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RED FOX (*VULPES VULPES*) AS THE MAIN VECTOR OF ANIMAL'S RABIES IN THE FOREST-STEPPE ZONE OF REPUBLIC OF MORDOVIA

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Abstract

Rabic infection currently determines the epidemic and epizootic state in many countries. In this study, we revealed the value of red fox (*Vulpes vulpes* Linnaeus, 1758) as a carrier of rabies in the forest zone. Altogether, the research was conducted in 22 districts and the city of Saransk during the period from 2009 to 2018. The work uses a comprehensive epizootological analysis, including methods of modern diagnostics, veterinary and sanitary statistics, epizootological examination, as well as other methods generally accepted in epizootology. When determining the boundaries of the risk of rabies virus in the Republic, we found that the main clusters of epizootic foci of infection are located on the territory of Bolsheignatovskiy, Ichalkovskiy, Chamzinskiy and Atyashevskiy districts. It was found that the expansion of the infection zone over the years on the territory of the Republic is associated with the dynamics of the main host of the pathogen – red fox. In our Republic, the population density of foxes varies from 1.1 to 1.6 individuals per 1000 ha. In some areas, it is twice the average. The highest population density was observed in 2010 – 1.6 individuals per 1000 ha. The same year, there was a large proportion (66 %) of infected foxes with rabies, compared to other animals. The first rise of diseases coincides with the period of fox rut (early spring) and the second-with the settlement of young animals (autumn-winter).

Key words: forest ecosystem, rabies virus, tank, wild animals.

Introduction

Rabies is a very dangerous deadly infectious disease caused by rabies virus *Rabies virus* (*Lyssavirus*, family Rhabdoviridae). It is specific encephalitis in animals and humans. Rabies virus is a well-adapted pathogen of the mammalian nervous system, where it mostly infects neurons. This virus is typically transmitted by animal bites, although some cases of aerosol contamination have been described. Virus particles from the saliva of infected animals or progeny virus particles produced by muscle infection enter the nervous system via a sensory nerve through nerve spindles or via the neuromuscular junctions where motor axons bifurcate in

invaginations of the muscle surface. Rabies virus particles then travel along the spinal cord to the brain, before spreading to the salivary glands. Virions are excreted in the saliva and are transmitted to other hosts by bites (Rupprecht et al. 2002, Belotto et al. 2005, Lafon, 2005).

Rabic infection currently determines the epidemic and epizootic state in many countries. Rabies is registered annually on all continents and in all natural and climatic zones. It occupies an extremely important place in pathology, since the disease affects a large number of species of domestic and wild animals. The disease is a deadly danger to humans (Jackson et al. 2003, Hemachudha et al. 2013, Morters et al. 2013, Fooks et al. 2014, Al-Abaidani et al. 2015, Hampson et al. 2015, Paroshin et al. 2017).

In Russia human deaths when dealing with dogs have constantly been recorded since the 16th century. The share of dogs in human hydrophobia infection reached 85 % from the end of the 19th to the middle of the 20th centuries. The epidemic value of foxes is cyclical. In the late 18th century fox rabies in Russia was not known. People died from hydrophobia after fox bites in the early 19th century, but since 1825 cases of human hydrophobia due to contacts with foxes stopped. Fox again started infecting people only since the 1940's. In some years from 1970 to the 1990's, fox was the source of hydrophobia in 50–52 % cases. In the 21st century, its role in human infection has decreased to 16 %, but the value of that predator in animal infection increased to almost 50 % (Deviatkin et al. 2017, Sidorov et al. 2016, 2019).

The problem of studying rabies in Mordovia was covered by us and our colleagues (Chumakov and Alferina 2009, Gurina 2009, Tolokonnikova et al. 2015, Alferina et al. 2016). However, it requires constant monitoring.

The purpose of this article is to study the role of the red fox as carrier or reservoir of rabies.

Material and Methods

The work uses a comprehensive epizootological analysis, including methods of modern diagnostics, veterinary and sanitary statistics, epizootological examination, as well as other methods generally accepted in epizootology. The work was carried out in all regions of Mordovia. The Republic of Mordovia is located in the centre of the European part of Russia. Its extreme points are defined by geographical coordinates 42º11' – 46º45' E and 53º38' – 55º11' N (Fig. 1). The maximum distance from west to east is 298 km and the distance from north to south is 57 to 140 km. The area of the republic is 26,200 km^2. Features of the geological structure of Mordovia are determined by its location in the central part of the Russian Platform and the north-western slopes of Volga Upland. In the western part, Volga Upland reaches Oka-Don Lowlands.

