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The Influence of Climatogeographic Conditions on the Expansion of the Range of Ixodes Ticks (Review)

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ABSTRACT

Global warming contributes to the widespread spread of some of the main vectors of natural-focal infections. Ixodid ticks can inhabit large numbers both in woodlands and in meadow and pasture areas. Recent decades have seen a shift in the habitats of many parasites to the northern regions, which contributes to the survival and reproduction of not only the vectors themselves but also to the completion of the development cycle of ticks. The growth of the population size and duration of the spring-autumn period of tick activity increases the period of the epidemic season. The epidemiological situation is complicated by the persistence and almost constant activity of natural foci of arthropod-borne infections. Weather conditions, precipitation, humidity (relative humidity of at least 85%), and air temperature affect the life cycle and range of ixodid ticks. These factors make a certain contribution to geographical expansion due to changes in the habitats of vegetation and carriers in the wild (animals, birds, and rodents), which carry ticks to new territories. The northern border of the area of ixodid infections – viral tick-borne encephalitis and ixodid borreliosis - lies now beyond the borders of the Arctic. However, there is evidence of a possible movement of these boundaries to the north, so the southern part of the Arctic region may fall into the zone of potential risk of transmission of these infections.

Keywords: Ixodid ticks, Infections, Climate, Habitat expansion, Viability.

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INTRODUCTION

Ixodes ticks have quite diverse habitats. They are found in coniferous, deciduous, and mixed forests, in fresh clearings and old felling sites, in the grass, etc [1, 2]. The most important conditions for the existence and development of ticks in forest biotopes are the sparseness of the growing stock, moderate soil moisture, developed grass cover, and strong forest litter. Currently, parasites are increasingly found in forested areas of large cities and suburban areas [3]. Under the influence of environmental and socio-economic factors, the number of biotopes favorable for the development of ticks changes. Most often, the habitat of carriers of vector-borne diseases is much wider than the focus of these diseases. This is due to higher requirements for the vital activity of the pathogen than for the carrier itself. Changes in climatic and meteorological conditions over the past 25 years (increase in average annual air temperature in spring, summer, autumn, and even winter, high humidity) contribute to an increase in the population size and the period of activity of ixodid ticks in natural biotopes [4]. In the wild, the main groups of feeders are: large ungulates and predatory mammals: moose, roe deer, wild boars, badgers, foxes, and wolves; various small animals and especially rodents: hares, squirrels, chipmunks, mice, shrews, hedgehogs; birds, reptiles and in some cases even amphibians. Ticks can parasitize and transmit infectious agents among anthropogenically adapted animals to large and small cattle, sheep, rabbits, horses, dogs, and cats [4, 5].

Tick-borne infections transmitted by ticks of the genus Ixodes have now become a standard component of citizens' diseases. This is due to both the lengthening of the period of spring-autumn tick activity and the increase in contacts of the population with nature, and to the fact that during seasonal migrations of birds along green corridors, they bring ticks to the park areas of cities – reservoirs of infections. Currently, there is already a shift of more thermophilic vegetation to the northeast and the habitats' expansion of many carriers of parasitic diseases pathogens to higher latitudes. Migratory birds play a greater role in the spread of infectious agents around the globe than population migration. Birds, being reservoirs of pathogens of various natures (viral, bacterial, fungal, protozoal), may not suffer from these microorganisms. Migrating birds transport ectoparasites – carriers of pathogens of many arboviruses affecting animals and humans. Ixodes ticks the natural habitat of which takes almost the entire territory of the Eurasian part of the Palearctic are of particular importance in this regard. Global warming in addition expands the boundaries of their distribution to the north [6-8].

The goal of the research is to analyze the literature data on the influence of changes in climatic and geographical conditions on the expansion of the ixodid tick's habitat.

MATERIALS AND METHODS

In this study, we examined the available scientific literature (scientific publications, book chapters, abstracts, dissertations) published in the period from 1993 to 2023 from the following sources: the Russian Scientific Electronic Library, Cyberleninka, PubMed, WoS, and Scopus. The review examines data on the impact of changes in climatic and geographical conditions on the expansion of the ixodid tick's habitat. The search of primary keywords (ixodid ticks, infections, climate, habitat expansion, viability) identified 61 entries, of which 48 were Russian-language publications, and 13 were English-language publications. We applied systematic, comparative, and analytical research methods.

