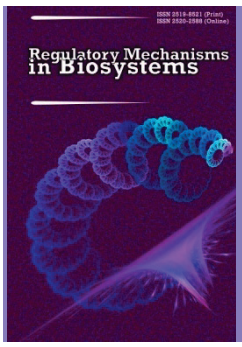

Regulatory Mechanisms in Biosystems

ISSN 2519-8521 (Print)
ISSN 2520-2588 (Online)
Regul. Mech. Biosyst.,
2022, 13(4), 346–353
doi: 10.15421/022245

Epizootological and epidemiological situation of anthrax in Ukraine in the context of mandatory specific prevention in susceptible animals

L. Y. Korniienko*, V. V. Ukhovskyi*, **, O. A. Moroz*, O. M. Chechet*, O. S. Haidei*, T. M. Tsarenko**, T. M. Bondarenko***, M. S. Karpulenko*, N. P. Nenych****

**State Scientific and Research Institute of Laboratory Diagnostics and Veterinary and Sanitary Expertise, Kyiv, Ukraine*
***Bila Tserkva National Agrarian University, Bila Tserkva, Ukraine*
****Public Health Center of the Ministry of Health of Ukraine, Kyiv, Ukraine*
*****Chernihiv Regional State Laboratory of the State Service of Ukraine on Food Safety and Consumer Protection, Chernigiv, Ukraine*

Article info

Received 16.08.2022
Received in revised form 11.09.2022
Accepted 12.09.2022

State Scientific and Research Institute of Laboratory Diagnostics and Veterinary and Sanitary Expertise, Donetska st., 30, Kyiv, 03151, Ukraine. Tel.: +38-066-789-85-19. E-mail: uhovskiy@ukr.net

Bila Tserkva National Agrarian University, Soborna st., 8/1, Bila Tserkva, 09117, Ukraine. Tel.: +38-068-353-63-69. E-mail: taras.m.tsarenko@gmail.com

Public Health Center of the Ministry of Health of Ukraine, Yaroslavska st., 41, Kyiv, 04071, Ukraine. Tel.: +38-095-139-91-90. E-mail: bondarenko.lab@gmail.com

Chernihiv Regional State Laboratory of the State Service of Ukraine on Food Safety and Consumer Protection, 1 May st., 180, Chernigiv, 14034, Ukraine. Tel.: +38-096-311-29-25. E-mail: leonid.korniienko.09@googlemail.com

Korniienko, L. Y., Ukhovskyi, V. V., Moroz, O. A., Chechet, O. M., Haidei, O. S., Tsarenko, T. M., Bondarenko, T. M., Karpulenko, M. S., & Nenych, N. P. (2022). Epizootological and epidemiological situation of anthrax in Ukraine in the context of mandatory specific prevention in susceptible animals. Regulatory Mechanisms in Biosystems, 13(4), 346–353. doi:10.15421/022245

The problem of zoonoses remains relevant in the context of reliable prevention of human disease and effective ways to achieve this result, in particular through the impact on susceptible animals by the efforts of veterinary medicine. Anthrax is an acute, particularly dangerous infectious disease of all species of farm, domestic and wild animals, as well as humans, which is caused by *Bacillus anthracis* microbes. The causative agent of anthrax belongs to the group of aerobic spore-forming bacteria and exists in two main forms: vegetative and spore. The vegetative form in the body of an infected animal can form a "capsule". In Ukraine, according to the provisions of the current "Instruction for the prevention and control of animal anthrax" (2000), the main method of preventing anthrax among animals is regular vaccination of animals susceptible to this disease. The authors conducted a retrospective analysis of the epizootic and epidemiological situation of anthrax in Ukraine for the period 1994–2021 and made a critical assessment of the performance of mandatory measures for specific prevention of susceptible animals. In order to find out the ecological and geographical features of the spread of anthrax, data on outbreaks of the disease in cattle, swine, small ruminants and humans on the territory of Ukraine were analyzed by regions for the time period under investigation. Over the past 28 years in Ukraine, animal anthrax was registered in in all areas except Zhytomyr region. In total, during the analyzed period, 177 affected points and 637 infected animals (cattle, small ruminants, pigs, horses, wild and fur-bearing animals, dogs) were registered (estimated at 3.59 animals per outbreak). Cattle were most often involved in the epizootic process, followed by pigs and small ruminants, while horses and other animal species were least infected. Ecological and geographical analysis showed that the largest number of affected points among animals during the analyzed period was found in Kyiv, Volyn, Kharkiv, Luhansk, Khmelnytskyi, Cherkasy, Odesa, and Vinnytsia regions. A small number of affected points during the analyzed period were found in Zakarpattia, Ternopil, Kherson, Autonomous Republic of Crimea, Poltava, Dnipropetrovsk and Ivano-Frankivsk regions. During the analyzed period, 68 people in 11 regions of Ukraine were infected with anthrax, 15 outbreaks were registered (4.46 people per outbreak). Most cases were reported in Donetsk, Kyiv and Odesa regions. The association between outbreaks of anthrax in animals and cases of anthrax among humans has been established, this dependency was 86.6% (the index of contiguity, which takes into account the number of years with simultaneous registration of animal and human cases, was 0.5). The authors thoroughly proved that it is vaccination among susceptible animals that will finally prevent the incidence of anthrax among people.

Keywords: *Bacillus anthracis*; epizootic process; cattle; pigs; small ruminants; humans; bacteriological studies; mapping.

Introduction

Historically, anthrax has been registered in more than 200 countries of the world. Currently, anthrax in farm and wild animals is registered on almost all continents. Outbreaks of anthrax in wild animals have been recorded in countries in Asia, North America, and Africa (Kamal et al., 2011; Lukhnova et al., 2018; Walsh et al., 2018; Manish et al., 2020). As a result of global warming, anthrax began to be registered in northern latitudes, where previously it was practically not widespread. For this reason, this disease has been identified as a climate-sensitive infection (Revich et al., 2012; Parkinson et al., 2014; Walsh et al., 2018).

Every year, anthrax is recorded in almost 100 countries in animals of 54 species. In developed countries, outbreaks of this disease among people are either sporadic or absent, but in developing countries (Asia, South America and Africa) this disease is quite common. In general, this infection is now often recorded in Africa, Asia, the Middle East, North and South America, Europe and Australia. Mass outbreaks of anthrax among animals result in significant morbidity among humans. In fact, the annual incidence of anthrax in the world fluctuated in the last century in the range of 20,000–100,000 people (Hugh-Jones, 1999; Kamal et al., 2011; Doganay & Demiraslan, 2015; Munyua et al., 2016). Currently, approximately 2,000–20,000 cases of anthrax are reported worldwide each year (Makurumidze et al., 2021). According to Carlson et al. (2019), 1.83 billion people live in regions at risk of anthrax. Moreover, the anthrax pathogen is now recognized as the most dangerous agent of bioterrorism (Klietmann & Ruoff, 2001; Webb, 2003). The quantitative risk group for anthrax

morbidity is considered to be approximately 64 million people and 1.1 billion livestock (Carlson et al., 2019). In maintaining the stationarity of soil foci of anthrax, herbivores of certain territories play a leading role, which can guarantee constant recontamination of soils (Yamtitina & Makarov, 2018). It is estimated that 95% of anthrax cases in humans are due to cutaneous anthrax, for one human case of cutaneous anthrax there are 10 slaughtered and processed carcasses of anthrax-infected animals, and for approximately every 150 cutaneous anthrax cases there is one case of generalized anthrax (Makarov & Mahamat, 2019). Chinese researchers, analyzing the epidemiological situation in China for the period 1955–2014, indicated that the majority (97.7%) of reported cases in humans were represented by cutaneous anthrax (Li et al., 2017; Li et al., 2020).