The climate of the region is moderately continental with pronounced seasons throughout the year. The influx of direct solar radiation in Mordovia varies from 5.0 in December to 58.6 kJ/cm^2 in June. Total radiation throughout the year is 363.8 kJ/cm^2, the radiation balance is 92.1 kJ/cm^2. The average annual air temperature varies from 3.5 to 4.0 °C. The average temperature of the coldest month (January) is in the range of –11.5 to –12.3 °C. Temperature drops down to –47 °C occur. The average temperature of the warmest month, i.e. July, is in the range of +18.9 to +19.8 °C. Extreme temperatures in the summer reach 37 °C. The

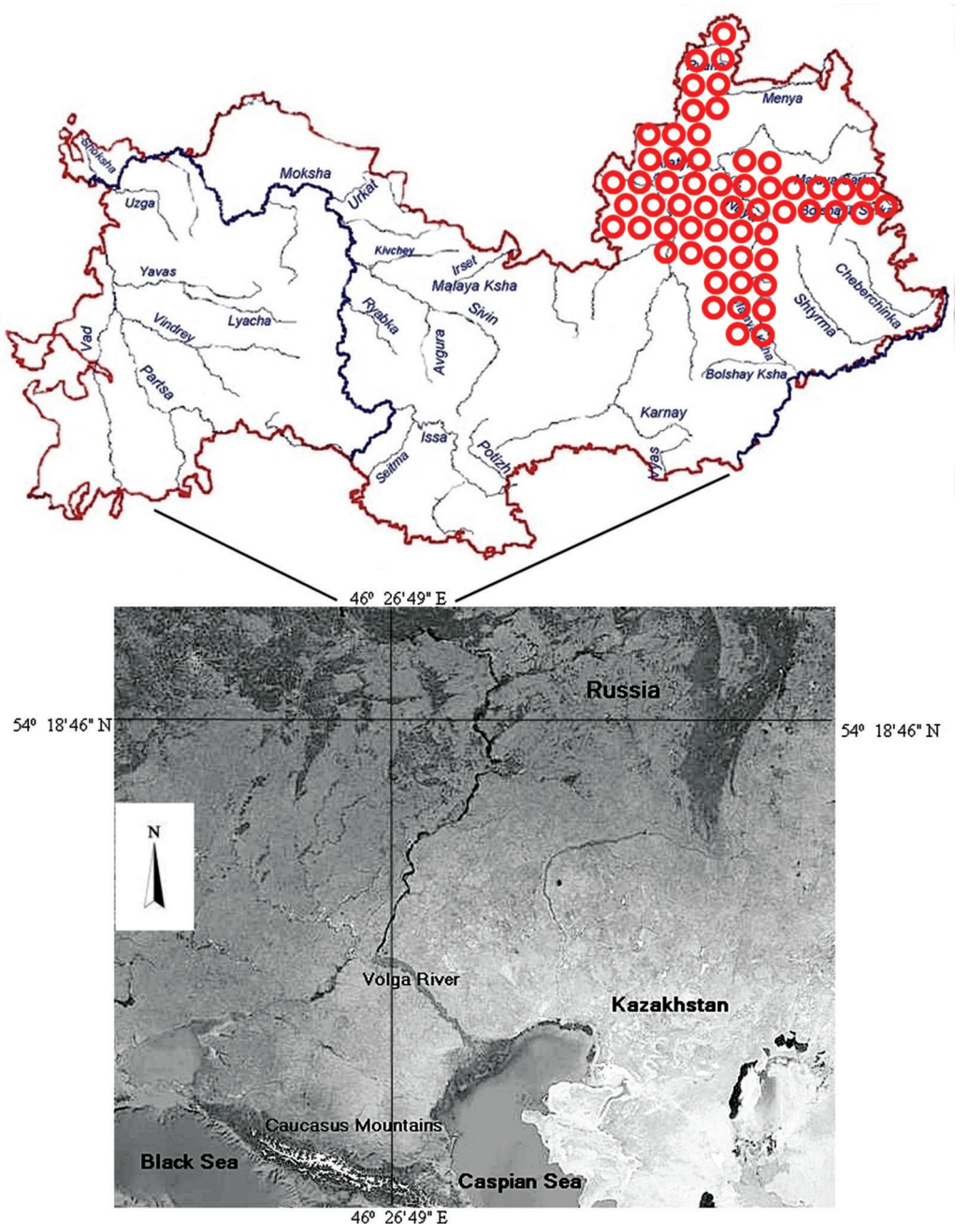

Fig. 1. Location of districts with high infection of foxes with rabies.
Note: red circle – Bolsheignatovskiy, Ichalcovskiy, Chamzinskiy, Atyashevskiy districts.

