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EPIDEMIOLOGICAL SURVEY OF MAMMALS AND HARD TICKS IN URBAN AND PERI-URBAN AREAS OF VORONEZH IN 2001-2016

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Аннотация. Динамики численности иксодовых клещей и их прокормителей – млекопитающих – изучены в урбосистемах г. Воронежа и его окрестностях в 2001-2016 г. Рассмотрено их эпидемиологическое значение в связи с прогнозирование вспышек зоонозов на территории города.
Ключевые слова: зооноз, урбосистемы, динамика численности, грызуны, насекомоядные, собаки, лисицы, кошки, иксодовые клещи, эпидемиология

Abstract. Population dynamics of tick species and their mammal feeder species were studied in urban ecosystems of Voronezh and its peri-urban area from 2001 to 2016. The epidemiological role of these animals in zoonotic outbreaks in the city is discussed herein.
Keywords: zoonosis, urban ecosystem, peri-urban area, population dynamics, rodents, insectivorous mammals, dogs, cats, foxes, ixodid ticks, epidemiology

Zoonosis is defined as a disease that is naturally transmissible from vertebrate or invertebrate animals to humans and vice-verse (reverse zoonosis) [1]. Some of these diseases are transmitted by a vector. Vertebrate animals which can carry viruses or bacteria (or protozoon cysts, worm eggs and larvae) include bats, rodents, apes, monkeys, opossums, horses, deer, sheep, racoons, hamsters, cats, dogs, cattle, and many species of birds; as well as vectors (mosquitoes, black flies, sand-flies, horse flies, lice, fleas, and blood-sucking ticks and mites). Zoonoses are considered to be one of the most important threats for Public Health worldwide [2]. More than 75 % of human diseases are of zoonotic origin, which is why it is crucial to understand the interrelations between wildlife, synanthropic and domestic animals and humans in peri-urban and urban areas [3, 4]. Vector-borne diseases remain an increasing threat for many countries, include developed ones.

During the past 30 years human populations in cities were affected by zoonotic diseases, including Lyme borreliosis, various types of hemorrhagic fevers, etc. These spilled over into human populations due to interactions between the carrier hosts and domestic animals. Some endemic zoonotic diseases have dramatically expanded their nosoareals, such as Lyme borreliosis, tick born encephalitis, West Nile, Dengue and Zika fevers, rabies and hemorrhagic fever with renal syndrome (HFRS). Other zoonotic diseases which have been under control for decades are now returning to animal and human populations. Plague, tularemia, some kinds of typhus and spotted fevers are examples of them. Evolution towards person-to-person transmission depends on the biological features of the pathogen, but may well be triggered or facilitated by external factors such as changes in human exposure. Disease emergence may thus be depicted as an evolutionary response to changes in the environment, including anthropogenic factors such as new agricultural practices, urbanization, and climate change.

Modern cities and towns provide specific ecological niches for many organisms, including birds, mammals and blood sucking arthropods. Urban environments are populated by synanthropic species, which serve as reservoirs for pathogenic agents. Some zoonotic diseases circulate in both natural and urban cycles [5] based on cenotic conditions and ecological interrelations.

Urbanization has an impact on the transmission of zoonotic agents. Adaptable wild animals are attracted to peri-urban and urban areas [6] for many reasons. First of all, some wild species settle in peri-urban and even urban habitats due to the existence of rich food supplies. Public food chains, storage and organic garbage provide animals with abundant amounts of nutritious materials. Second, different kinds of buildings and constructions provide shelter where species of wild animals can settle.

Peri-urban areas contain elements of suitable ecological conditions conducive to the survival of wild animals. They are located between the rural core and urban ecosystems, and encompass characteristics of both in different rates and proportion depending on the degree of anthropogenic impact. The composition and structure of animal communities differ between natural, peri-urban and urban environments. However, food chains between plants, animals and humans develop in both peri-urban and urban areas. Modern cities and provincial towns provide ecological niches for stray and feral dogs and cats, some wild carnivorous, insectivorous and rodent species, birds and arthropod vectors such as ticks, mites, fleas, and mosquitoes. The transmission of parasites and infections from wild to domestic animals and to humans in peri-urban and urban environments is quite complicated and often depends on the level and type of urbanization. Human activity impacts the environment which leads to an imbalance in the structure and functions of parasitic systems, undermining the stability of relationships between parasites and their typical hosts. By penetrating into natural focuses of zoonotic diseases along with agricultural and domestic animals, humans become part of parasitic systems. Anthropogenic transformation of a natural environment (anthropopression) leads to qualitative and quantitative changes to host circles for some parasites [7-8]. The mechanisms of autoregulation of parasitic system become defective as well. Under these conditions the infection rate of humans and animals is higher than in a non-transformed environment. In urban ecosystems the anthropogenic transformation of cenotic conditions is irreversible. At the same time, urban systems and peri-urban areas create new ecological niches for some parasites and their hosts. As a result, synanthropic cycles of zoonotic diseases develop. In new or seriously transformed parasite-host systems, inhibition of mutual adaptations takes place. It is a significant factor contributing to parasite species switching from typical to new hosts.