RESULTS AND DISCUSSION

The influence of abiotic factors on the spread of ticks

The morbidity level in the population with infectious diseases transmitted through tick bites largely depends on the influence of natural and climatic factors that determine not only the tick population's size but also the number of infected individuals. The most important factor affecting all stages of tick development is the air temperature. This indicator determines not only when the period of ticks' activity begins but also the number of imagos in the next year since it affects both the preservation of the viability of wintering forms, the processes of embryogenesis, and the survival of larvae that can survive only limited temperature ranges. The significance of this factor is confirmed by the correlation between temperature indicators in February, March, April, July, August, and October and the high or low incidence of tick-borne viral encephalitis. Strong correlations between the number of cases of tick-borne viral encephalitis (per 100 thousand inhabitants) and the macrocycles of temperature in February, March, May, and August and the sum of the average monthly temperatures in the warm and cold periods of the year were revealed. A statistically significant indirect impact of the average monthly temperature of July and September of the previous year on the number of patients with ixodid tick-borne borreliosis was established. The decrease in the incidence of tick-borne viral encephalitis at a high number of ticks, periodically observed after a relatively warm winter period, can be explained by the fact that along with highly pathogenic, low-virulent strains of the virus also survive, causing mild, often not registered forms of infection. Only the most virulent strains of the tick-borne viral encephalitis pathogen can withstand extremely low air temperatures [9].

Every year, weather conditions are becoming more favorable for the circulation of pathogens of vector-borne infections. Warm winters and early spring lead to an increasing percentage of Ixodes ticks successfully overwintering. Winter is the time of diapause for ticks. In winter, ticks are found in the forest litter. The places where they most often overwinter are grass, fallen leaves, moss, compost piles, stored firewood, and brushwood, deposits of natural debris on the plots, forest litter, and space under tree roots.

Under the snow, the temperature in the litter does not fall below 0 ° C, thanks to this, the ticks have adapted to wintering in such a climatic zone. They become active when the air warms up to + 5-10 ° C, and at night the temperature does not drop below zero. Only the warm weather stimulates ticks to start the activity. At the same time, early warm weather causes not only ticks to become active but also their feeders [4].

Scientists believe that one of the reasons for this phenomenon is the warming of the climate and the fact that migratory birds can carry ticks over long distances. Before the warming ticks failed to take root in the northern territories, now the situation has changed. An important factor is that in many countries of the world, winter has become shorter and milder. Thus, the boundaries of tick expansion in Sweden and Norway for the period 1994-2008 moved more than 200 km north along the Baltic coast; on the North American continent - almost 1000 km north vs. the 1943-1983 period, and in the mountains in the north of the Czech Republic, where the temperature has increased by 1.4 ° C over four decades, they now can be found at an altitude of up to 1300 m above sea level [10, 11].

When analyzing climate and geographical changes and features of tick habitats, it should be noted that ticks intensively move from purely forest and field areas towards urban ones (that is, to settlements, urban areas), actively populating parks and squares. In accordance with anamnestic data, it was found that in all cases of tick attacks on domestic animals (cats, dogs) about 50% of all reported cases of tick attacks occurred directly in parks and squares of cities (settlements). It should also be noted that tick attacks in some cases happened in places with low grass and open areas in direct sunlight. The data obtained on the spread and seasonality of tick attacks in the Republic of Belarus explain the revealed seasonality in the incidence of the canine family with piroplasmosis (babesiosis), which is growing from year to year. Earlier this pathology was registered from the beginning of April to July and from the end of August to October, then in recent years (2017-2020) pyroplasmosis was noted very early, in 2017 – in March, in 2018 – in February, in 2019 - in February, and 2020 – in January. The data obtained in recent years confirm a trend that the possibility to get infected with pyroplasmosis and several other infections and invasions throughout the year develops. In addition to domestic and wild animals, ticks pose a significant danger to humans, as they are carriers and keepers of various types of pathogenic microorganisms, including pathogens of tick-borne borreliosis (Lyme disease) and tick-borne encephalitis. Indicators of morbidity of the population with diseases carried by ticks on the territory of the Republic of Belarus have a pronounced tendency to annual growth. According to sanitary and epidemiological observations, 76% of the area of Belarus is unfavorable for tick–borne encephalitis, 92% - for Lyme borreliosis [12].