Vegetative forms of the anthrax pathogen (*Bacillus anthracis*) are not resistant. They die in the corpse of an animal within 2–3 days. In a week, the corpse can be free of anthrax pathogen, provided that it was not dissected. Spores of *B. anthracis*, on the contrary, are extremely resistant. They can survive for many years in water, corpses, and for decades in soil (the possibility of reproduction of the pathogen in soil has now been proven) (Schmid & Kaufmann, 2002). Anthrax is an infectious disease, which belongs to saprozoonoses, when pathogens have a predominantly free lifestyle, not tied to vertebrates, and the reservoirs and sources of the pathogen are factors of the abiotic environment. The concept of "abiotic" environment is much broader, because each environment includes a huge number of parasitic and other symbiotic systems, which epidemiologists and epizootologists interpret as a kind of "abiotic" substance (water, soil, etc.). The external environment is, first of all, biota, because abiotic environments do not actually exist in nature (Korniienko et al., 2009; Belov & Ogarkov, 2010).

Despite ongoing control and prevention measures, the anthrax pathogen continues to circulate in ecosystems, affects the number and regulation of wildlife populations, and often causes outbreaks among humans and animals. Analysis and understanding of such epidemiological features can help in predicting undesirable consequences and their prevention (Vergnaud, 2020; Timofeev et al., 2021). Bacillus anthracis is widespread in European soils, and foci of animal disease occur particularly in Southern and Eastern Europe. Sporadic human cases occur in these areas, and sometimes additional cases arise after consumption or use of contaminated imported materials or come from countries outside Europe where anthrax is quite widespread (Schmid & Kaufmann, 2002). Researchers indicate that the survival and spread of the pathogen in soils can be impacted by the amount of rainfall and soil characteristics (alkaline soils are preferable for the survival of the pathogen). Indeed, favourable conditions for the emergence of anthrax are wet and warm winters, which rapidly turn into dry summers, and the spores of the pathogen appear on the soil surface (Hugh-Jones & Blackburn, 2009; Carlson et al., 2019; Pittiglio et al., 2022). Other factors that have contributed to the emergence and spread of anthrax outbreaks include high livestock densities (Chen et al., 2016), as well as movement and grazing, such as population movement and trade (Blackburn et al., 2015).

Based on the above, we set ourselves the aim to study the epizootic and epidemiological situation of anthrax in Ukraine in the historical context. Particular attention was paid to the vaccination of susceptible animals against anthrax in order to more effectively prevent this disease in animals and humans.

Materials and methods

The authors performed retrospective analysis of the epizootic situation of anthrax in animals and humans in Ukraine in 1994–2021. For this purpose the authors studied, systematized and analyzed reports (Form 2-Vet "Report on the work of state laboratories of veterinary medicine") of regional laboratories of the State Service of Ukraine on Food Safety and Consumer Protection and obtained data of State Scientific and Research Institute of Laboratory Diagnostics and Veterinary and Sanitary Expertise (SSRILDVSE, Kyiv, Ukraine) for the period 28 years.

The authors also performed a retrospective analysis of the epidemiological situation of anthrax in humans in Ukraine in 1996–2021. For this purpose, the data of Public Health Center of the Ministry of Health of Ukraine reports were studied, systematized and analyzed. Numerical data are presented without taking into account the temporally occupied territory of the Autonomous Republic of Crimea, the city of Sevastopol and part of Donetsk and Luhansk regions.

Information about the total number of susceptible animals was obtained from the State Statistics Service of Ukraine (http://ukrstat.gov.ua).

Mapping was presented in the software Quantum GIS 3.16.0 (USA), which is free on website (www.qgis.org/ru/site/forusers/download.html). The vector layers for the borders of Ukraine's regions were downloaded from the site www.diva-gis.org/Data. Quantile classification with 5 classes of the data was chosen. With this classification, an Equal Count of oblasts fall into each class.

The index of epidemicity/epizooticity, which the authors define as the ratio of the number of years during which the disease was registered to the total number of years for the relevant period, and the index of contiguity, which the authors define as the ratio of the number of years during which animal and human anthrax were simultaneously registered to the number of affected years for the relevant period, were calculated according to previously proposed methods (Makarov & Mahamat, 2019).

Results

In total, during 1994–2021, 146 outbreaks of bovine anthrax were detected in Ukraine (Fig. 1), and 382 cattle tested positive for anthrax during this period (Fig. 2).

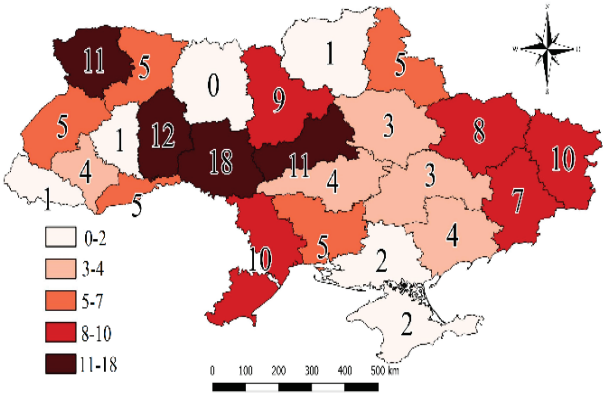

Fig. 1. Density map of anthrax outbreaks in cattle in Ukraine (1994–2021)

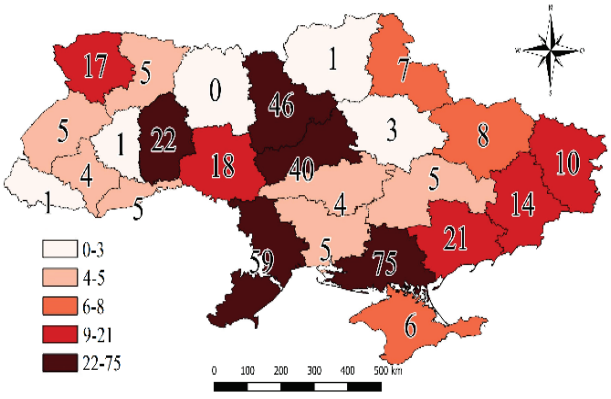

Fig. 2. Density map of positive cases of anthrax in cattle in Ukraine (1994–2021)

For the purpose of territorial analysis of the spread of anthrax among cattle, the "Density map of anthrax outbreaks in cattle in Ukraine" and "Density map of positive cases of anthrax in cattle in Ukraine" (Fig. 1, 2) were compiled, which visualize the density of anthrax outbreaks and the number of cattle positive for anthrax in the regions of Ukraine by different intensity of colouring of each region. As the maps show, the largest number of anthrax outbreaks in cattle was registered in Vinnytsia (18), Khmelnytsky (12), Volyn (11) and Cherkasy (11) regions. The smallest number of outbreaks was registered in the AR of Crimea (2), Transcarpathian (1), Ternopil (1) and Chernihiv (1) regions. In Zhytomyr region, during the entire analyzed period, no outbreaks of anthrax in cattle were registered.

The comparative dynamics of the number of anthrax outbreaks in cattle and the number of positive cases of anthrax in cattle during the analyzed period is presented in Figure 3.