V.P. Sergeev [9] noticed that the danger to humans posed by parasitic species connected with birds, synanthropic or domestic animals is high. At least 26 zoonotic diseases are associated with birds, 32 with synanthropic rodents, and 65 with dogs. Some zoonoses connect with agricultural animals: 35 with horses, 42 with pigs, 46 with small livestock, and 50 with cattle.

I. Uspensky [10] emphasized that current strategies for conservation and preservation of biodiversity include creation of green corridors and other forms of connectivity between wilderness and urban areas, and between green patches within cities. This is typical of megapolices all around the world. The presence of suitable environments inside the cities and their peri-urban zones allows various mammals and bird species to inhabit those areas and establish permanent urban populations [10]. The composition of mammal species in urban and peri-urban conditions varies in different regions.

The cases of animal penetration in peri-urban and urban areas mostly involved small animals (mice, rats, voles) [11, 12]. In addition , these areas are also colonized in different countries by rabbits (*Oryctolagus cuniculus*) in Poland and Slovakia, European brown hares (*Lepus europaeus*) in Germany, red foxes (*Vulpes vulpes*) in Russia, France, Switzerland, red squirrels (*Sciurus vulagaris*)in many countries, hedgehogs (*Erinaceus europeaus*) in France and Switzerland [13-18].

Many developed countries face the problem of zoonotic diseases in urban and peri-urban areas [2, 19-22]. For example, nine of 16 European countries show evidence of increasing incidence of Lyme borreliosis. Poland, eastern Germany, Slovenia, Bulgaria, Norway, Finland, Belgium, Britain and the Netherlands are among them. The largest rates of increase that occurred between 2003 and 2004 were 44% in Belgium, 74% in Norway, 51% in Finland, and 73% in Bulgaria [23-24].

In 2005 outbreaks of hemorrhagic fever with renal syndrome (HFRS) occurred in five neighbouring countries (Belgium, France, Germany, the Netherlands and Luxembourg) [25-26]. This epidemic was characterized by the extension of the known endemic area in several of the affected countries, and the involvement of urban areas for the first time.

Mass activity of hard ticks in urban and peri-urban areas have been observed in some regions of Russia [28-31]. In Voronezh there are ample zones suitable for coexistence of ticks and their feeders [32-33]. This situation leads to establishment of urban focuses of zoonotic diseases. Voronezh Region includes natural focuses (niduluses) of Lyme borreliosis (tick-born borreliosis) [27, 32, 34-35], West Nile fever, tularaemia, HFRS [36-37]), rabies [38], and Q-fever, leptospirosis [27]. Also zoonotic diseases caused by protozooans and helminths were reported in peri-urban and urban areas of Voronezh (pyroplasmosis and toxoplasmosis [39-41] and toxocarosis and dirofilariosis [42-44]).

The number of tick species and their trophic relations in the region have been investigated in both wild and peri-urban conditions [32, 45-50]. Research of mosquitoes species and their ecology has started in the Region [51-52]. During the last decade, from 40 to 60 cases of Lyme borreliosis and 2 to 5 cases of Q-fever have been registered annually. Also, in every year since 2010, cases of WNF have been reported. Outbreaks of tularemia occurred in 2005-2006, HFRS in 2007, leptospirosis in 2007, 2009 and 2013, West Nile Fever in 2011-2012. Infective agents of those diseases as well as HGA (human granulocytic anaplasmosis) and HME (human monocytic ehrlichiosis) are regularly found among wild vertebrates and blood-sucking arthropods.

The aim of this research is to analyze zoonotic diseases in Voronezh city from 2001 to 2016 according to ecological conditions in the peri-urban and urban areas inhabited with specific mammals and hard ticks species.

