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气候变化导致俄罗斯联邦某些地区的自然重点区域发生变化
TRANSFORMATION OF THE NATURAL FOCUS AREAS IN CERTAIN REGIONS OF THE RUSSIAN FEDERATION CAUSED BY CLIMATIC CHANGE

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The problem of the tick-borne infections: tick-borne viral encephalitis (TBE), ixodic tick-born borreliosis (Lime disease) stays acute for the majority of the RF regions. These infections make up 36% of all natural-focal diseases [16]. As an exception, in 2019 tick-borne infections were surpassed by hemorrhagic fever with renal syndrome. Social and economic losses incurred from the spreading of the tick-born infections have amounted to 2.107 billion rubles.

The areas of tick-born zooanthroponoses largely coincide with main carriers habitats (fig. 1) – ixodid ticks (*Parasitiformes*, *Ixodidae*) *Ixodes ricinus* (European part) and *I. persulcatus (some places in the European part, Ural region, Siberia, Far East)*. In Siberia and Far East, the virus might be spread through *I. pavlovskyi* tick species.

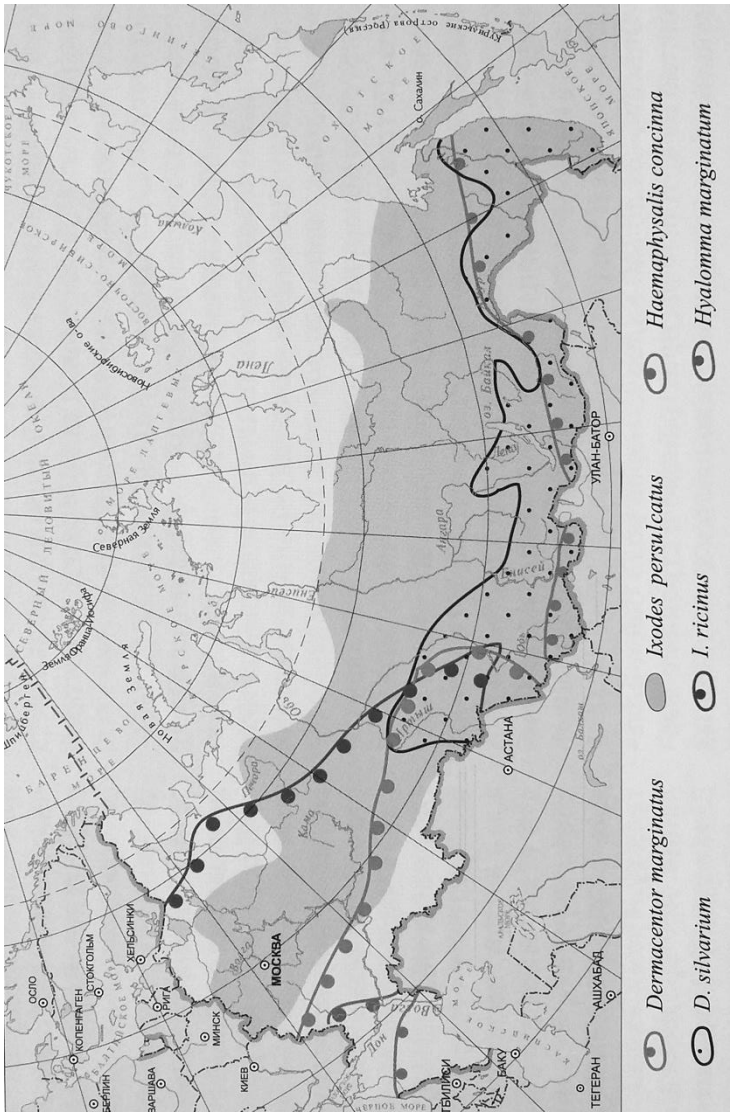

Figure 1. *Ticks habitats on the territory of the Russian Federation [11]*

Conditioned by climate change, the natural focal areas of tick-borne zooanthroponoses are subject to major transformation. The rise of winter temperatures, the increase of precipitation, especially in summer, the prolonged period of warm weather in most cases have had boosting effect on the habitats and the population of taiga ticks. The original habitat of Ixodes persulcatus on the RF territory (from 42° to 62° north latitude) is shifting to more continental north-eastern regions [1, 6, 7, 10, 18, 19]. Some researchers predict Ixodes ricinus habitat expansion in Europe by 2040-2060, and by the end of the 21st century the northern boundary of this species habitat can reach 70° north latitude [20].

According to Instructional Guidelines 2.1.10.0057-12. 2.1.10. "Influence of environmental and living conditions on public welfare. Assessment of risk and damage generated by climate change impact such as surges in infection and death rates in high-risk groups of population" (issued by Rospotrebnadzor on 17.01.2012) collection of data on tick-borne infections has to include: number of people affected by tick bites, number of people with TBE and Lime borreliosis, ticks density index, data on TBE-infected ticks. The present article analyses the tendencies in certain RF regions for these groups of indicators.