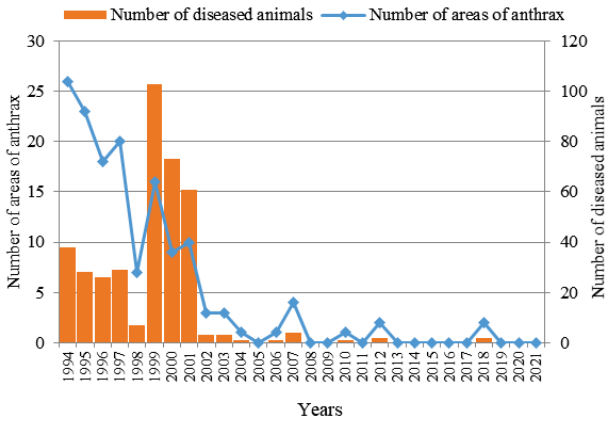

Fig. 3. Dynamics of the number of positive cases (diseased animals) of anthrax in cattle in Ukraine (1994–2021)

Describing Figure 3, it should be noted that the highest number of anthrax outbreaks in cattle was registered in 1994, 1995 and 1997 (26, 23 and 20 outbreaks, respectively). In 1999, 2000 and 2001 the highest number of cattle with anthrax was registered (103, 73 and 60 animals respectively). Over the following years, the number of outbreaks and infected animals decreased significantly, so from 2002 to 2012 their total number was 15 outbreaks. In the period from 2013 to 2021, only two outbreaks were observed in 2018 (one case of diseased cattle in each outbreak).

In the period from 1994 to 2021, 16 swine anthrax outbreaks were registered in Ukraine (Fig. 4), and 29 pigs tested positive for anthrax during this period (Fig. 5).

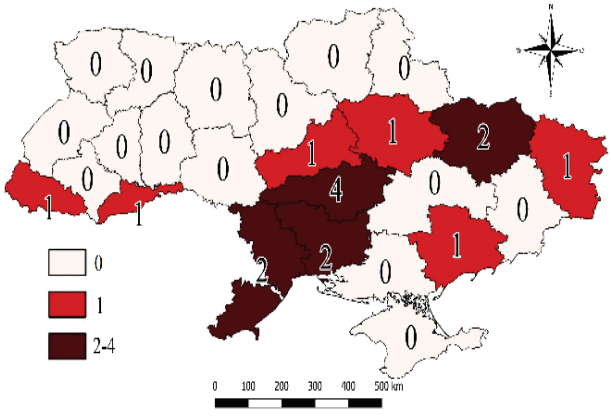

Fig. 4. Density map of anthrax outbreaks in swine in Ukraine (1994–2021)

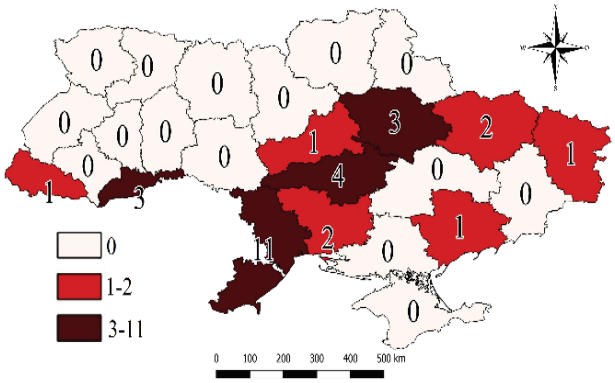

Fig. 5. Density map of positive cases of anthrax in swine in Ukraine (1994–2021)

Also, we compiled "Density map of anthrax outbreaks in swine in Ukraine" and "Density map of positive cases of anthrax in swine in Ukraine" (Fig. 4, 5). The maps demonstrate that the largest number of outbreaks of anthrax in swine was registered in Kirovohrad (4), Mykolaiv (2), Odesa (2) and Kharkiv (2) oblasts. In such regions as Zakarpattia, Zaporizhzhia, Luhansk, Poltava, Cherkasy and Chernivtsi regions only one outbreak in each region was registered during the reporting period. In all other regions, no outbreaks of swine anthrax were registered.

The comparative dynamics of the number of anthrax outbreaks in swine and the number of swine positive cases of anthrax during the analyzed period is presented in Figure 6.

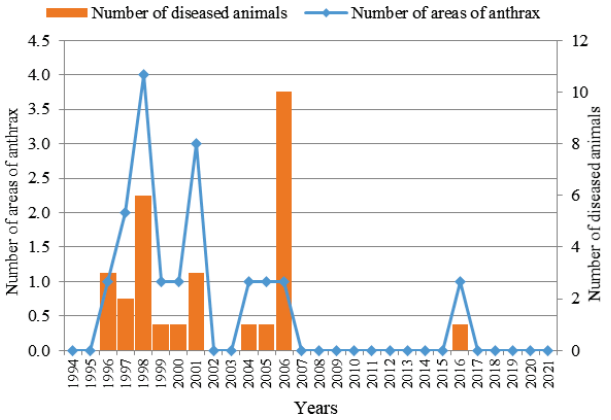

Fig. 6. Dynamics of the number of swine anthrax positive cases (diseased animals) in Ukraine (1994–2021)

As shown in Figure 6, the highest number of swine anthrax outbreaks was recorded in 1997, 1998 and 2001 (2, 4 and 3 outbreaks, respectively). The highest number of swine anthrax cases was registered in 1998 and 2006 (6 and 10 animals respectively). Since 2007, the number of outbreaks and cases has decreased significantly (only one outbreak in Kharkiv region was registered in 2016).

On the territory of Ukraine for the period 1994–2021, 8 anthrax outbreaks in small ruminants were detected (Fig. 7) and 23 small ruminants tested positive for anthrax (Fig. 8).

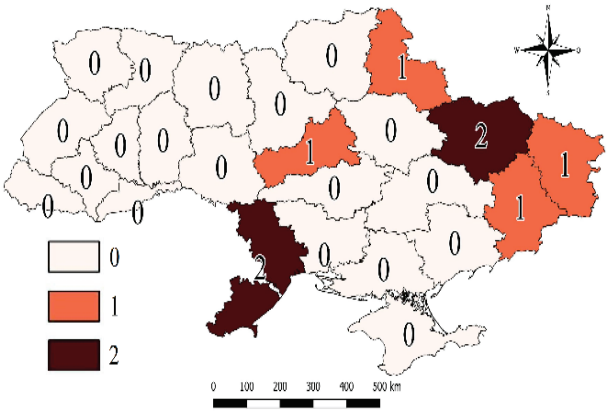

Fig. 7. Density map of anthrax outbreaks in small ruminants in Ukraine in Ukraine (1994–2021 years)

On the "Density map of anthrax outbreaks in small ruminants in Ukraine in Ukraine" and "Density map of positive cases of anthrax in small ruminants in Ukraine" (Fig. 7, 8), the density of the number of anthrax outbreaks and positive cases of anthrax in small ruminants in Ukraine is shown by regions of Ukraine. As can be seen from the maps, the largest number of anthrax outbreaks was registered in Odesa and Kharkiv regions, 2 outbreaks each. Also, 1 disadvantaged point was registered in Donetsk, Luhansk, Sumy and Cherkasy regions. In all other regions, no outbreaks of anthrax were registered.

The comparative dynamics of the number of anthrax outbreaks in small ruminants and the number of positive cases of anthrax among small ruminants during the analyzed period is presented in Figure 9. The data presented in Figure 9, show that the highest number of anthrax outbreaks in small ruminants was recorded in 1994 – 2 outbreaks. In 1996, 1997,

2002, 2004, 2005 and 2017, one outbreak per year was registered. According to the results of the studies, it was found that the index of epizooticity for cattle anthrax for the period 1994–2021 is 0.57, for swine anthrax – 0.35, for small ruminants' anthrax – 0.28, for horse anthrax – 0.14, for fur animals' anthrax – 0.07, for wild animals' and dogs' anthrax – 0.035. The epizooticity index for anthrax in all animal species is 0.71.