MATERIAL AND METHODS

The number of micromammalians was calculated using the ratio of trap-lines (t/l) to trapping per 100 trap-days (t/d) in ecologically different areas of the city and peri-urban environments [53]. Cats and dogs were counted visually every month. Foxes were counted both visually and by traces. Earlier published survey data were also used [32-35, 45-50; 54-57].

1. Survey of ixodid tick dynamics in the urban and peri-urban areas and urban systems of Voronezh city

The ticks found in Voronezh and peri-urban area belong to 4 species: *Ixodes ricinus* (L.), *Dermacentor marginatus* (Sulzer), *Dermacentor reticulatus* Fabricius, and *Rhipicephalus rossicus* Yakimov et Kohl-Yakimova (all three samples of the later species found in 2015 were damaged and might belong to closely-related species *Rh. pumilio* P. Sch.).

These ticks feed on blood of more than 80 species of vertebrates (mainly mammals) and have 3-host life cycles. The larvae feed on small mammals, including rodents. Nymphal ticks suck blood of rodents, cats, dogs, foxes and people in urban environments. Adult ticks feed on blood of dogs, people, goats and sheep inside the city area and suburbs. All of their hosts exist in urban environments. During the following spring when the rodent population "booms", the ticks lay their eggs, thus ensuring a food supply for sub-adult ticks.

In 2001-2016 the population numbers of ixodid ticks were changeable (tabl. 1, fig. 1) with a strong growth trend. The highest number of these ticks was observed in 2008-2009 and 2014-2016. An outbreak of their activity occurred in October-November 2010 during an abnormally warm fall. In all years *D. reticulatus* prevailed. However, in last several years the population of *I. ricinus* increased noticeably.

Table 1

Number of adult ixodid ticks in urban and peri-urban areas of Voronezh in 2001-2016

	Ixodes ricinus	Dermacentor marginatus	Dermacentor reticulatus	Всего
2001	57	33	50	140
2002	78	42	54	174
2003	67	25	98	190
2004	44	19	68	131
2005	265	87	473	825
2006	75	36	236	347
2007	158	72	483	713
2008	351	128	578	1057
2009	472	246	343	1061
2010	145	247	252	644
2011	410	316	565	1291
2012	324	192	512	1028
2013	111	118	267	496
2014	423	210	654	1287
2015	476	224	618	1318
2016	829	1097	1349	3275

Table 2

Dynamics of the numbers of larvae and nymphae of ixodid ticks in urban and peri-urban areas of Voronezh in 2003-2016

	Ixodes ricinus. l	*Ixodes ricinus*. n	*Dermacentor* spp.. l	*Dermacentor*. n
2003	26		63	
2004	34		54	
2005	97		132	
2006	57		94	
2007	75		300	
2008	207		246	
2009	224	218	264	250
2010	63	49	118	109
2011	88	63	322	329
2012	81	65	165	83
2013	52	40	117	61
2014	137	73	279	96
2015	312	125	200	94
2016	416	219	383	126

Dynamics of subadult hemipopulations fluctuated (tabl. 2). The peak of larval and nymphal stages takes place from the end of May till the beginning of August. Their main feeders (hosts) in Voronezh and peri-urban area were muscomorph rodents, voles, some insectivorous mammals and passerine birds. Abundance of subadult ixodids is connected with the number of the rodents.

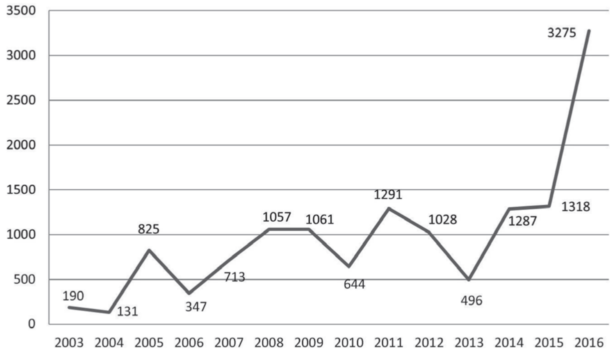

Fig. 1. Dynamics of total number of the ixodids in Voronezh in 2003-2016

Presence of dead leaf litter and wooden mat is an important factor for successful hibernation of adult ticks, development of their eggs and subadult malting. The litter plays the role of shelter and regulator of soil temperature and humidity, especially in hot and cold seasons. Humidity in the litter is usually higher than in the air. In artificial suburban forests, urban parks, cemeteries, forests at the edges of the city and in peri-urban areas, conditions are quite favourable for ticks and their development. In April between 15 and 30 ixodid samples can typically be found per 1 flag/hour. In 2015-2016 up to 60 ticks were collected per 1 flag/hour. At the end of May the number of ticks decreased two times in comparison with April, and at the end of June by three times in comparison with May. At the end of June adult ticks become inactive while their larvae and nymphs become active on their feeders.