In recent years, anthropogenic transformation of landscapes has been progressing, this process leads to the attenuation or elimination of foci of infection, or vice versa, to their progressive development and spread. For a tick-borne focus, a change in the natural structure is of great importance. Thus, ixodid ticks favor wood-cutting areas in the Southern Taiga region and in the area of coniferous-deciduous forests of the European part of Russia, where wood is not completely evacuated. Their vital activity completely depends on feeders, for example, microclimatic conditions in a clearing overgrown with young raspberries are very favorable for forest mouse-like rodents. Since the number of individuals increases in these areas after successful overwintering, the habitat areas of ixodid ticks and accordingly pathogens of borreliosis get significantly expanded. The presence of dense forest litter, and humid and warm climates create favorable conditions for the female tick to lay eggs in the soil, where ticks can then overwinter in some stages of the life cycle, which is very important for survival. In the Southern Taiga region and the area of coniferous-deciduous forests, cattle breeding is one of the main branches of agriculture. On forest pastures, cattle are of paramount importance in feeding sexually mature ixodid ticks. As a rule, in the forest zone, the largest number of ixodid ticks is recorded on pastures. It is important that in the developed territories with dismembered relief, cattle are driven through a variety of different habitats on the way to the pasture. The possibility of its contact with hungry ticks increases, and the probability of transferring sucked female ticks to new habitats increases.

Thus, farm animals are not only feeders of ixodid ticks but also their active carriers. According to scientists, with the warming of the climate, ticks are becoming more and more every year, since recently winters have been characterized by unusually high air temperatures. Ticks do not freeze out but wake up earlier than usual (even at the end of March). High morbidity rates were recorded in the West Ural taiga region. As with tick-borne encephalitis, numerous cuttings, which are then overgrown with young aspen-birch and pine-birch forests, the formation of dense grass cover, are the main factor in the high level of infection with tick-borne borreliosis in the West Ural taiga region, since birch forests provide favorable conditions for the habitat of the vector of infection. Due to fires and logging, waterlogging develops on the gentle slopes of watersheds and in flat river valleys, especially where spruce forests with cedar, birch, and pine with rich undergrowth are common. Significant shading, high humidity, and freshness of the forest litter (such as soft humus) create optimal conditions for the life of the carrier of borreliosis, and cedar cones serve as a good source of nutrition for small rodents that feed ticks. Also, a high abundance of ticks is characteristic of anthropological foci that have got formed as a result of economic activity near taiga settlements. The vast majority of active foci in the Middle Urals belong to the wild type, since, the number of wild animals that ensure the existence of foci is quite large due to the small development of the territory due to difficult accessibility. Thanks to favorable feeding conditions, moose and bears evenly populate the territory of the district, and this, in turn, leads to a uniform and widespread of ticks and cases of borreliosis. Although there are often no natural foci in mountainous areas, they may also be found in some areas. In years with a cold, prolonged spring, anthropological foci pose a greater epidemiological danger than wild-type foci. Pets are one of the most important factors in maintaining tick populations in cuttings near inhabited territories [13-17].

Boundaries of tick habitats shift

The northern border of the area of ixodid infections – viral tick-borne encephalitis and ixodid borreliosis - lies now beyond the borders of the Arctic. However, there is evidence of a possible movement of these boundaries to the north, so the southern part of the Arctic region may fall into the zone of potential risk of transmission of these infections. A significant advance of ixodid ticks to the north of the Komi Republic and the Arkhangelsk region of Russia has already been established [18, 19]. In Northern Norway, the tick-borne encephalitis virus was detected at latitude 65.1 ° C [20]. For the territory of Sweden, a significant advance in the boundaries of the tick habitat to the north, and an increase in their population size and density has been established for a long time [21]. Natural focal diseases play one of the key roles in shaping the level of health of the Arctic population living in a significantly different physical and social environment vs. the more southern territories. Among the natural factors affecting the health of the population in the northern regions, the leading role is played by the climate, which has a significant and sometimes decisive influence on the formation of areas of pathogens, vectors, and carriers of natural focal diseases. The climatic factor can be considered one of the main factors in the formation of a specific medical and geographical situation in the northern regions. One of the most debated issues of the spread of infectious and parasitic diseases in the Arctic and subarctic regions is the influence of climate warming against the background of an increasing accumulation of scientific data that the warming of the Arctic territory goes ahead of other regions of the world [22].

Weather conditions, precipitation, humidity (relative humidity of at least 85%), and air temperature affect the life cycle and habitat of ixodid ticks. These factors make a certain contribution to geographical expansion due to changes in the habitats of vegetation and carriers in the wild (deer, birds, and rodents), which carry ticks to new territories. For example, the *Ixodes ricinus* tick has spread to the northern regions of Sweden and Norway. In addition to this expansion, an increase in the number of tick bites was associated with an increase in annual temperature. Human contact with wild fauna due to urbanization and the appearance of green areas in cities, as well as changes in behavioral trends (an increase in the number of people who are fond of hiking, wildlife lovers, and pets), have led to an increased risk of exposure to tick-borne pathogens [23, 24] **(Figure 1)**.