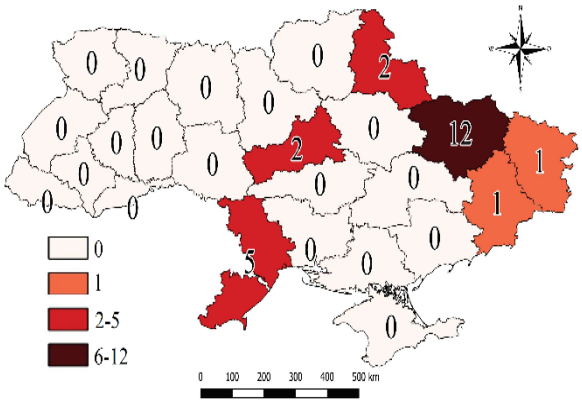

Fig. 8. Density map of positive cases of anthrax in small ruminants in Ukraine (1994–2021)

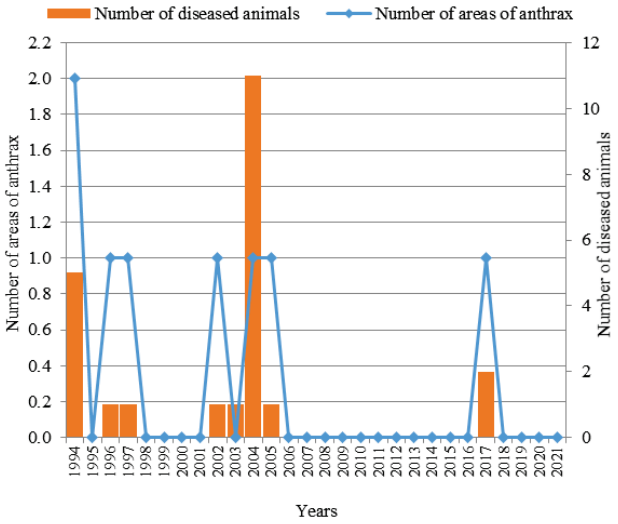

Fig. 9. Dynamics of the number of anthrax positive cases in small ruminants (diseased animals) in Ukraine (1994–2021)

For the purpose of geographical analysis of the spread of anthrax among humans, a "Density map of positive anthrax cases in humans in Ukraine" was compiled (Fig. 10).

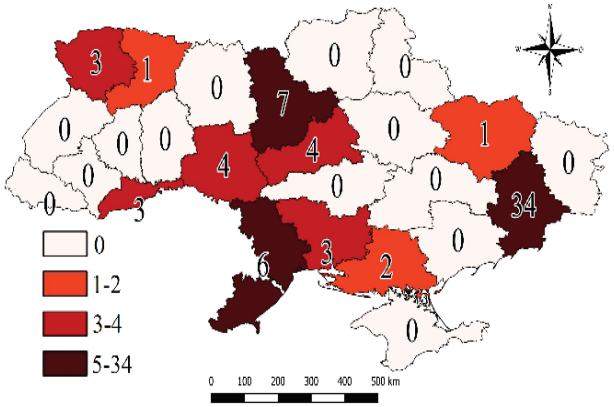

Fig. 10. Density map of positive anthrax cases in humans in Ukraine (1996–2021)

Analyzing the data presented in Figure 10, it should be noted that 68 people were infected by anthrax in Ukraine during 1996–2001. In total, 15 outbreaks were registered during this period (4.46 people per outbreak). Most outbreaks were sporadic (9), when 1–2 people were infected. During outbreaks in Odesa region 6 people were infected, in Kyiv region – 7, in Donetsk region – 34 people. The largest number of outbreaks among people was registered in Cherkasy region – 3, Mykolaiv region – 2, Odesa region – 2. Almost all cases of anthrax among humans were preceded by outbreaks among animals – 13 out of 15 or 86.6%. Only in Odesa region in 2020 and in Kharkiv region in 2021 was human disease not preceded by animal cases according to official reporting. Perhaps in this case, the diagnosis was not established in animals, but livestock products were nevertheless a factor in the transmission of the infectious agent. The index of epidemicity was 0.38, the index of contiguity (which takes into account the number of years with simultaneous registration of animal and human morbidity) was 0.5.

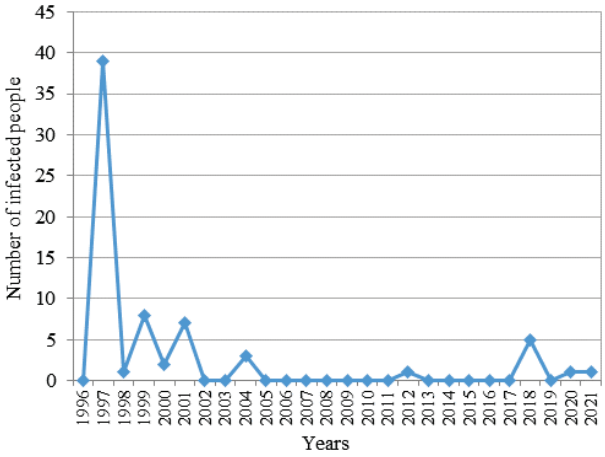

Fig. 11. Dynamics of the number of human anthrax positive cases (infected people) in Ukraine (1994–2021)

The data presented in Figure 11, indicate that the largest number of human cases of anthrax was registered in 1997 (one outbreak of anthrax was registered in the Donetsk region with 34 people and one outbreak in the Mykolaiv region with 2 people).

In total, during the analyzed period, 177 outbreaks and 637 infected animals (cattle, small ruminants, pigs, horses, wild and fur-bearing animals, dogs) were registered (3.59 animals per outbreak). In 59.9% of cases, cattle were infected, 146 locations were affected, which was 82.4% of all affected locations during the study period. Cases among other animal species ranged from 0.02–4.4% of the total number of cases detected in 1–16 affected locations. Among fur-bearing animals, 117 animals were infected in 1 affected location in Volyn region and 57 animals in 1 affected location in Luhansk region in 1994, and in 1999 in 18 animals in 1 affected location in Khmelnytsky region, thus 3 affected locations accounted for 192 infected animals or a total 30.1% of all infected animals during the study period. For pigs and small ruminants and horses, a larger number of affected locations and a smaller number of infected animals in each location was more typical. Single cases of the disease were recorded among dogs and wild animals.

The largest number of outbreaks during the analyzed period was detected in Kyiv (10), Volyn (12), Kharkiv (12), Luhansk (13), Khmelnytsky (13), Cherkasy (13), Odesa (14), Vinnytsia (18) regions. A small number of outbreaks during the analyzed period were detected in Transcarpathian (2), Ternopil (2), Kherson (2), Crimea (2), Poltava (3), Dnipropetrovsk (3) and Ivano-Frankivsk (4) regions. A significant number of infected animals is associated with mass outbreaks of the disease among cattle, small ruminants and fur-bearing animals. In Volyn region, 134 animals were infected during the analyzed period, in Kherson – 75, in Odesa – 72, in Luhansk – 69 animals.

The total dynamics of the number of outbreaks among all animal species and the number of positive cases of animal anthrax for the analyzed period is presented in Figure 12. As shown in Figure 12, the highest number of anthrax outbreaks was recorded in 1994, 1999, 2000 and 2001. Since 2002, the number of outbreaks and infected animals has decreased significantly.