average annual precipitation in the territory of Mordovia is 480 mm. Over the course of observation lasting many years, periods of more and less humidification were noted, ranging between the minimum and maximum values of 120–180 mm. Distribution of precipitation across the territory is not very diverse. The average long-term value of evaporation is calculated to be in the range of 390–460 mm (Yamashkin 1998). The total number of foxes studied for rabies was 386 individuals, of which 145 were infected.

Results and Discussion

The habitat of the red fox is extremely diverse. The fox, as a species, is a fairly sedentary animal, it does not tend to migrate. The development of new territories is carried out by young animals (Andreychev et al. 2015). With the beginning of autumn, foxes older than six months leave their parents' territory, migrate to a distance of about 20 km and begin an independent life. It is believed that the territory controlled by a single fox family, depending on the food supply and the nature of the habitat, is 2–10 km^2. In our Republic, the population density of foxes varies from 1.1 to 1.6 individuals per 1000 ha (Andreychev et al. 2012). In some areas, it is twice the average. The highest population density was observed in 2010 – 1.6 individuals per 1000 ha. The same year, there was a large proportion (66 %) of infected foxes with rabies, compared to other animals. The dependence of the number of registered sick foxes on the overall population dynamics in Mordovia is observed. In particular, with the total number of foxes in Mordovia in 2017 was 3294 individuals, the share of foxes infected with rabies accounted for 63 % of cases among all animals. A similar situation was observed in 2010. When the number of foxes was 3738 individuals, the share of foxes infected with rabies accounted for 66 % of cases among captured animals. In 2014, with a fox population of 2441 individuals, rabies-infected foxes accounted for 38 % of cases among captured animals.

Our data confirm the results obtained for Russia as a whole. Based on the analysis of the rabies rate of animals for the period of 1960–2006 and on the assessment of the number of wild dogs (Canidae) for 1981–2006 and their infection, a prevailing role of red fox in spreading of rabies among wild mammals (91.7 %) is established. The high correlation between the number of this predator and infected animals was confirmed (Sidorov et al. 2010).

When determining the boundaries of the risk of rabic infection in the Republic, we found that the main clusters of epizootic foci of infection are located on the territory of Bolsheignatovskiy, Ichalkovskiy, Chamzinskiy, and Atyashevskiy districts (Table 1). These districts are unfavourable for other infectious diseases (Andreychev et al. 2019, Andreychev and Boyarova 2020). It was found that the expansion of the zone of infection over the years on the territory of the Republic is associated with the dynamics of the main host of the pathogen – red fox. The number directly depends on the dynamics of the number of small mammals, which are the main food resource of the predator. Earlier, we traced a similar dependence of the population dynamics of other predators on the dynamics of the number of their victims (Andreychev et al. 2014, 2016a, 2016b; Andreychev and Lapshin 2017).

Table 1. Dynamics of the number of infected red foxes with rabies by region.