Ticks focuses, based on the peculiarities of their formation, comprise two main groups: primary and secondary. The primary ones form in natural cenosis, while the secondary become established in areas transformed by humans. In Voronezh and peri-urban area there are stable primary tick focuses with relatively high subpopulation sizes, and throbbing focuses whose numbers vary sharply from year to year. Usually throbbing focuses appear in small zones where fluctuations in tick numbers are strongly correlated to the number of feeders.

In Voronezh, especially at the edges of the city and in the parks, secondary tick focuses exist. A high concentration was observed in 2010-2011 after an abnormally hot summer caused massive fires in the forests. In some cases, ecological conditions inside the city can be more favorable than in natural biotops. Stable local subpopulations of three tick species exist in Voronezh city.

Lyme borreliosis is a zoonosis transmitted to humans from rodents or some other mammals by ticks that feed on both sets of hosts. Urbanization and other anthropogenic factors can be implicated in the spread of Lyme disease to humans. Expansion of suburban neighborhoods and of the edges of peri-urban areas has led to gradual deforestation of surrounding wooded areas and increased border contact between humans and tick-dense areas. Artificial aforrestation in particular parts of the city leads to similar effect. As a consequence of increased human contact with host and vector, the likelihood of transmission of the disease has greatly increased. Lyme disease starts its circulation in peri-urban and urban systems. Quite similar situation can be noticed in many other regions of Russia.

In Voronezh the typical hosts of *Borrelia burgdorferi* are house mice, rats, bank voles and field striped mice. In some years these rodents have population waves and become extremely abundant. Some species also migrate to urban ecosystems in the fall. At the same time, the tick population is increasing from year to year.

The rate of infection of ixodids by *Borrelia* spp. was up to 40 % in 2005-2006 гг. [32]; tularemia antigen has been reported annually since 2003 and ranges from 0,5 % to 8,5 %. Q-fever antigen was found in 2005 and 2007 in 1 % of tests. In 2011, WNF antigen was found in tick *D. reticulates*, and in 2012 in *Ixodes ricinus*. In 2015 23,8 % of ticks carried *Borrelia* spp., 12,1 % carried Human Granulocytic Anaplasmosis (HGA), 9,4 % carried Human Monocytic Ehrlichiosis (HME), and 10.5 % had mixed infection [27].

2. Survey of micromammalians in urban and peri-urban areas of Voronezh city

Some species of small mammals are attracted by peri-urban and urban areas due to the existence of a rich food supply and available shelter.

Dynamics of rodent species populations in Voronezh Region have been studied for the last several decades [33, 45-50; 54, 56-58]. In 1975-2000 in the spring and fall, increases in populations of house mouse and brown rat were observed, likely due to the appearance of additional places for their habitat and the deterioration of sanitary and structural condition of some buildings. Feeding and reproduction by these rodents took place inside the city and in the buffer recreation zone, rural areas and artificial forests. In this period the relative number of synanthropic rodents ranged from 0.3 to 0.8 per 100 trap/days, with peaks of populations in 1979, 1982, 1983, 1997 [56].

The population of small mammal species is also influenced by climatic factors which may have favorable or adverse impacts on food resources and reproduction, especially after an abnormally warm spring following a mild winter. This is in addition to cyclic fluctuations of rodent species population sizes.

Increases in the number of rodents that serve as carriers and reservoirs of zoonotic infections (HFRS, Lyme borreliosis, tularemia and some others) inside the city and in peri-urban area present epizootological and epidemiological hazards for humans. Small mammals are also the main feeders of larval and nymphal ixodid ticks that serve as vectors of agents of Lyme disease, tularemia and pyroplasmosis in the recreational buffer zones of Voronezh. Epidemiological and epizootological connections between infective agents, reservoirs of infection and vectors are thus established and give a ground to form foci of zoonotic diseases inside the city.