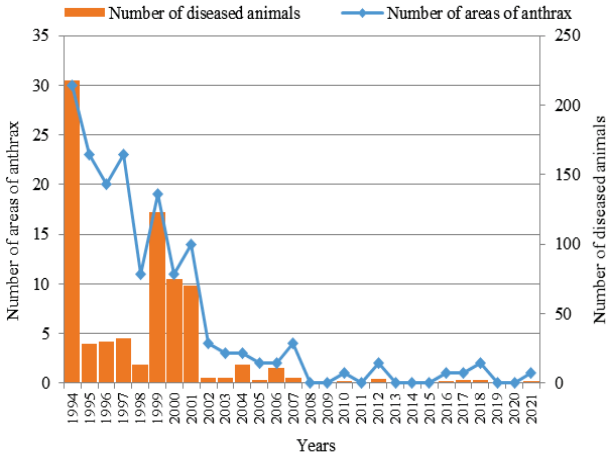

Fig. 12. Dynamics of the total number of anthrax outbreaks and infected animals (cattle, small ruminants, pigs, horses, wild animals, fur animals, dogs) in Ukraine (1994–2021)

As for specific anthrax prophylaxis among animals, 97,244.6 thousand animals were vaccinated by veterinary specialists during the last 17 years (2005–2021) (Table 1, Fig. 13).

Analyzing the information in Table 1, it should be noted that during the period 2005–2021, the number of preventive vaccinations of cattle and horses decreased by 2.68 times or from 9290.5 thousand head to 3455.2 thousand head. A significant decrease in the number of vaccinated animals is explained by a catastrophic reduction in the total number of livestock in Ukraine. The decrease in the number of livestock (e.g. cattle) fully coincides with the decrease in the number of vaccinations (Fig. 13). However, as can be seen from the table and figure, a quite high percentage of vaccination coverage of susceptible livestock is provided. The average percentage of vaccination coverage for the analyzed period is 94.5% for cattle, 105.0% for small ruminants (sheep and goats), and 98.9% for horses. Although, it should be noted that in the period 2014–2021, preventive vaccination plans for cattle were not regularly implemented, and the implementation for this type of animal was 56.1–98.3%, vaccination plans for small ruminants were not implemented in the period 2014–2017 and in 2020 and their implementation was 59.7–97.9% and 97.1%, respectively, preventive vaccination plans for horses were not implemented in the period 2014–2010 and their implementation was 58.6–95.8.

Table 1
Preventive vaccination of susceptible animals against anthrax for the period 2005–2021 and actual implementation of the plan

Years	Number of animals	Species of animals			Total number of vaccinated animals
		cattle	small ruminants	horses	
2005	vaccinated animals (thousand)	7355.1	1357.1	578.3	9290.5
	plan realization (%)	101.9	121.4	131.5	
2006	vaccinated animals (thousand)	6854.5	1438.7	455.0	8747.2
	plan realization (%)	102.2	114.1	111.4	
2007	vaccinated animals (thousand)	6478.5	1586.4	440.5	8505.4
	plan realization (%)	99.8	137.7	108.8	
2008	vaccinated animals (thousand)	5708.1	1522.4	388.7	7619.2
	plan realization (%)	97.7	117.2	100.3	
2009	vaccinated animals (thousand)	5102.4	1413.4	356.5	6872.3
	plan realization (%)	100.4	114.4	107.6	
2010	vaccinated animals (thousand)	4853.8	1508.9	359.9	6722.6
	plan realization (%)	102.5	109.5	105.1	
2011	vaccinated animals (thousand)	4282.3	1486.4	309.4	6078.1
	plan realization (%)	97.1	104.1	97.1	
2012	vaccinated animals (thousand)	4336.9	1355.3	315.5	6007.7
	plan realization (%)	106.2	107.7	101.2	
2013	vaccinated animals (thousand)	4206.7	1341.8	304.0	5852.5
	plan realization (%)	101.1	104.6	105.7	
2014	vaccinated animals (thousand)	38328.1	1134.9	261.0	5224.0
	plan realization (%)	87.4	95.5	91.8	
2015	vaccinated animals (thousand)	3603.9	1082.7	241.3	4927.9
	plan realization (%)	91.5	97.0	91.1	
2016	vaccinated animals (thousand)	2026.2	617.8	136.6	2780.6
	plan realization (%)	56.1	59.7	58.6	
2017	vaccinated animals (thousand)	2853.5	935.5	196.9	3985.9
	plan realization (%)	85.3	97.9	85.6	
2018	vaccinated animals (thousand)	2918.8	869.7	186.4	3974.9
	plan realization (%)	98.3	101.3	93.8	
2019	vaccinated animals (thousand)	2770.1	860.3	168.4	3798.8
	plan realization (%)	94.7	101.1	95.8	
2020	vaccinated animals (thousand)	2538.2	750.3	166.7	3455.2
	plan realization (%)	86.9	97.1	92.5	
2021	vaccinated animals (thousand)	2418.4	829.4	154.1	3401.8
	plan realization (%)	96.8	105.2	103.2	

Note: forced vaccination of swine was carried out only on farms where outbreaks of anthrax occurred.

Analyzing the data of Figure 14 on the number of outbreaks and human cases for the period 1996–2021, first of all, the idea that anthrax in animals is associated with cases of the disease among the human population is confirmed. After all, in this case, livestock products become factors in the transmission of the infectious agent when people who consume contaminated products or participate in the slaughter or processing of products from infected animals. The analysis of the numerical series shows that large peaks of the disease among animals (1999) or people (1997) are most likely exceptions. Mostly, the number of outbreaks coincides with the sporadic incidence among animals and humans, i.e. 1 animal outbreak is associated with 1–2 infected humans (1998–2001, 2004, 2012, 2018, 2020, 2021) or animals (1996–1998, 2002, 2003, 2005, 2007, 2010, 2012, 2016–2018).

Discussion

The spread of anthrax worldwide has historically been of anthropogenic origin (Vergnaud, 2020). In fact, human activity during significant resettlements, military occupations of territories, migrations has always been accompanied by the movement of large numbers of animals (domestic, pack, horse), trade in animal products (meat, milk, wool, etc.). The modern system of sanitary and epidemic control ("One Health" con-

cept) and the vaccine prophylaxis system adopted in many countries allows this disease to be fully controlled in most countries, including Ukraine. The sporadic nature of anthrax cases in many countries is explained by the high vaccination coverage of susceptible populations (Finke et al., 2020). Vaccination in endemic areas continues to this day and prevents the replenishment of soil with dangerous spores (Schmid & Kaufmann, 2002). Almost 100% vaccination coverage against bovine anthrax is achieved. Finally, the incidence of anthrax in animals and humans depends on the vaccination coverage of susceptible animals and specific groups of people who work in sanitary slaughterhouses, harvest animal skins, etc. Vaccines and therapeutic antibodies are currently the most important components of anthrax prevention (pre- and postexposure) and treatment. Improvements in the availability and safety profile of vaccines and therapeutic antibodies have helped to reduce the global burden of the disease enormously (Schiffer et al., 2016; Manish et al., 2020). Mass preventive vaccination of animals in Ukraine results only in sporadic morbidity among susceptible animals, and, as a result, insignificant morbidity among humans.