District	Years										Total by district
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	
Ardatovskiy	2	2	2	0	0	0	0	1	0	0	7
Aturevskiy	0	3	0	0	1	0	0	0	1	0	5
Atyashevskiy	8	2	1	0	2	3	0	0	0	0	16
Bolsheberezhnikovskiy	0	2	1	0	0	1	0	0	0	0	4
Bolsheignatovskiy	7	3	0	0	0	1	0	1	1	1	14
Dubenskiy	0	0	0	0	0	0	0	0	0	0	0
Elnikovskiy	0	0	1	0	0	0	0	0	0	0	1
Zubovo-Polyansky	0	0	0	0	1	0	0	0	0	0	1
Insarskiy	2	1	0	0	0	0	0	0	0	0	3
Ichalkovskiy	6	7	2	0	0	2	1	0	0	4	22
Kadoshkinskiy	0	0	0	0	0	0	0	0	0	0	0
Kovylkinskiy	1	2	0	1	1	1	2	0	0	0	8
Kochkurovskiy	1	4	1	0	0	1	0	0	0	1	8
Krasnoslobodskiy	0	1	2	0	0	1	1	0	0	0	5
Lyambirskiy	0	2	0	0	0	1	0	0	0	1	4
Romodanovskiy	1	1	0	0	0	0	0	0	0	1	3
Ruzaevskiy	2	1	0	0	1	1	0	0	1	0	6
Staroshaigovskiy	3	1	0	0	0	1	0	0	0	2	7
Tengushevskiy	1	0	0	0	0	0	0	0	1	1	3
Temnikovskiy	1	1	0	0	0	0	0	0	0	0	2
Torbeyevskiy	0	0	0	0	0	0	0	0	0	0	0
Chamzinskiy	0	6	5	2	0	2	0	0	0	0	15
Saransk	4	2	0	0	0	3	0	0	1	1	11
Total per year	39	41	15	3	6	18	4	2	5	12	145

Note: grey color indicates areas with a high percentage of infected foxes.

In the long-term dynamics of the time boundaries of epizootic manifestations of rabies, we were able to establish a pronounced periodicity with a synchronous alternation of declines and rises in epizootic tension. The results of the analysis of archival documents in the dynamics of rabies over the last ten years, you can select multiple cycles of rise and decline, which suggests a cyclical upswing rabies infection in the country, which manifests itself with an interval of 3–4 years (Fig. 2). The smallest percentage of infected foxes among other animals was noted in 2012 and 2015. The peaks of rabies infection were observed in 2009, 2010, 2013, and 2017.

We were able to establish the annual dynamics (seasonality) for the research period from 2009 to 2018, due to the cyclical biological activity of the main host of the pathogen. The first rise of diseases coincides with the period of fox rut (early spring) and the second – with the settlement of young animals (autumn-winter). There were 17 cases of foxes infected with rabies in February and 22 cases in March (Fig. 3). There were 17 cases of foxes infected with rabies in November and 14 cases in December. The fewest

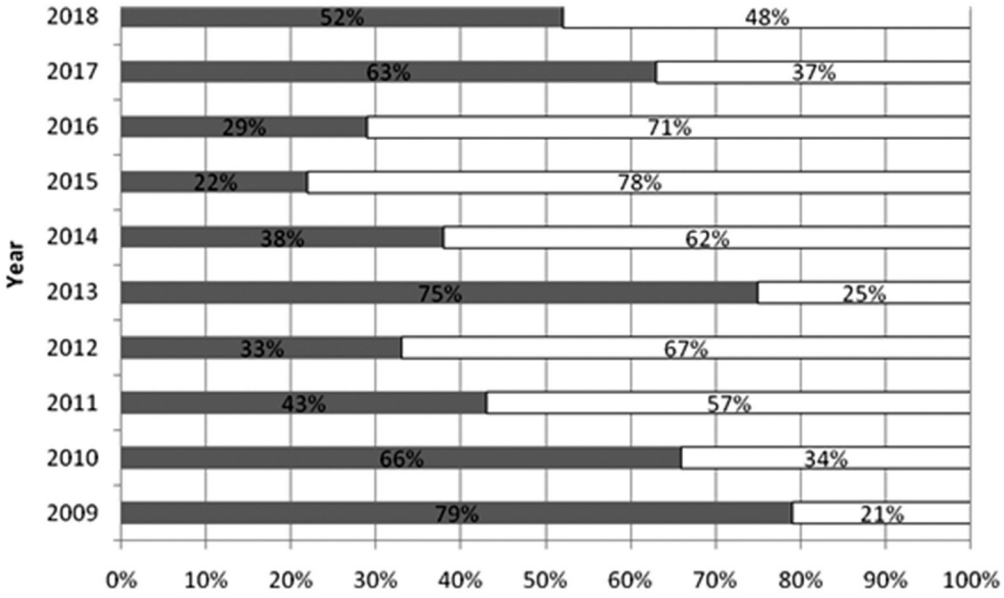

Fig. 2. Percentage of foxes infected with rabies (grey) to other animals (dogs, cats, cattle, small cattle) (white) in Mordovia.