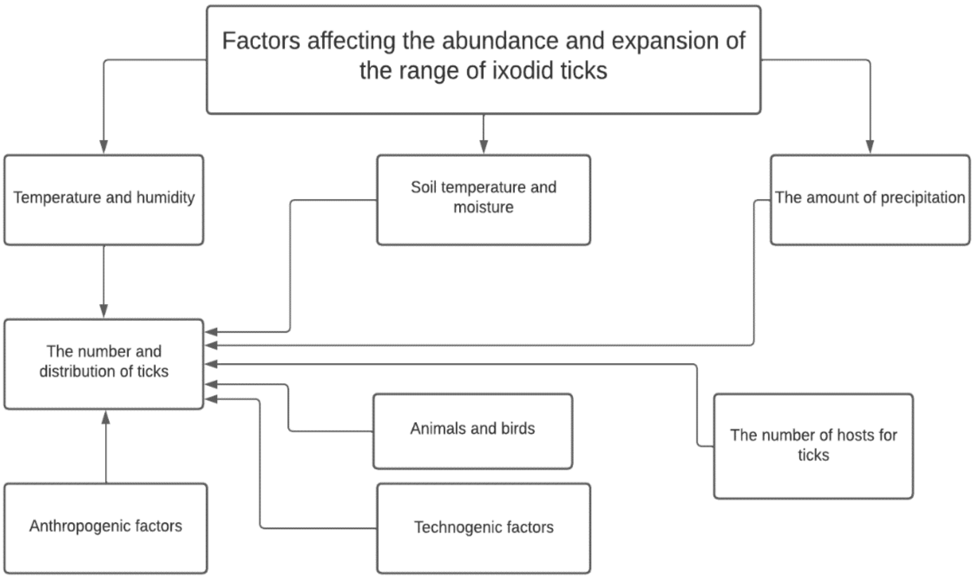

Figure 1. Factors affecting the number and expansion of the range of ixodic ticks

The trend of climate warming on the territory of the Russian Federation continues, it manifests in the form of raised temperature anomalies of all seasons of the year and has a favorable effect on all stages of the development of *H. marginatum* ixodid ticks and contributes to the fact that the boundaries of the circulation of the Crimean-Congo hemorrhagic fever virus (CCHF) shift to the north. The high number of the main carrier of the causative agent of Crimean hemorrhagic fever (CHF) and the expansion of its distribution area contributes to the increase in the incidence in the population. Thus, the observed current trends in climate change in Russia have a positive impact on the development of *H. marginatum* ixodid ticks. The high epizootic activity of the natural focus of CHF contributes to the preservation of a tense epidemiological situation on this disease in the southern European part of the Russian Federation. The results of the conducted studies demonstrate the complex multifactorial influence of climate on the change of all stages of the life cycle of the main vector and reservoir of the CHF virus. In addition to the well-known effect of air temperature on the development of ixodid ticks, the relationship of the dynamics of epidemic manifestations of CCHF with the humidification regime of the territory in different periods of the year has been established. It was established that the most significant influence on the vital activity of *H. marginatum* has the temperature and the amount of precipitation in late May and June – early July when the egg-laying process and the development of preimaginal phases take place. In addition, the preservation of the viability of wintering individuals of ticks depends on the temperatures in January – early February. Thus, the multifactorial effect of climate determines not only the duration of the imago activity period but also the number of individuals of subsequent generations. Due to the ongoing climate warming, the boundary of the CHF pathogen is shifting in the northern direction. This creates a risk of infection spreading beyond the southern regions of the Russian Federation with the involvement of new territories in the epidemic process [25].

The problem of tick-borne infections is becoming more and more urgent due to the intensive introduction of blood-sucking arthropods parasitizing birds: the shift of the habitats of birds carrying them to the northern regions contributes to the survival and reproduction of not only the vectors themselves but also to the completion of the development cycle of tick-borne pathogens in them, being the cause of pathogen invasions. The conducted studies have shown that the change in the areas of blood-sucking ectoparasites and the pathogens they carry is a consequence of global climate warming. In this regard, the shift of the southern boundaries of the IE and borreliosis habitats to the north is due to changes in the structure of vegetation and an increased dryness at the southern boundaries of the ranges of these vectors. The boundaries of the permitted development of the IE vector in mountainous areas are shifted upwards, and its foci are found at a higher altitude. The increase in temperatures increases the time when infected ticks can attack a person. The onset of the more thermophilic *I. ricinus* with the predominance of borrelia species in it, or the expansion of sympatric territories, as well as the displacement of *I. persulcatus* to the northeast in relatively sparsely populated areas of Russia are observed. It should be emphasized that the invasion of new species of tick-borne pathogens is associated not only with their infestation of *I. ricinus* ticks but also with the introduction of new species of blood-sucking ixodids by birds. It was the climate molding that contributed to the penetration of the species of southern blood-sucking *Hyalomma marginatum marginatum Koch, 1844* and *Ixodes frontalis Panzer*, 1798 ticks to the north and, quite possibly, will contribute to the transformation of the accidental introduction of these vectors into their naturalization. Under the influence of climate warming and increased environmental pollution, new populations of existing vector species with new modified properties will appear [6-8, 26-28].