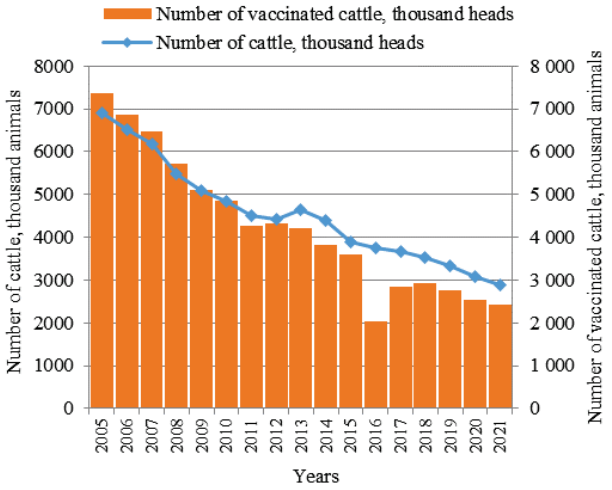

Fig. 13. Dynamics of the number of cattle and preventive vaccinations of this type of animal for the period 2005–2021

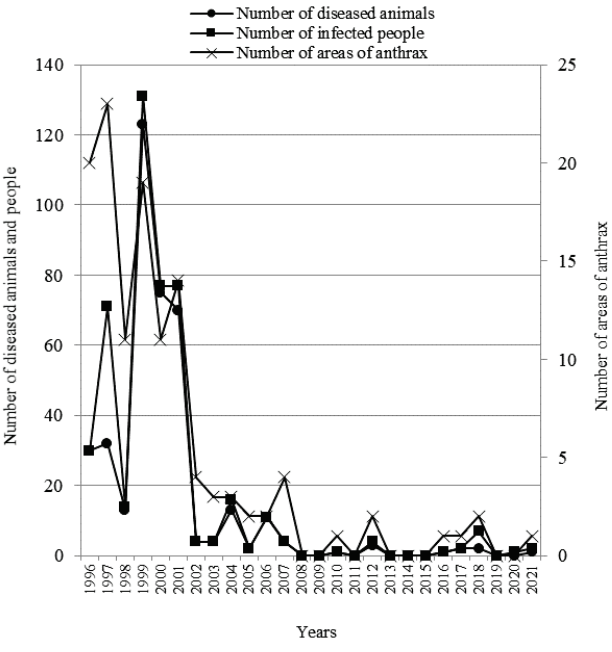

Fig. 14. Number of outbreaks, diseased animals and infected people for the period 1996–2021

About 10 years ago, some researchers in Ukraine began to talk about the cancellation of preventive vaccinations of all animal species against anthrax. They say that vaccination is not necessary, firstly, because it means significant costs, and secondly, because some authors note that the anthrax pathogen survives in the soil for only about 3 years and the soil is "cleared" of spores and the amount of the pathogen is not significant (Hugh-Jones, 1999). These authors suggest that the reproduction of the pathogen is possible only in the body of a susceptible animal. Some researchers, noting the incidence among wild animals (elk, wild boars), suggest monitoring studies among these species, indicating a possible reservoir role of wild animals (Bezymennyi et al., 2014). Another concept, which we adhere to, is that the anthrax pathogen in the soil can germinate from a spore into a vegetative form, under appropriate conditions, which gives it an advantage over other microorganisms. Epizootological outbreaks of anthrax in animals after periods of prolonged drought or heavy rainfall followed by flooding provide indirect support for this concept (Schmid & Kaufmann, 2002). The concept of saprophytic life of the pathogen, to some extent, characterizes it as a self-sufficient species. If it enters the body of an animal, it begins to behave like a typical parasite.

The possibility of a saprophytic way of life of this pathogen, which under favourable conditions germinates from a spore into a vegetative form, repeats at least one more vegetative generation, and again forms a spore, was proved by some researchers (Rodzikovskiy, 1993). The adaptive abilities of this microorganism allow it not to worry, namely to lead a saprophytic way of life and live in the soil, not to be completely dependent on animals and seasonal and climatic factors. Black earth, heavy humus, rich in organic residues soils are well suited for the life of this pathogen.

The results of Ukrainian researchers in previous years directly confirm the second concept of the actual "saprophytic life" of the anthrax pathogen. There are data (Korotych & Pohrebniak, 1976) that the number of stationary affected areas in the forest-steppe zone in 1976 was 24.5, in the Steppe – 13.8, in Polissya – 8.4, in the foothill and mountainous areas of the Crimea and the Carpathians – 4.4. According to (Tarshis, 1996), the most favourable conditions for the storage of anthrax spores are provided by chernozemic and similar soils. Currently, there are more than 10 thousand anthrax-affected locations in Ukraine (Iovenko, 2004). It should be noted that even in the former USSR (including on the territory of Ukraine) the burial of anthrax dead animals in the soil was officially restricted only in 1953 (Seliverstov & Yaremenko, 2002). In areas with solonchak soils and brown sands, anthrax stationarity was not observed. According to data (Danilova, 1971), 50.7% of anthrax-affected locations in Ukraine are placed on chernozem soils, 31.6 – on chernozem soils in combination with podzolized soils, 9.9 – on podzolized soils, 5 – on sod-podzolic and brown earth soils and only 2.8% – on bog and sod-podzolic soils. A similar pattern was noted by other researchers (Korniienko et al., 2009), who noted that if the total number of outbreaks on podzolic loams is taken as 1, then on ordinary chernozem they would be 6 times more. Studies (Korotych & Pohrebniak, 1976) revealed intensive contamination of chernozem and sod-podzolic soils of cattle cemeteries with the *Bacillus anthracis* pathogen. The persistence of anthrax outbreaks depends not only on the presence of anthrax spores in the soil, but mainly on their accumulation as a result of repeated vegetation. Soil areas infected in the past can be found in various geographical zones of Ukraine. As a result of water and wind erosion, rainfall, river overflows, excavation works, in the process of vital activity of animals that dig the ground (moles, mice, rats, etc.), with earthworms and during plant germination, spores are brought to the surface and they are able to be transferred to new areas, which creates a danger of infection of animals.

The detailed statistical data on the incidence of anthrax given in the publication give the opportunity to assert that in 1920–1978 the largest number of cases of anthrax was registered in the central, northern, eastern and southern regions, 1054–1910 cases (Vinnytsia, Zaporizhzhia, Luhansk, Kirovohrad, Kyiv, Odesa, Poltava, Sumy, Kharkiv, Khmelnytsky, Cherkasy, Chernihiv regions). In the western regions of Ukraine (Transcarpathian, Zhytomyr, Ternopil, Ivano-Frankivsk, Rivne) and southern Mykolaiv region, the number of cases was in the range of 234–651. In the remaining regions, 711–890 cases were registered during this period, these are the southern Autonomous Republic of Crimea, Donetsk, Dnipropetrovsk, Kherson and western Chernivtsi regions. In all regions, cattle were infected the most, about 70–80% of the total number of infected animals, small ruminants were infected in most regions 2–3 times more than infected pigs, although sometimes the number of cases among these animals

was the same. Horses were the least infected, the number of anthrax cases in each region was the smallest.

According to the "Catalogue of burial places of dead animals that died from anthrax in the Ukrainian SSR 1920–1970" there are 4630 cemeteries places of dead animals. In the period 1920–1970, 396 cemeteries of animals were registered in Vinnytsia region, 16 in Volyn region, 146 in Dnipropetrovsk region, 80 in Donetsk region, 117 in Zhytomyr region, 83 in Zakarpattia region, 108 in Zaporizhzhia region, 82 in Ivano-Frankivsk region, 275 in Luhansk region, 229 in Lviv region, 267 in Kirovohrad region, in the Autonomous Republic of Crimea – 69, in Kyiv – 182, in Mykolaiv – 193, in Odesa – 170, in Poltava – 274, in Rivne – 22, in Sumy – 251, in Ternopil – 332, in Kharkiv – 338, in Kherson – 161, in Khmelnytsky – 243, in Cherkasy – 189, in Chernivtsi – 71, in Chernihiv – 336 animal cemeteries.