Hemorrhagic fever with renal syndrome is caused by strains of *Hantavirus*, which are carried by rodents. The occurrence of this disease in endemic areas is at its highest when rodent densities are highest (May-June and October-November). In urban areas, the predominant reservoir is the house mouse; in wild environments and peri-urban areas, *M. gloreolus* and *A. agrarius*. People can become infected with these viruses and develop HFRS after exposure to aerosolized urine, droppings, infected rodent saliva or dust from their nests. An outbreak of HFRS in Voronezh Region took place in 2007 when 154 people were infected. Today, HFRS is widespread in Voronezh region and many other Russian cities. At present, more than 50% of cases pertain to people who were infected in the city.

Counts of 13 main small mammal species have been conducted in Voronezh in 2001-2016 (fig. 2, table 3).

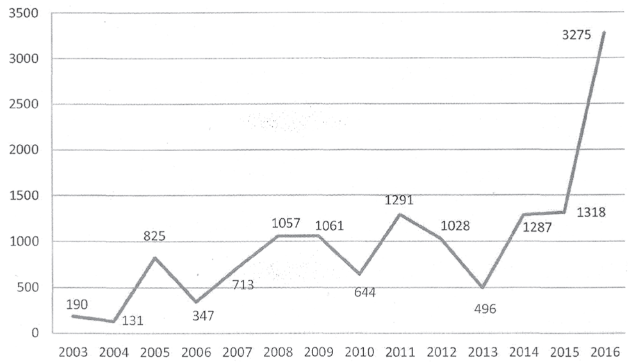

Fig. 2. Species composition and relative number of the rodents in Voronezh and its buffer area in 2001-2016 (per 100 traps/day)

The relative number of the main small mammal species in Voronezh and its peri-urban area varied in 2001-2016 (fig. 3, tabl. 2) with peaks in 2007, 2010-2011, 2014-2016. The rank of different species also varies in different years. In the spring of 2007, mass reproduction of the rodent species took place after an abnormally mild winter 2006-2007. After a short-term drop in spring-summer 2010, mass reproduction of the rodents rebounded in the fall 2010 and spring 2011.

The dominant species in the city and in its buffer area was the house mouse, while the brown rat and

Table 3

Small mammals dynamics in wild, peri-urban and urban areas of Voronezh-city (2012-2016) (%)

		Wild environment					Peri-urban areas					Urban areas, include private houses in the city				
		2012	2013	2014	2015	2016	2012	2013	2014	2015	2016	2012	2013	2014	2015	2016
1	*M. musculus*	0.0	0.0	0.0	0.0	0.0	14.9	15.6	18.8	18.3	11.5	84.5	82.8	76.0	71.9	79.2
2	*R. norvegicus*	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.1	5.2	3.3	3.4	3.2	10.3
3	*Ap. agrarius*	6.6	8.4	3.6	0.4	36.6	23.8	27.1	10.9	1.2	41.3	1.1	2.5	0.4	0.1	12.6
4	*S. uralensis*	15.1	23.6	45.7	62.6	25.6	19.2	20.6	32.2	50.5	18.4	5.6	8.8	19.0	23.8	6.3
5	*S. flavicollis*	6.4	6.6	5.6	10.3	0.8	4.1	3.2	3.4	7.7	3.8	0.0	0.1	0.0	0.0	0.1
6	*M. glareolus*	39.3	25.6	25.2	10.6	20.8	32.3	28.6	25.0	9.8	12.8	0.6	0.4	0.2	0.2	0.9
7	*Microtus* spp.	31.7	35.4	18.2	12.6	9.9	2.8	2.2	6.1	8.7	7.8	3.0	2.1	0.8	0.7	0.6
8	*M. minutus*	0.4	0.2	0.2	0.4	0.8	0.0	0.0	0.1	0.1	0.5	0.0	0.0	0.0	0.0	0.0
9	*Cr. migratorius*	0.1	0.4	0.1	0.8	0.3	0.0	0.0	0.1	0.0	0.2	0.0	0.0	0.0	0.0	0.0
10	*Cr. suaveolens*	0.2	0.6	1.2	1.2	1.2	0.0	0.6	0.8	2.1	1.3	0.0	0.0	0.1	0.0	0.0
11	*S. araneus*	0.1	0.2	0.1	0.8	3.8	2.4	2.0	2.1	0.9	2.0	0.0	0.0	0.1	0.1	0.0
12	*Ar. terrestris*	0.1	0.0	0.1	0.0	0.1	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0
13	*D. nitidula*	0.0	0.0	0.0	0.1	0.1	0.4	0.0	0.2	0.4	0.2	0.0	0.0	0.0	0.0	0.0