The study of the complex effect of climatic factors of different seasons on the development of all stages of the life cycle of *H. marginatum* and the dynamics of morbidity of the population of CHF was carried out on the example of the Stavropol Territory. Strong correlations of the air temperature, the amount of precipitation in the winter (direct correlation) and spring (inverse correlation) of the current year with the index of the abundance of ticks on farm animals, their number when collecting "on the checker", and the summer period (previous epidemic season) – with the indices of the abundance of larvae, *H. marginatum nymphs*, and also with the number of registered patients with CHF [29, 30].

The presence of four species of Ixodes ticks has been established on the territory of the city of Stavropol (Russia): *Dermacentor marginatus, D. reticulatus, Ixodes ricinus, Rhipicephalus sanguineus*. Activation of *D. marginatus* after the winter diapause occurs in the spring period (March, April). In winter, during thaws, *D. marginatus* becomes more active in mid-February, which was confirmed by the fact that people came to medical institutions and when examining domestic carnivores (dogs). The peak of imago parasitization is observed in the third decade of April. During the summer period (July, mid-August), the imago has diapause. The number of *D. marginatus* in the autumn months is much lower. Activation can be recorded starting in the third decade of August. Parasitism on animals and cases of attacks on humans can be registered until November. *R. sanguineus* is a massive species of the Ixodaceae family, parasitizing carnivores. Activation happens in March-April. The peak of imago parasitization on feeders falls in the first decades of May. In summer, there is a slight depression, and the autumn wave then is much smaller than the spring one. Parasitization of the preimaginal phases of development on feeders is noted in June with a peak in July. Observations indicate the synanthropy of this tick since most of the collections were performed during the examination of pets (dogs, cats). The circle of *R. sanguineus* feeders is represented mainly by domestic carnivores – dogs, and cats, while the first dominate. During the examination of natural biotopes, *R. sanguineus* is found mainly in settlements, private households, near outbuildings, in open-air cages and dog kennels, and in their litter. There were cases of tick penetration into residential premises. People removed ticks from a blanket, an armchair, a palace, from curtains, which most likely was because *R. sanguineus* was brought directly by both pets and people themselves on clothes. In addition, there were cases of this tick attacking a person. In the vicinity of the city of Stavropol, in addition to these species, there are *Haemaphysalis punctata* ticks. In suburban areas neighboring cattle grazing sites, *H. marginatum* is found [31].

Infections transmitted by ticks due to the availability of vast natural territories that are their nosoareals require constant epidemiological and epizootological monitoring and control. The number of requests for medical care in the Russian Federation for the suction of ticks in 2021 amounted to 309.49 per 100 thousand population, and the average annual figure for the entire period of official registration of such requests (2014-2021) was 342.34 per 100 thousand population [32].

CONCLUSION

Habitat boundaries, the number of ixodid ticks, and manifestations of epidemiological activity have been changing in recent decades, as a result of intensive anthropogenic impact on natural complexes against the background of climatic deviations. The epidemiological situation is complicated by the persistence and almost constant activity of natural foci of vector-borne infections, the expansion of the area, and an increase in the number of ticks, while specific prevention is applied only in tick-borne encephalitis and tularemia. Hence, there is a need to have information about the current species composition of these parasitic arthropods. It is established that to date, the dominance indices of Dermacentor and Ixodes ticks do not depend on the types of natural biotopes: parasites can live in significant numbers both in forests and in meadow and pasture areas. The data obtained as a result of the study indicate the need for a more detailed study of the biological and physiological characteristics of ixodid ticks in the context of their actual climate and geographical preferences, as well as effective monitoring of tick populations, even in non-endemic areas, to predict the occurrence or increase the incidence of tick-borne infections and invasions, their timely prevention and treatment [33].

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ETHICS STATEMENT: The study was conducted in accordance with international ethical standards.

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