The epidemiological situation in last decades is characterized by considerable increase in the number of people who suffered from tick bites. Health-seeking encounter cases after tick bites have risen from 396,000 in 2013 to 580,000 in 2019[16]. The biggest increase was registered in Tomsk oblast (from 1,413.90 to 2,097.2 per 100,000 people), Kaliningrad oblast (by 56%), and Krasoyarsky krai (by 49.5%). The rate in the Altai Republic, Kostromaskaya, Vologodskaya, Kirovskaya, Tyumenskaya, Kemerovskaya oblasts, and the Udmurt Republic is 3-5 times higher (395.34 per 100,000 people) than the average rate in the Russian Federation.

The number of health-seeking encounters after tick bites has significantly increased recently in north-eastern regions of the Udmurt Republic (Vyatka-Kama southern taiga province) despite of dispersed population. In 2019 the rate in these regions was over 3,000 cases per 100,000 people. On the east this territory borders with Elovsky, Ochersky, and Vereshchaginsky regions of the Perm krai with one of highest tick bites rates (over 1,000).

Many regions register the extended period of ticks' activity due to early start of the cycle and late diapause. Thus, in Sverdlovskaya oblast the cycle has extended from 177 days in 2004 to 219 days (from the end of March to the beginning of November) [4], in Udmurtia – from 160 to 220 days [9].

The TBE rate in the last quarter of the 20th century had increased 9-fold and reached 10,000 cases a year. By 2020 the decline of TBE infection rate was observed in all RF regions endemic to this disease. The indicators in the regions most badly affected by the infection – Tomsk oblast and the Altai Republic – are still

5 times higher compared to RF average (1.21 per 100,000 people) [16] despite of overall 2-fold decrease. The situation stays critically acute in Krasnoyarsky krai, Kirov oblast, and the Tyva Republic where despite the overall downward trend the TBE infection rate keeps within 8.92-14.64 cases per 100,000 people for the last 10 years. On the territory of Sverdlovskaya oblast the TBE dynamics since 1990s is characterized by up and down cycles with overall reducing trend at 3.5% annual rate [4].

Many research papers link changes in TBE infection rate to global warming. In Arkhangelskaya oblast the average annual temperature was registered at +0.7° C in 1960-1989. From 2000 to 2009 the readings surged to +2.0°C. Within the same period the human TBE infection rate also increased. The correlation of these two indicators between 1990 and 2009 kept at 0.71 [10] in the central parts of Arkhangelskaya oblast. Whereas the infection rate has reduced 2 times in Russia in recent years, in Arkhangelskaya oblast it has risen 3 times [8].

In Irkutsk oblast the February temperature rose by 6°C and the frostless season extended from 90-100 to 120-130 days. According to observation data in 1956-2003 the number of ixodic ticks increased 57.5 times and the infection rate 40.2 times [5]. Further rise of average annual temperature to +3.86°C resulted in considerable decrease of these numbers [12].

