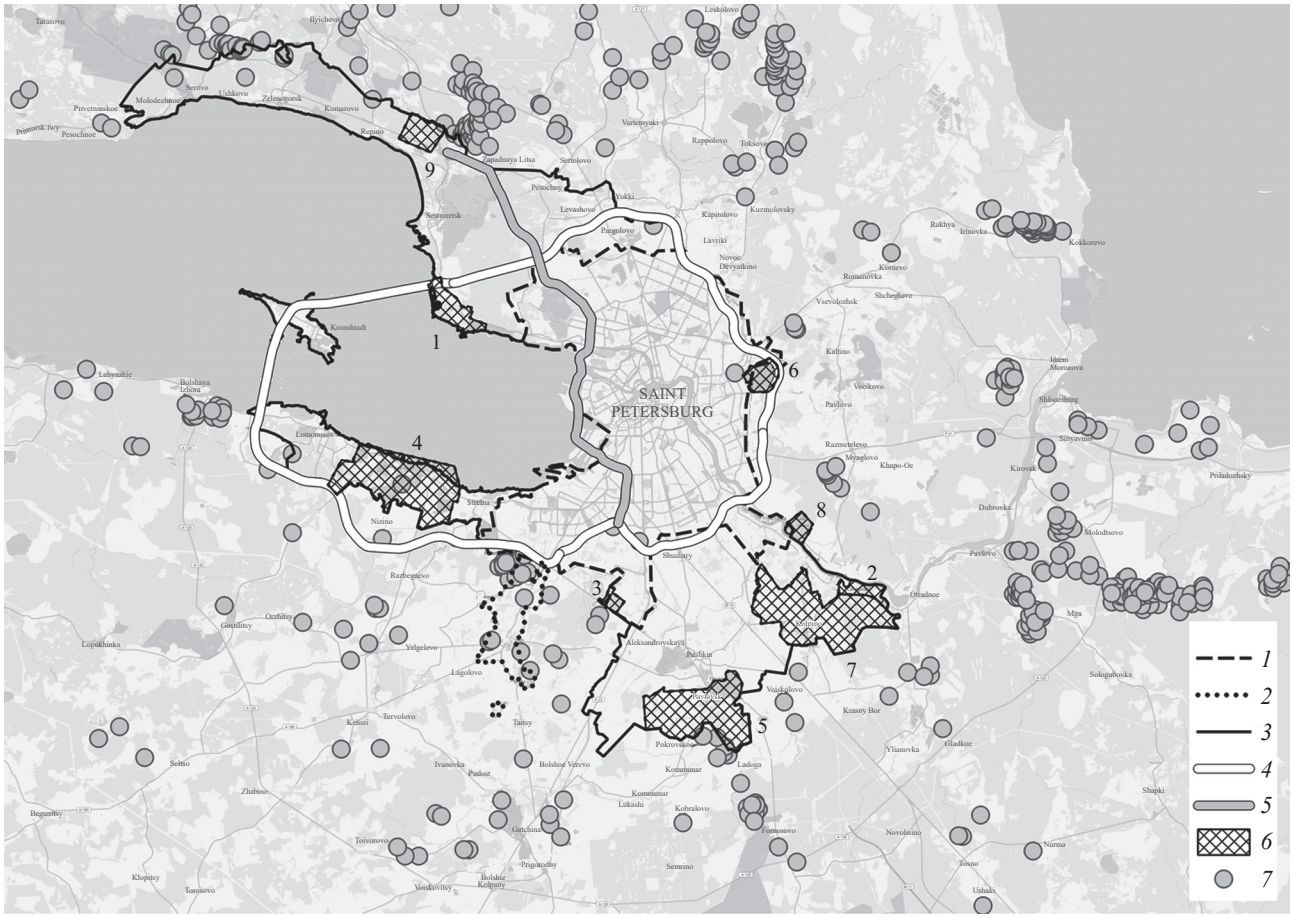

Fig. 1. Distribution of ixodid ticks in St. Petersburg: *1*, city boundary in 1961–1973; *2*, the same, in 1973–1990; *3*, the same, after 2005; *4*, Ring Road freeway; *5*, Western High-Speed Diameter toll road; *6*, parks containing stable populations of ixodid ticks (numbered as in Table 1); *7*, gardening communities.