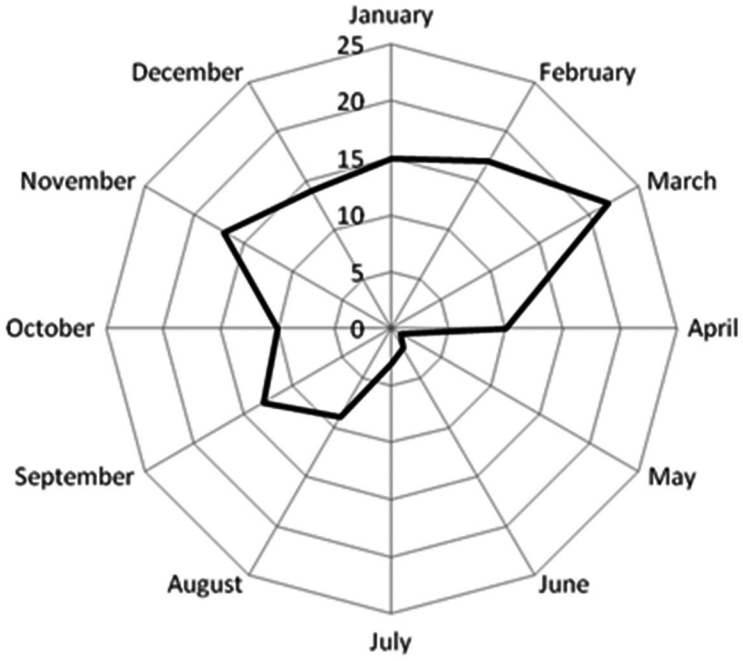

Fig. 3. Seasonal cycles of rabies among foxes in 2009–2018.

cases were reported in May (1), June (2) and July (3). Thus, foxes infected with rabies in Mordovia are registered monthly.

The analysis of the results of epizootological monitoring of rabies indicates that the territory of Mordovia is unfavourable for the incidence of rabies. When studying the pathogenicity spectrum of rabic infection, it was found that rabies was registered in foci (human settlements) among large and small cattle, domestic and unproductive animals (dogs and cats), as well as in autochthonous epizootic foci among wild carnivores (mainly red foxes). The degree of involvement in the epizootic manifestation of rabies infection of animals of various species is directly dependent on the probability of their population contact with the population of the obligate host – the fox. The formation of foci of rabies is associated with the natural and geographical conditions of the region. When determining the boundaries of the risk of rabies infection in the Republic, we found that the main concentrations of epizootic foci of infection are located in the territories of four districts in the North-Eastern part. In the dynamics of the time boundaries, there is a pronounced periodicity with synchronous alternation of declines and rises in epizootic tension, and in the annual dynamics – seasonality due to the cyclical biological activity of the main host of the pathogen.

In 1999, six cases of rabies were detected in animals in Mordovia, including one case in red fox, three cases in domestic animals, and two cases in farm animals. In 2001, Mordovia was classified as a poor region for rabies in the group with a low intensity of epizootic process. This group includes regions with the number of registered disadvantaged localities from one to five per year (Dudnikov 2002). Thus, it can be stated that for the period from 2013–2017, the region could be classified as a group with an average intensity of the epizootic process (the number of registered unfavourable points from seven to nineteen per year). And in 2018, Mordovia was included in the group with a high intensity of the epizootic process (the number of registered disadvantaged points is 20 or more per year).

Since 2000, there have been 4 cases of hydrophobia related deaths in Mordovia: one in Krasnoslobodskiy district (2003), one in Zubovo-Polyanskiy and Temnikovskiy districts (2004), and one in Ardatovskiy district (2009) (Alferina et al. 2016).

The situation with the distribution of rabies among different groups of animals in Mordovia is similar to the Volga region. In this economic region in 1999, a total of 553 rabies cases were identified, of which 244 were wild animals, 160 domestic carnivores, and 149 farm animals. In 2000, only 251 rabies cases were identified, of which 144 were wild animals, 69 domestic carnivores, and 39 farm animals (Dudnikov 2002). Thus, the share of wild animals, which are most often represented by common foxes, in Volga region's rabies accounted for 44.1 % in 1999, and 57.3 % in 2000.