Similarly, in the Udmurt Republic the human infection rate has plummeted in the last 15 years: TBE – by almost 5 times, tick-borne borreliosis – by almost 7 times [15]. Alongside the upsurge in annual temperatures (fig. 2), the annual average precipitation has risen from 501 to 650 mm, the depth of snow cover has increased 1.5 times, and the depth of soil freezing has reduced within the last 50 years [9, 10].

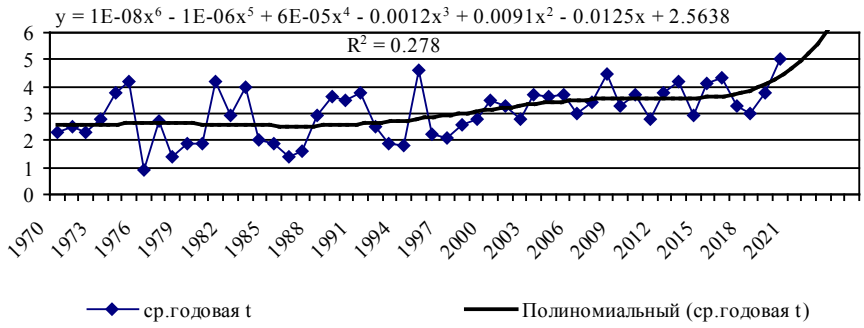

Figure 2. *Long-term changes of average annual temperature on the territory of the Izhevsk city, C and trend line*

In the period from 1954 to 1964 the first surge of tick-borne infection rates was registered (fig. 3). The most alarming situation was characteristic for central and southern regions of the republic (fig. 4). The period of low TBE infection rate (from 1965 to 1986) was determined not only by the predictable trend in the development of the natural epidemic, but by the extensive anti-tick treatment of the territory. The climax of the second wave of the infection rate falls onto 1990s. The sharp fall of indicators in 1994-1995 within the same decade coincides with the period of low average annual temperatures (fig. 2).

It should be noted that starting from late 1990s the infection rates in north-east regions surpass those in south-west 2 to 5 times [2]. Thus, in 2018 TBE rate in Kez region (the north-eastmost region) was 24.4. per 100,00 people which is 7 times higher than average in the republic; the Lime borreliosis rate was 58.8 per 100,000 people – 9 times above average.

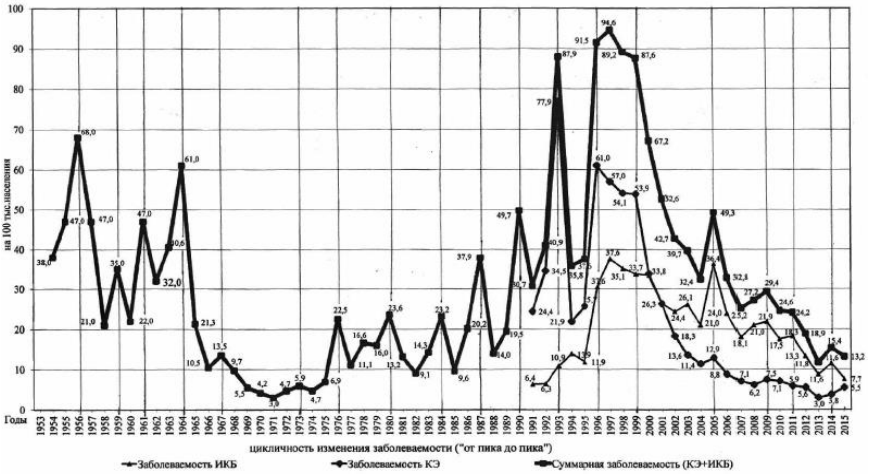

Figure 3. *Tick-born encephalitis (TBE) and ixodic tick-borne borreliosis (Lime disease) infection rates among the population of the Udmurt Republic [3]*

In Perm krai the proportion of the tick-borne infection in the structure of the natural-focus diseases reduced from 68.9% in 2011 to 51.4% in 2020. In 2020 TBE cases were 8.5 times less frequent compared to average long-term rates in 2016-2020 (7.15 per 100,000 people). Lime borreliosis rates reduced 3.6 times compared to 2019 (2.03 per 100,000 people) and were registered lower than the RF average for the first time [13].