dent from comparison of the tick densities recorded in the 1990s, the 2000s, and at present (Table 1). Social and cultural development, housing construction, and land improvement in Kurortny District led to changes in the natural biotopes and an abrupt decrease in *I. ricinus* population. As the city expanded, the parks which used to be closely connected to the forested areas of Leningrad Province became isolated, and the density of ticks in them decreased by 6–9 times. At the same time, the abundance of game animals in Leningrad Province has not changed much over the period of 2000–2018 (Table 2), according to the data of the Committee for Protection, Control, and Management of Faunal Objects of Leningrad Province (letter I-906/2019 of 2.04.2019). The numbers of large and medium-sized mammals in the peripheral forest parks seem to have decreased considerably, so that the tick populations are currently maintained at a low level by the scanty medium-sized hosts, in particular birds visiting the lower vegetation layer and also stray and outdoor dogs and cats, on which adult female ticks can feed. The principal hosts of the larvae and nymphs of *I. persulcatus* and *I. ricinus* are the bank vole *Myodes glareolus* Sch., the striped field mouse *Apodemus agrarius* Pall., the common vole *Microtus arvalis* Pall., the yellow-necked field mouse *A. flavicollis* Melch., and the common shrew *Sorex araneus* L. (Table 3).

The tick density in the forest parks of St. Petersburg is now estimated as low (less than 2 ind./flag-hour) or in exceptional cases as medium (2–10 ind./flag-hour), according to the scale of Tokarevich and co-authors (1975). However, as late as the 1970s high densities (11–20 ind./flag-hour) of both species were recorded in

Table 1. Mean density of adult ticks (ind./flag-hour) in St. Petersburg in 1970–2018

Tick species	Localities	1970s	1980s	1990s	2000s	2010–2018
Ixodes persulcatus	*1* Lisy Nos	15 (20)	7.5	5.8	5.2	2.0
	2 Saperny	–	6.0	3.8	3.3	0.9
	3 Yuzhnoye Cemetery	–	–	4.7	5.5	0.5
	4 Petrodvorets	–	0.2	1.3	0.3	0.1
	5 Pavlovsk	0.3	0.1	4.6	3.1	1.0
	6 Rzhevsky Forest Park	–	–	0.0	7.0	0.1
	7 Kolpino	–	–	3.0	0.7	0.5
	8 Nevsky Forest Park	–	–	–	–	3.5
Ixodes ricinus	*9* Kurortny District	17.5	7.5	5.8	5.2	2.0

The numbers of localities correspond to those in Fig. 1

Table 2. Abundance of game animals in Leningrad Province in 2001–2018

Species	2001	2005	2010	2015	2018
Red squirrel	128033	58948	30036	75371	38985
Gray wolf	446	241	230	223	500
Weasel	1654	1326	1559	526	498
Mountain hare	70361	62978	43177	43228	36638
Brown hare	823	494	607	534	344
Wild boar	1798	3804	7126	5575	7049
Roe deer	674	610	857	376	598
Baum marten	6703	7219	6661	4527	6331
Red fox	4718	4975	5069	3539	3536
Elk	9001	11151	11801	15983	21250
Lynx	491	402	263	135	322
Polecat	635	545	409	411	623
Wood grouse	40299	36299	85047	–	–
Heath hen	188678	128271	129611	–	–
Hazel hen	207882	139032	25910	–	–
Brown bear	–	–	1908	2307	2844
Raccoon dog	–	–	6845	5875	6682
Badger	–	–	3118	3114	3152

Kurortny District, and medium values were observed in the 1980–2000s in Kurortny District, Pavlovsk Park, Kolpino, Rzhevka, and Yuzhnoye Cemetery. Thus, the overall abundance of these ticks has decreased over the past 50 years, and especially the past 20 years.