Data for Mordovia is comparable to other regions of Volga region. The situation with the increase in the number of rabies among animals every year is typical for Nizhny Novgorod region. In 2005, the number of registered cases of rabies among animals there increased by 1.8 times compared to 2004. In 2006–2008, the epizootic situation remained tense with the involvement of 50 % of the region's territory (23 districts). At the same time, there was an increase in the degree of involvement of foxes (up to 63 % of the total number of sick animals) against the

background of an increase in their mortality by 1.7 times (Pashkina et al. 2016). In Ulyanovsk region, over 20 years of research, it is known that the sources of rabies are distributed evenly – 50 % wild carnivores (fox) and domestic animals (dog) (Nafeev et al. 2014). In Chuvashia, the share of red foxes in rabies is 60.6 %. This is significantly more than in dogs and cats (20.5 %) and farm animals (17.9 %) (Tikhonov et al. 2016). Foxes are the main reservoir of rabies virus in the Republic of Tatarstan. They account for 53.9 % of the total registered cases (Hismatullina et al. 2016). Two-thirds of all rabies cases in Kirov region were detected in red foxes (Savinykh et al. 2019).

The situation with the main role of the fox in rabies is typical for other regions of Russia. In Altai territory during the period from 2001 to 2008, the share of red foxes in the spread of rabies accounted for from 50 to 85 %, on average – 66.5 % (Andreycev and Baryshnikov 2009). Red foxes in Crimea account for 55% of all cases of rabies (Yantsev et al. 2013).

A large role of the fox belongs to the spread of rabies in the countries of the Commonwealth of Independent States. The main reservoir of the rabies pathogen in Ukraine is still the red fox – 38.1 % of all animals and 89.4 % of all wild animals (Pechinka and Gley 2013). The main reservoir of the rabies virus in Belarus is wild carnivores. Foxes account for 91.5 % of all rabies cases in wild animals (Usenya 2011). In the Republic of Moldova, during the research period from 2009 to 2018, foxes account for an average of 19.4 % of all rabies-infected animals (Starchuk et al. 2019).

Our data are consistent with data on rabies in foxes in Europe. In particular, with the deterministic, compartmental model (Anderson et al. 1981). Their research as a simple mathematical model for the overall dynamics of the interaction between fox populations and rabies is presented – the fox population is divided into susceptibles, infected that are not yet infectious, and infectious individuals. The model helps to explain epidemiological patterns observed in Europe, including the 3- to 5-year cycle in fox populations infected with rabies, threshold densities and average levels of prevalence of infection.

The situation is similar in Asia and Africa. However, there the dynamics of rabies disease is associated with the dynamics of the number of dogs (Knobel et al. 2005, Zhang et al. 2005, Hampson et al. 2009).

In Mordovia, we often registered dead fox cubs. They were often eaten by other animals. It remains questionable whether this is related to rabies. However, some facts are known from the literature. Although rabid cubs (3-month old) are sometimes reported, the number is insignificant, and these animals are most likely infected by adult territory members. The limited spatial activity of the cubs reduces the probabilities of encountering a rabid intruder considerably. Their intraspecific contacts are limited to group members. Thus, cubs are not involved in the maintenance of the chain of rabies infection, and can be considered as dead-end hosts (Vos 2003).

One of the main and effective methods of specific prevention of rabies is timely and effective immune prevention. It is based on the use of anti-rabies vaccines (Rosatte et al. 2007). As a result of oral vaccination of foxes against rabies, this virus disease has almost been completely eradicated from West and Central Europe (Vos 2003). Highly effective vaccines for oral vaccination of foxes, wolves and stray dogs in Mordovia are the drugs ‘Oralrabivak’ and ‘Sinrab’. It is optimal to add

1.8 mL of vaccine per 1 bait. The most attractive lures are chicken heads and meat briquettes from the production of canned food and sausages. In the conditions of Mordovia, the optimal layout is 20 baits per 1 km^2 of territory (Tolokonnikova et al. 2015).

Conclusion

We found, that the red fox is the main source of rabies in the region. This is possible due to its high number (up to 4700 individuals). We conclude, that the red fox in the Middle Volga region has favourable conditions for existence. In the dynamics of the time boundaries of epizootic manifestations of rabies in the Republic, there is a pronounced periodicity with synchronous alternation of declines and rises in epizootic tension, and in the annual dynamics – seasonality due to the cyclical biological activity of the main host of the pathogen. We recommend, that the control of rabies spread is carried out by timely and effective immune vaccination of red foxes.

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