Data collected in Perm krai shows that the long-term infection dynamics has cyclic character. The total duration of the TBE cycle is 33-34 years and consists

of 13-14 yearly phase of increased epidemic activity and 19-20 yearly phase of decreased activity (fig. 5)[13]. The first phases of increased (1960-1968) and decreased (1970-1989) TBE infection rates did not much differ in temperature conditions: air temperature was around 2.1-2.2°C (fig. 4). Next phases of the epidemiological process were accompanied by temperature rises. However, the downturn phases (2003-2008 and 2017-2020) match the highest temperature readings (3.5°C and 3.3°C correspondingly). This proves complex correlation between temperature factor and ticks activity. In 2005 the southern regions of Perm krai (Chastinskiy, Elovskiy, Bardymskiy, Uinskiy, Suksunskiy, Kishertskiy, B-Sosnovskiy) registered some of the highest TBE rates at 13.8 to 40.0 cases per 100,000 people. In 2020 the western Ocherskiy and Sivinskiy regions, as well as north-eastern Cherdynskiy and Krasnovisherskiy regions entered the "leaders" chart. For many years the highest rates are observed in Ocherskiy region (TBE – from 51.8 (2005) to 8.68 (2020), Lime borreliosis – 26.04 per 100,000 people) which borders Kez region of the Udmurt Republic on north-east.

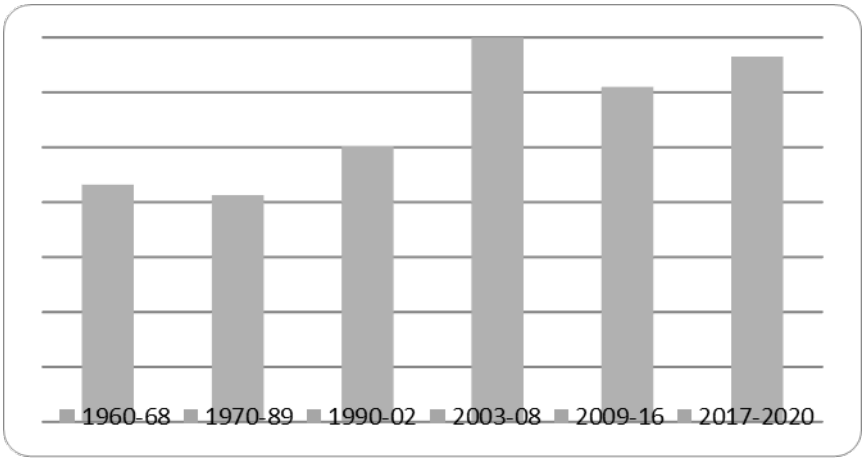

Figure 4. *Dynamics of tick-born zooanthroponosis rates and average annual air temperatures on the territory of Perm krai (based on [13] and http://www.pogodaiklimat.ru/history/28224.htm)*

The average TBE rate by landscape-climatic subzones of Perm krai has changed from 2.7 (middle taiga) to 11.3 (south taiga) per 100,000 people in the last 5 years which can be explained by difference in ticks abundance. In Kirov oblast 89% of cases are registered in south taiga nature zone, 8.5% - in middle taiga zone, and 2.5% - in coniferous-broad-leaved forests zone [17].