Epidemic risks are linked to the large-scale annual use of recreational green zones and seasonal migrations of the city residents into the suburbs of St. Petersburg and into Leningrad Province. The All-Russian agricultural census of 2016 showed that during the summer

Table 3. Relative abundance (%) of small mammals serving as hosts to the larvae and nymph of *I. persulcatus* and *I. ricinus* in St. Petersburg and Leningrad Province

Host species	St. Petersburg		Leningrad Province	
	I. persulcatus	*I. ricinus*	*I. persulcatus*	*I. ricinus*
Myodes glareolus Schr.	48.4	54.4	54.9	95.5
Sorex araneus L.	5.7	6.8	10.5	4.5
S. minutus L.	0.1	–	–	–
Microtus arvalis Pall.	6.3	1.1	–	–
M. agrestis L.	0.1	–	–	–
Micromys minutes Pall.	1.0	0.3	–	–
Apodemus uralensis Pall.	2.4	0.6	17.6	–
A. flavicollis Melch.	5.9	31.4	17.0	–
A. agrarius Pall.	28.9	5.4	–	–
Mus musculus L.	0.6	–	–	–
Sicista betulina Pall.	0.3	–	–	–
Rattus norvegicus Berk.	0.3	–	–	–

Table 4. Number of residents affected by tick bites in St. Petersburg in 1970–2018

District of St. Petersburg	1970s	1980s	1990s	2000s	2010–2018
Total for all districts	4251	5341	7467	9638	12557
Kurortny District	1321	1949	2604	3910	4998
Primorsky District	–	1114	1502	3463	2026
Pavlovsk	–	589	858	1175	1470
Pushkin	–	251	337	447	696
Kolpino	–	305	396	232	267
Rzhevsky forest park	–	–	–	37	324
Petrodvorets	–	119	138	156	356

season, over 2.4 million people resided in 265 gardening, horticultural, and vacation home communities in St. Petersburg and 3531 communities in Leningrad Province (Fig. 1). According to the Decree of the Government of Leningrad Province "On approval of the overall allocation of private housing and gardening zones in Leningrad Province" of 13.04.1995, at that time there were only 248 gardening communities with a total of about 350 thousand residents. Thus, in the past 20 years the number of gardening communities has increased by 15 times, and the number of people living in them, by 7 times. Most of the gardening communities are located 100–150 km from the city and surrounded by typical natural habitats of ixodid ticks. These territories were used as farmlands 20–30 years ago and did not provide suitable conditions for ixodid tick development. However, since that time the suburban agriculture came into decline and the farmlands got overgrown with weed trees and shrubs, i.e., replaced with secondary natural biotopes actively visited by tick hosts and supporting low densities of tick populations. After the expansion of the administrative borders of St. Petersburg in 2005, some of these territories were allocated for multi-storey housing projects while others, which remained within

Table 5. Mean density of adult ixodid ticks (ind./flag-hour) in Leningrad Province in the 1970s and in 2000–2018

District	*Ixodes persulcatus*		*Ixodes ricinus*	
	1970s	2000–2018	1970s	2000–2018
1 Boksitogorsk	10.0	2.5	–	–
2 Volosovo	13.5	5.0	1.5	5.0
3 Volkhov	16.4	8.5	6	2.3
4 Vsevolozhsk	6.0	3.1	3.5	3.1
5 Vyborg	6.0	1.5	6	2.0
6 Gatchina	1.25	4.5	2.5	4.5
7 Kingisepp	6.0	8.0	1.2	6.0
8 Kirishi	4.8	9.5	6.0	1.8
9 Kirovsk	7.5	14.0	6.0	4.5
10 Lodeinoe Pole	22.5	11.5	7.5	11.5
11 Lomonosov	6.0	1.5	6.0	1.5
12 Luga	1.0	2.0	1.0	3.0
13 Podporozhie	6.0	4.5	15.0	4.5
14 Priozersk	1.2	–	15.1	1.5
15 Slantsy	1.5	2.0	1.5	5.0
16 Tikhvin	12.3	3.3	–	–
17 Tosno	8.5	5.5	6.0	5.5

Table 6. Mean density of adult ixodid ticks *Ixodes persulcatus* and *I. ricinus* (ind./flag-hour) in Leningrad Province