Even a simple analysis of the number of anthrax outbreaks and cattle cemeteries carried out in 1920–1980 shows that the regions with fertile and organic residues-rich soils (Vinnytsia, Cherkasy, Kyiv, Khmelnytsky, Poltava, Odesa, etc.) are in the lead. The current situation is not indicative, because specific prevention of anthrax in cattle, small ruminants and horses is carried out with coverage of almost 100% of the population of these species in all regions of Ukraine. Outbreaks of the disease often occur in those farms that for some reason have not vaccinated susceptible animals. Our analysis of animal morbidity in the period 1994–2001 shows that the prevailing tendency of the disease occurs in areas with chernozems and heavy humus soils. After all, a large number of affected locations were registered in Vinnytsia, Odesa, Cherkasy, Khmelnytsky, Luhansk, Kharkiv, Volyn and Kyiv regions.

Our calculations show that during the period 1920–2021, 25.095 anthrax outbreaks were registered in 10.031 settlements of Ukraine.

The decrease in the number of diseased animals over time is explained by the increase and strict control of vaccination of animals against anthrax. According to reports (Korotych & Pohrebniak, 1976), who analyzed the incidence of anthrax in animals for the period 1946–1970 (five five-year periods), and found that for the period 1946–1950 44.25% of the infections during total period occurred, 1951–1955 – 26.1%, 1956–1960 – 13.28%, 1961–1965 – 11.83%, 1966–1970 – 4.54%. Approximately since 2002, outbreaks of anthrax among animals in Ukraine can be characterized as exclusively sporadic. Thus, in the period 2002–2007, no more than 4 anthrax outbreaks were registered annually, and from 2008–2021, no more than 2 anthrax outbreaks per year and with no more than 3 infected animals. In 2008–2009, 2011, 2013,2015, 2019–2020, no anthrax outbreaks and, accordingly, no infected animals were registered in Ukraine. Continuous preventive vaccination of animals gradually led to a decrease in the incidence among humans. According to reports (Bobylova et al., 2001), 14,702 people were infected anthrax in Ukraine during the period 1924–1926. The authors also point to a decrease in the incidence among people as a result of preventive vaccination among animals. Thus, if in 1947 527 people were infected, in 1957 – 287. In 1950–1954, 1213 people were infected, in 1955–1959 – 652, in 1960–1964 – 284, in 1965–1969 – 131. In 1978–1985, anthrax was registered in people sporadically. In 1982, 1987 and 1988, anthrax was not registered in humans. During the period 1986–1993, 23 people were infected. In 1994, an outbreak of anthrax was registered in the Autonomous Republic of Crimea – 17 people were infected. During the period analyzed by us from 1996–2001, 15 outbreaks of anthrax among people were registered in Ukraine, in which 68 people were infected.

Effective prevention of anthrax is based on systematic vaccination of animals susceptible to this disease with one of the vaccines authorized for use in Ukraine. Preventive vaccinations are carried out on farms, at enterprises and organizations, regardless of ownership and subordination, which breed, raise or use animals adequately to the anthrax immunization plans. This event, which is held annually by veterinary medicine specialists, makes it possible to prevent the incidence of anthrax among people.

The phenomenon when a disease is controlled by the introduction of routine vaccinations (by definition, this is practically the same as the WHO Expanded Programme on Immunization for Certain Infections in Humans) is called vaccine dependence (Korniienko et al., 2009). WHO introduced the Expanded Programme on Immunization in 1974 to ensure that all people have access to routinely recommended vaccines to prevent various infectious diseases (Reid & Fleck, 2014). Thus, the control of anthrax among animals in Ukraine is extremely dependent on the use of vaccines. The causative agent of this disease belongs to the third pathogenicity group of extremely threatening infections (ETI). WHO classifies such representatives as those that are capable of causing highly contagious diseases with rapid spread and capable of causing an emergency situation with lethal effects (Methodological manual: OIE, 2010).

A negative factor in the fight against and prevention of the disease in Ukraine is the lack of a unified register or cadastre of places permanently contaminated with anthrax. In Ukraine, there should be created a "Cadastre" of anthrax-contaminated places or a corresponding "Register", which should be used by medical and veterinary specialists. Taking into account the latest developments, this should be a geographic information system that includes relevant information on all (regardless of the period of limitation) anthrax outbreaks ever registered on the territory of Ukraine, and on the territory of which (using historical data) cases or outbreaks of this disease in animals and/or humans were ever registered. Such a program should be generalized, systematized and unified.

Conclusions

Adoption of the concept of saprophytic anthrax pathogen as a microorganism that can lead a saprophytic way of life in nature implies the planning and continuous implementation of specific preventive vaccinations among susceptible animal species. Finally, it is vaccination among susceptible animals that prevents the incidence of anthrax among humans.

Natural conditions in Ukraine (the presence of a significant amount of chernozem and heavy humus soils) provide the anthrax pathogen with favourable conditions for survival and reproduction.

The authors would like to acknowledge the specialists of State Service of Ukraine on Food Safety and Consumer Protection and the State Laboratories of Veterinary Medicine in regions for presenting the official reports and for assistance.

The authors declare that there is no competing of interest.

References

Belov, A. B., & Ogarkov, P. I. (2010). Biologicheskoe raznoobrazie vozbuditeley infektsionnyih bolezney i epidemicheskiy protsess [Biological diversity of the causative agents of infectious diseases and the epidemic process]. Epidemiologiya i Infektsionnyie Bolezni, 1, 53–57 (in Russian).

Bezymennyi, M., Bagamian, K. H., Barro, A., Skrypnyk, A., Skrypnyk, V., & Blackburn, J. K. (2014). Spatio-temporal patterns of livestock anthrax in Ukraine during the past century (1913–2012). Applied Geography, 54, 129–138.

Blackburn, J. K., Odugbo, M. O., Van Ert, M., O'Shea, B., Mullins, J., Perreten, V., Maho, A., Hugh-Jones, M., & Hadfield, T. (2015). *Bacillus anthracis* diversity and geographic potential across Nigeria, Cameroon and Chad: Further support of a novel West African lineage. PLoS Neglected Tropical Diseases, 9(8), e0003931.

Bobylova, O. O., Mukharska, L. M., Nekrasova, L. S., & Nesterenko, L. P. (2001). Sybirka v Ukraini. Epidemiolohichnyi analiz za 55 rokiv (1946–2001) [Anthrax in Ukraine. Epidemiological analysis for 55 years (1946–2001)]. Suchasni Infektsii, 3, 5–9 (in Russian).

Carlson, C. J., Kracalik, I. T., Ross, N., Alexander, K. A., Hugh-Jones, M. E., Fegan, M., Elkin, B. T., Epp, T., Shury, T. K., Zhang, W., Bagirova, M., Getz, W. M., & Blackburn, J. K. (2019). The global distribution of *Bacillus anthracis* and associated anthrax risk to humans, livestock and wildlife. Nature Microbiology, 4(8), 1337–1343.

Chen, W. J., Lai, S. J., Yang, Y., Liu, K., Li, X. L., Yao, H. W., Li, Y., Zhou, H., Wang, L. P., Mu, D., Yin, W. W., Fang, L. Q., Yu, H. J., & Cao, W. C. (2016). Mapping the distribution of anthrax in mainland China, 2005–2013. PLoS Neglected Tropical Diseases, 10(4), e0004637.

Danilova, K. S. (1971). Geograficheskoe rasprostranenie sibirskoj yazvy v Ukrainskoy SSR [Geographic distribution of anthrax in the Ukrainian SSR]. In: Danilova, K. S. (Ed.). Aktualnye voprosy profilaktiki sibirskoj yazvy v SSSR [Topical issues of anthrax prevention in the USSR], Urozaj, Kiev. Pp. 19–20 (in Russian).

Dey, R., Hoffman, P. S., & Glomski, I. J. (2012). Germination and amplification of anthrax spores by soil-dwelling amoebas. Applied and Environmental Microbiology, 78(22), 8075–8081.