the pygmy wood mouse were subdominant. Brown rat and house mouse are typical synanthropic species in Voronezh. In all years studied, the largest population observed was *Mus musculus,* with peaks in 2001, 2003-2004, 2007, 2009, 2012-2014. This species prevails in the industrial part of the city, with its food trade, food shops, public chains and residential buildings (65-70 %). Brown rat was found in storage locations for vegetables, crops and food (25-30 %) as well as in basements of city buildings and garbage containers (up to 70-75%). House mouse and brown rat are active during whole the year.

Pygmy wood mouse was found only at the edges of the city (6-7 %) and in sheds in the private housing sector of the city. Bank vole was mainly observed in artificial forests and city forests in the recreational buffer zone (60-62 %), and was also trapped in private houses where abundant food supplies existed. Gray voles *Microtus* spp. (twin-species) inhabitnatural biotops and peri-urban area (65%), however they visit private houses (25%).

General growth of small mammal species populations in the city, its buffer zone and peri-urban area was induced by a rich food supply and abnormally warm and humid winters and springs in several years. In the zone of private houses, the number of bank (3-4 %) and gray voles (1-2 %) increased; sometimes yellow-necked mouse (about 1 %). was observed In recreational buffer and peri-urban areas, small mammals were strongly infested by ticks and gamasid mites. 4.400 ixodid tick larvae and nymphae were collected from small mammals: 41,8 % of them from bank voles, 35,32 % from yellow-necked mice, 13,18 % from voles, and 9,7 % from other mammal species. The rate of synanthropic rodents (house mice and brown rats) as feeders of subadult ticks increased. Along the urbanization gradient from peri-urban to industrial urban ecological conditions, the number of small mammal species decreases [47-48].

The distribution of small mammal species and their numbers under specific ecological conditions (waterfowl, meadows, forest stations) vary significantly [58]. The peri-urban area supports combinations of ecological stations, making it attractive for many small mammal species with initially different ecological requirements.

At present, common dormice (*Dryomys nitedula*) and hamsters (*Cricetus cricetus*) are quite common and relatively abundant in peri-urban environment. Hedgehogs (*Erinaceus europeus*) (Insectivora), squirrels (*Sciurus vulagaris*) (Rodentia), and common hares (*Lepus europeus*) (Lagomorpha) are also found in peri-urban area, but their number and density are low. Red squirrels reach a population density up to 7-8 individuals per hectare, and common hare about 4 per hectare depending on the season.

The total number of small mammals species (rodents and insectivorous) in natural conditions was 13, in peri-urban area 15, and in the city (including recreational buffer area) 6. The number of mammal species is decreasing along the gradient of increasing urbanization [43].

4. Survey of carnivorous mammals in urban and peri-urban areas of Voronezh city

Modern cities and provincial towns provide ecological niches for stray and feral dogs and cats. Both species serve as hosts for adult ticks and play a part in the circulation of Lyme disease. Our research shows that stray and feral dogs and cats serve as the main feeders of adults ticks in the city and its recreational buffer area. In peri-urban areas, foxes are the most important host for adult ticks. The prevalence of tick infestation was about 30-45 % in dogs and 8-11 % in cats.

Stray and feral dogs and cats can also spread the rabies virus in cities, which has become a serious problem in many regions of Russia, including Voronezh, wherethe circulation of *Lyssavirus* in the wild is supported by foxes and raccoon dogs, and in the last two years, by wolves as well.

In Voronezh city, according to our estimation, there are about 600 stray and feral dogs with a population density of 0,8 per 1 sq. km (tabl. 4) [55]. In peri-urban areas and at the edge of the city, red foxes (*Vulpes vulpes*) are the most common carnivorous mammal species [38]. Red foxes, especially those infected with *Lyssavirus*, tend to come into urban areas and make contact with humans, dogs and cats. They easily infect dogs and cats, resulting in circulation of the virus in urban areas.