District	1970s	1980s	1990s	2000s	2010–2019
Mean for Leningrad Province	4.9	8.9	4.5	2.7	4.5
Boksitogorsk	10.0	–	–	–	2.2
Volosovo	7.9	4.8	–	–	5.0
Volkhov	11.2	5.4	1.4	–	–
Vsevolozhsk	4.6	–	0.6	–	3.5
Vyborg	6.0	0.5	–	–	0.7
Gatchina	3.8	2.1	6.8	4.1	5.7
Kingisepp	6.0	–	–	–	8.2
Kirishi	5.3	7.6	–	–	–
Kirovsk	8.7	5.3	4.5	2.4	9.5
Lodeinoe Pole	15.0	–	–	–	11.5
Luga	1.0	1.3	2.3	–	3.3
Podporozhie	10.4	0	–	–	4.5
Priozersk	8.1	0.5	–	–	1.3
Slantsy	2.6	–	–	1.0	4.5
Tikhvin	12.3	–	0	4.0	3.6
Tosno	8.8	11.6	8.1	2.8	5.1

Table 7. Number of residents affected by tick bites in Leningrad province in 1970–2018

District	Number of cases in 2010–2018	Population in 2019, thousands
Total for Leningrad Prov.	94309	1813.6
Boksitogorsk	387	19.4
Volosovo	1454	46.9
Volkhov	4838	95.2
Vsevolozhsk	14395	160
Vyborg	12962	109.3
Gatchina	11021	128.6
Kingisepp	3188	81.9
Kirishi	2797	66.8
Kirovsk	9153	60.7
Lodeinoe Pole	1081	34.3
Luga	7480	86.2
Podporozhie	528	15.6
Priozersk	9779	44.9
Slantsy	708	45.4
Tikhvin	790	15.5
Tosno	8875	72.6

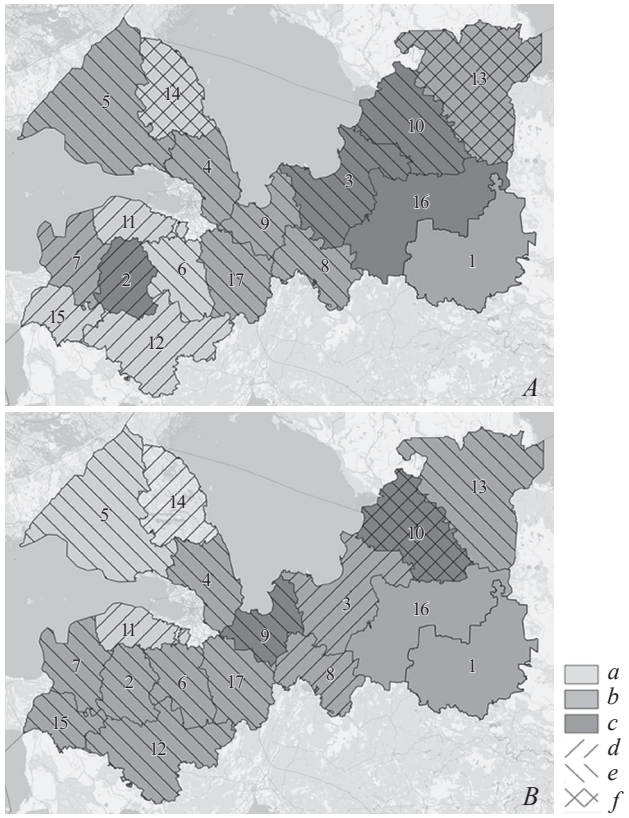

Fig. 2. Distribution and abundance of *I. persulcatus* (*a*–*c*) and *I. ricinus* (*d*–*f*) in Leningrad Province: (*A*) in the 1970s; (*B*) in 2000–2018. The districts of Leningrad Province are numbered as in Table 5. Density of adult ticks: *a*, *d*, low (less than 2 ind./flag-hour); *b*, *e*, medium (2–10 ind./flag-hour); *c*, *f*, high (over 10 ind./flag-hour).

Leningrad Province, became available for private housing construction. Under these circumstances, the number of people seeking medical help due to tick bites increased considerably (Table 4), although the density of ixodid ticks in the biotopes remained low. The high level of human activities in the natural biotopes obviously increased the number of potential contacts with ticks despite their low densities.