In many regions the tick-born zooanthroponosis infection rate has fallen from

the beginning of 2000s, although the ticks density has increased. For example, in urban forest and parkland zones of Izhevsk city the average ticks density in the period of mass activity has increased 2-fold: from 11.1 ticks per flag/km in 2001 to 24.2 in 2013. According to the data provided by Hygiene and Epidemiology Center the highest ticks density on the territory of central Udmurtia was registered in 2015: 67.8 ticks per flag/km in May, 54.7 ticks per flag/km in June. In 2018 the number of ticks collected per flag in May-June was 1.5 times lower; however, ticks density considerably grew in July-September. Ticks density also greatly increased in the period of mass activity for south taiga landscapes: from 3.3 to 27.5 ticks per flag/hour [9]. That said, ticks density readings in taiga zone of Udmurtia stay 4.5 times lower than in sub-taiga zone.

Data collected on permanent observation points in Sverdlovskaya oblast from 2002 to 2012 indicates that ticks density reduced more than 3 times (fig. 7). The most pronounced reduction of ticks density from 14.3 to 0.4 per flag/km is characteristic of aspen-birch forests sub-zone. As regards forest zone, the maximum readings were fixed in 2002-2009 with sharp decline to 0.4-0.8 ticks per flag/km in 2012. In recent years the highest ticks density (6.6-26.7 ticks per flag/km) was registered in north forest-steppe sub-zone. Hence, based on ixodic ticks density monitoring data collected between 1990-2012 the south-west regions of Sverdlovskaya oblast is the area of the most serious epidemiological concern [4]. In 2019 ticks density varied from a single specimen to 90 ticks per flag/km (in 2018 – up to 180 specimens per flag/km) and matched the long-term annual average level (1.3 ticks per flag/km) [14].

In Sverdlovskaya oblast the ticks density reduction results in fewer number of virus-carrying ticks. The number of TBE-infectious specimens collected from tick-bitten population decreased from 32.4% in 1990 to 4.4.% in 2019. As for ticks collected at field stations the indicators for the same period dropped 34 times (to 1%). On the territory of the Udmurt Republic the rate of TBE infectious ticks fell from 21% (2021) to 3.2% (2018). Number of Lime borreliosis positive ticks reached 55-67% in 2010-2013, since 2014 this index has remained at 30-40%.

In recent years the clinical pattern of tick-borne infections has changed as well. In some regions (Udmurtia, Perm krai) the number of cases of febrile TBE - a relatively less acute form of the disease - is growing, and severe TBE forms are being registered much less often. On the contrary, in Baikal region the number of sever (focal) cases surged from 5% to 11% in course of 25 years. Among clinical forms of Lime borreliosis the number of erythema-free cases has considerably increased (from 0% to 50%).

To sum up, evidence from many regions confirms the supposition that the virulence of the tick-borne encephalitis grows from south-west to north-east corresponding the more severe winter conditions climate pattern. The colder winters

are, the more hazardous the virus strain is, and the more acute the disease. The severity of the tick encephalitis form increases parallel to climate conditions severity. That means, warmer summer conditions lead to increase of ticks activity, expansion of their habitat, and more bites. However, warmer winters result in less severe forms of the disease due to more ticks carrying less virulent encephalitis virus. This, in turn, reduces the human infection rates due to light cases, oftentimes not registered, or the disease does not develop altogether.

The changes in hydrothermal conditions reflect upon the dynamics of all components of tick-borne zooanthroponosis parasitic system affecting the severity of epidemiological situation in natural focus areas both directly and indirectly. The spatial transformation of the natural focuses is confirmed by all three indicator groups of ixodic ticks activity: human tick-borne zooanthroponosis infection rate, number of registered tick bites, and ticks territorial density. Tendency towards climate warming is accompanied by TBE and lime borreliosis infection rates increase on the southern boundaries of the diseases environments, whereas southern parts of same environments may have unfavorable for ixodic ticks habitats which results in lower infection rates on such territories. It is predicted that relapsing borreliosis fevers carried by argasid ticks inhabiting Central Asian countries may also spread in RF.

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