We have observed many direct contacts between foxes and dogs in the suburbs. Annually from 350 to

Table 4

Stray and feral dogs and cats number in Voronezh in 2008-2016

	2008	2009	2010	2011	2012	2013	2014	2015	2016
Dogs	634	723	618	585	473	524	713	685	720
Cats	1250	1120	1275	1207	1317	1222	976	956	1012
Total	1884	1843	1893	1792	1790	1746	1689	1641	1732

500 foxes have been reported in the buffer zone of Voronezh, with an increase in 2015-2016. Besides rabies, red foxes can carry *Borrelia* species, *Leptosira*, *Ehrlichia, Anaplasma* and *Coxiella burnetii* within the region.

In urban areas of Russia and some European countries, the incidenceof leptospirosis correlates with the size of stray dog populations. *Leptospira canicola* is the agent of this disease, and dogs can carry this bacteria for 3 years after infection. As a result leptospirosis has become widespread in Moscow, S.-Petersburg, Volgograd, Vladivostok, Perm, Ulyanovsk and some other cities. In Voronezh Region, outbreaks of leptospirosis took place in 2007, 2009 and 2013.

Dogs are also hosts of some parasitic worms which are dangerous to people. For example, during last 15 years the number of toxocarosis cases in humans has increased 100 times. This is a result of the high number of stray and domestic dogs in many cities, where there are not facilities for treating animal feces. Every gram of canine feces contains roughly 40 thousand *Toxocara* eggs. The incidence of *Toxocara* in dogs is about 55% in Moscow. In Voronezh city, this rate is even higher [39, 42-44]. Analysis of soil from playgrounds, parks and areas around buildings showed *Toxocara* eggs in 40-45 % of samples.

There are trophic connections between urban rodents and cats. About 40 % of feral cats' food consists of small mammals in the city and its suburban edges. Since rodents serve as intermediate hosts of *T. gondii*, trophic connections between cats and rodents increase the risk of *Toxoplasma* spreading to humans in the city [40-41, 44]. On the other hand, cats also regulate the number of rodents species in urban and peri-urban areas.

CONCLUSIONS

1. This research confirms the presence of local subpopulations of four tick species in peri-urban and urban areas of Voronezh. In 2001-2016, their population sizes and seasonal activity fluctuated according to climatic factors, the degree of anthropogenic impact and the presence of ground litter in woodlands to support tick hibernation.

2. Tick feeders in urban and peri-urban environments of Voronezh are abundant, particularly rodents, stray and feral cats and dogs and species of small birds. Primary feeders of subadult ixodids are: in the urban zone, *M. musculus*; at the edges of the city (recreational buffer zone), *A. agrarius*, *S. uralensis* and *Microtus* spp.; and in peri-urban areas, also *M. glareolus*.

3. Some wild species of small mammal feeders find more favourable conditions in urban and peri-urban areas than in natural ecosystems, due to rich food supplies and available shelters.

The number of small mammal species (including rodents, insectivores and lagomorphs) is 13 in wild ecosystems, 15 in peri-urban areas and 6 in urban zones, but only two synanthropic species were observed in the industrial part of the city. In urban ecosystems the number of mammal and bird species is decreasing with increasing urbanization.

4. Growing populations of rodents inside the city and its peri-urban area pose a serious epidemiological problem, as they can accumulate and carry agents of zoonotic diseases (HFRS, Lyme borreliosis, tularemia and some others). Ecological connections between infective agents, reservoirs of infection and vectors give rise to focuses of zoonotic diseases inside the city.

5. In urban, peri-urban and recreational buffer areas of the city, red foxes (*Vulpes vulpes*) along with stray and feral dogs and cats are the main carriers of rabies and are feeders of adult ticks... The number of red foxes increased in 2015-2016. Besides rabies, red foxes, dogs and cats can carry *Borrelia* species, *Leptosira*, *Ehrlichia, Anaplasma* and *Coxiella burnetii* and some protozoon and helminthes dangerous to humans in the region.

6. Megacities serve as incubators for emerging zoonoses. In Voronezh there are ample territories which provide favorable ecological conditions for tick populations and their hosts, especially for rodents. Relatively poor biodiversity of these areas leads to a concentration of zoonotic agents in the species which tend to become synanthropic or semisynznthropic. Peri-urban areas with their microconditions are also favourable for supporting a high number of micrommamalia and arthropod vectors which can lead to the spread of diseases in a more rapid and efficient manner. The strong and sustainable connections between blood-sucking arthropods and their hosts support the circulation of infections and invasions in both peri-urban and urban ecosystems.

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