Doganay, M., & Demiraslan, H. (2015). Human anthrax as a re-emerging disease. Recent Patents on Anti-infective Drug Discovery, 10(1), 10–29.
Finke, E. J., Beyer, W., Loderstädt, U., & Frickmann, H. (2020). Review: The risk of contracting anthrax from spore-contaminated soil – A military medical perspective. European Journal of Microbiology and Immunology, 10(2), 29–63.
Hugh-Jones, M. (1999). 1996–1997 global anthrax report. Journal of Applied Microbiology, 87(2), 189–191.
Hugh-Jones, M., & Blackburn, J. (2009). The ecology of *Bacillus anthracis*. Molecular Aspects of Medicine, 30(6), 356–367.
Iovenko, A. V. (2004). Vplyv gruntovoho faktora na roztashuvannia statsionarno neblahopoluchnykh shchodo sybirky punktiv na terytorii pivdennoho rehionu Ukrainy [Influence of the soil factor on the location of anthrax-affected areas in the southern region of Ukraine]. Veterynarna Medytsyna Ukrainy, 11, 12–13 (in Ukrainian).
Kamal, S. M., Rashid, A. K., Bakar, M. A., & Ahad, M. A. (2011). Anthrax: An update. Asian Pacific Journal of Tropical Biomedicine, 6, 496–501.
Klietmann, W. F., & Ruoff, K. L. (2001). Bioterrorism: Implications for the clinical microbiologist. Clinical Microbiology Reviews, 14(2), 364–381.
Korniienko, L. I., Nedosiekov, V. V., Busol, V. O., Korniienko, L. M., Ushkalov, V. O., & Holovko, A. M. (2009). Sapronozni infektsiini khvoroby tvaryn [Sapronic infectious diseases of animals]. Bila Tserkva State Agrarian University, Bila Tserkva (in Ukrainian).
Korotych, A. S., & Pohrebniak, L. Y. (1976). Sybyrskaia yazva [Anthrax]. Urozhai, Kiev (in Russian).
Li, S., Ma, Q., Chen, H., Liu, Y., Yao, G., Tang, G., & Wang, D. (2020). Epidemiological investigation and etiological analysis of a cutaneous anthrax epidemic caused by butchering sick cattle in Guizhou, China. Frontiers in Public Health, 8, 65.
Li, Y., Yin, W., Hugh-Jones, M., Wang, L., Mu, D., Ren, X., Zeng, L., Chen, Q., Li, W., Wei, J., Lai, S., Zhou, H., & Yu, H. (2017). Epidemiology of human anthrax in China, 1955–2014. Emerging Infectious Diseases, 23(1), 14–21.
Lukhnova, L. Y., Izbanova, U. A., Sansyzbayev, Y. B., Meka-Mechenko, T. V., & Suschikh, V. Y. (2018). Review of epidemic, epizootic situation on splenic fever in Kazakhstan, neighbouring countries and beyond. Medicine (Almaty), 192, 40–47 (in Russian).
Makarov, V. V., & Mahamat, N. Y. (2019). Globalnaya epizootologiya sibirskoy yazvy. Zabolevaemost cheloveka kak indikator epizooticheskogo neblagopoluchiya i faktoryi riska [Global epizootology of anthrax. Human morbidity as an indicator of epizootic distress and risk factors]. Veterinariya Segodnya, 1, 63–67 (in Russian).
Makarov, V. V., Gusev, A. A., Guseva, E. V., & Suharev, O. I. (2001). Epizootologicheskiy leksikon [Epizootological lexicon]. Kolos-S, Moscow (in Russian).
Makurumidze, R., Gombe, N. T., Magure, T., & Tshimanga, M. (2021). Investigation of an anthrax outbreak in Makoni District, Zimbabwe. BMC Public Health, 21(1), 298.
Manish, M., Verma, S., Kandari, D., Kulshreshtha, P., Singh, S., & Bhatnagar, R. (2020). Anthrax prevention through vaccine and post-exposure therapy. Expert Opinion on Biological Therapy, 20(12), 1405–1425.
Munyua, P., Bitek, A., Osoro, E., Pieracci, E. G., Muema, J., Mwatondo, A., Kungu, M., Nanyingi, M., Gharpure, R., Njenga, K., & Thumbi, S. M. (2016). Prioritization of zoonotic diseases in Kenya, 2015. PloS One, 11(8), e0161576.
Parkinson, A. J., Evengard, B., Semenza, J. C., Ogden, N., Børresen, M. L., Berner, J., Brubaker, M., Sjöstedt, A., Evander, M., Hondula, D. M., Menne, B., Pshenichnaya, N., Gounder, P., Larose, T., Revich, B., Hueffer, K., & Albihn, A. (2014). Climate change and infectious diseases in the Arctic: Establishment of a circumpolar working group. International Journal of Circumpolar Health, 73, 25163.
Pittiglio, C., Shadomy, S., El Idrissi, A., Soumare, B., Lubroth, J., & Makonnen, Y. (2022). Seasonality and ecological suitability modelling for anthrax (*Bacillus anthracis*) in Western Africa. Animals, 12(9), 1146.
Reid, M., & Fleck, F. (2014). The immunization programme that saved millions of lives. Bulletin of the World Health Organization, 92(5), 314–315.
Revich, B., Tokarevich, N., & Parkinson, A. J. (2012). Climate change and zoonotic infections in the Russian Arctic. International Journal of Circumpolar Health, 71, 18792.
Schiffer, J. M., McNeil, M. M., & Quinn, C. P. (2016). Recent developments in the understanding and use of anthrax vaccine adsorbed: Achieving more with less. Expert Review of Vaccines, 15(9), 1151–1162.
Schmid, G., & Kaufmann, A. (2002). Anthrax in Europe: Its epidemiology, clinical characteristics, and role in bioterrorism. Clinical Microbiology and Infection, 8(8), 479–488.
Seliverstov, V., & Yaremenko, N. (2002). Sibirskaya yazva: Mify i deystvitelnost'. Svod pravil soblyudaetsya [Anthrax: Myths and reality. Code of practice enforced]. Veterinarnaya Gazeta, 220, 4–5 (in Russian).
Stella, E., Mari, L., Gabrieli, J., Barbante, C., & Bertuzzo, E. (2020). Permafrost dynamics and the risk of anthrax transmission: A modelling study. Scientific Reports, 10(1), 16460.
Tarshis, M. (1996). Pochva i "pochvennyie" infektsii [Soil and "soils" infections]. Veterinarnaya Gazeta, 102, 3 (in Russian).
Timofeev, V. S., Bahteeva, I. V., Titareva, G. M., Goncharova, Y. O., & Dyatlov, I. A. (2021). Puti rasprostraneniya sibirskoy yazvy v prirodnykh ekosistemakh [The ways of spreading anthrax in natural ecosystems]. Problemy Osobo Opasnykh Infektsiy, 3, 23–32 (in Russian).
Vergnaud, G. (2020). *Bacillus anthracis* evolutionary history: Takingadvantage of the topology of the phylogenetic tree and of human history to propose dating points. Erciyes Medical Journal, 42(4), 362–369.
Walsh, M. G., de Smalen, A. W., & Mor, S. M. (2018). Climatic influence on anthrax suitability in warming northern latitudes. Scientific Reports, 8(1), 9269.
Webb, G. F. (2003). A silent bomb: The risk of anthrax as a weapon of mass destruction. Proceedings of the National Academy of Sciences of the United States of America, 100(8), 4355–4356.
Yamtitina, M. N., & Makarov, V. V. (2018). Globalnaya epizootologiya sibirskoy yazvyi. Vospriimchivyie zhivotnyie [Global epizootology of anthrax. Susceptible animals]. Veterinariya Segodnya, 4, 49–52 (in Russian).