Ixodid ticks are distributed non-uniformly in Leningrad Province; *I. persulcatus* and *I. ricinus* occur sympatrically in this territory (Filippova, 2017) and may be simultaneously present in the same biotope (Tokarevich et al., 1975).

As the result of large-scale surveys carried out in 2010–2019 by researchers from the Hygienic and Epidemiological Center for Leningrad Province (Table 5; Table 6), it was found out that only *I. persulcatus* occurred in Boksitogorsk and Tikhvin districts. Both species were present in the remaining territory of the province (Fig. 2), but *I. ricinus* comprised no more than 10% of the total number during the spring collections. The abundance peak was observed in the beginning third of May in the southern taiga subzone and in late May and early June in the middle taiga subzone, coinciding with the onset of stable positive air temperatures.

The principal hosts of the larvae and nymphs of *I. persulcatus* and *I. ricinus* are the bank vole, the pygmy and yellow-necked field mice, and the common shrew (Table 3). The hemisynanthropic yellow-necked field mouse and common vole actively visit the biotopes adjoining residential areas and can spread the tick larvae and nymphs in settlements and smallholdings. Correspondingly, increasing densities of these small mammals in regular zoological surveys can be interpreted as an indication of redistribution of the ticks between the forest and the environs of settlements.

Table 8. Number of patients infected with tick-borne encephalitis and Lyme disease due to tick bites in St. Petersburg and Leningrad Province in 1970–2018

Territory	Disease	1970s	1980s	1990s	2000s	2010–2018
St. Petersburg	Tick-borne encephalitis	18	15	17	15	1
	Lyme disease	–	26	328	216	107
Leningrad Province	Tick-borne encephalitis	186	262	453	562	347
	Lyme disease	–	262	2520	2940	2115

The overall abundance of ixodid ticks in Leningrad Province has considerably decreased over the past 50 years (Table 5; Table 6; Fig. 2). At the same time, the number of people suffering from tick bites has been steadily increasing: 9 441 cases in the 1970s, 25 440 in the 1980s, 44 122 in the 1990s, and 79 782 cases in the 2000s. Starting with 2010, cases are recorded separately for different districts (Table 7). The greatest number of tick bites has been recorded in Vsevolozhsk, Vyborg, Gatchina, and Tosno districts, directly adjacent to the territory of St. Petersburg and characterized by the greatest number of residents but low densities of ixodid ticks (Table 7; Fig. 2). By contrast, the smallest number of cases has been recorded in the east of the province, where the tick populations are maintained at high densities due to the presence of vast forest areas with large mammals serving as hosts to adult ticks. The difference may be attributed to the different levels of anthropogenic impact. Besides, it should be noted that people living far from administrative centers would less frequently apply for medical help after tick bites.

The territory of Leningrad Province includes natural foci of tick-borne encephalitis and other infections transmitted by ixodid ticks. The first encephalitis foci were discovered there in 1942–1943 (Zolotov et al., 1974), and cases of this infection have been recorded annually since that time (Table 8). Besides, cases of ixodid tick-borne borrelioses (Lyme disease) and occasional cases of human monocytic ehrlichiosis have also been recorded annually since the 1980s. The presence of several tick-borne infections, the possible cases of concurrent infection, and sometimes also the absence of background records of tick bites pose a public health issue, since they can increase the diversity and continuity of the symptoms and complicate differential diagnostics.

Thus, as compared with the data of the 1970s, the abundance of ixodid ticks has decreased by 6–9 times in the parks and nearest suburbs of St. Petersburg and by 1.5–10 times in Leningrad Province. At the same time, the anthropogenic impact on the territories of Leningrad Province bordering the city has increased due to the population growth and seasonal migration of people. This has led to more frequent contacts of people with ixodid ticks despite the low densities of the latter. As a result, the recorded number of tick bites has increased, and the epidemic situation with tick-borne infections has been aggravated.

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COMPLIANCE WITH ETHICAL STANDARDS

The authors declare that they have no conflict of interest. All the applicable international, national, and/or institutional guidelines for the care and use of animals were followed. All the procedures performed in studies involving animals were in accordance with the ethical standards of the institution or practice at which the studies were conducted.

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