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Distribution Structure of the Great Gerbil (*Rhombomys opimus* Licht, 1823) in the Western Part of the Betpakdala Desert of Kazakhstan: Biotransformation of Arid Lands

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ABSTRACT

Earth's climate changes that occur as a result of global climate change are changing the biosphere of our planet as a whole. As a result, many animal species change their geographical ranges, seasonal activity, migration patterns, abundance and interaction with other species, including microorganisms, the facts of which are observed in the deserts of Kazakhstan. The main carrier of the causative agent of the plague in the desert natural focus of the Betpakdala plague of Kazakhstan is the great gerbil (*Rhombonus opimus*), where the plague epizootic was first discovered in 1959, the area of which was then 30,000 km^2 until 1990. Due to the rapid industrial development of the Betpakdala desert, the impact of global climate change on earth and other factors over the past 30 years, the area of this natural plague outbreak has increased by 50.12% (60.14 thousand km^2) in the northern direction due to the biological transformation of the area of the main carrier, which led to the expansion of plague epizootics among rodents. At the same time, the plague microbe was also involved in the transformation process, increasing its natural area of the pistil (the area of distribution of the microbe), which increased the risk of infection of people with plague infection. The paper presents our results of epizootological monitoring for the period 2009-2022 (50.0 thousand km^2) and laboratory studies of 522376 samples of field material for plague. The structure of the focus was shown, and the reason for the expansion of the settlement area of the rodent population was revealed. The number of sectors with different levels of epidemic danger and epizootic activity were determined, and the main phenotypic and genotypic properties of *Yersinia pestis* strains circulating in this natural plague focus were also given.

Keywords: Plague; Plague foci; Area of focus; *Rhombomys opimus*; Biotransformation; Epizootological monitoring.

INTRODUCTION

Plague is an acute natural focal infectious disease of a group of quarantine infections, occurring with an exceptionally severe general condition, fever, and damage to lymph nodes, lungs and other internal organs, often with the development of sepsis. In the past, the disease was characterized by a high, almost 100% lethality and very high contagiousness. The causative agent of the infection is the plague bacillus (*Yersinia pestis*). In natural foci of the plague, the sources and reservoirs of the causative agent of infection are mainly rodents, marmots, ground squirrels and gerbils, mouse-like rodents, and hares. Carriers of the causative agent of infection are fleas of 55 different species [1].

Yersinia pestis circulates in animal reservoirs, particularly in rodents, in the natural foci of infection found on all continents except Australia. The natural foci of plague are situated in a broad belt in the tropical and sub-tropical latitudes and the warmer parts of the temperate latitudes around the globe, between the parallels 55° N and 40° S [2].

Various types of natural plague foci (desert, steppe, high-altitude and mixed) in the territory of Kazakhstan occupy 1083.9 thousand square kilometers, which is approximately 40% of the territory, including cross-border high-altitude plague foci (Kyrgyzstan, Mongolia, China, Russia), where outbreaks of plague among the population have repeatedly occurred in the past [3,4]. The studied desert plague center of Betpakdal (Betpakdal autonomous plague center) is part of the Central Asian desert natural plague center

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of Kazakhstan, where the main carrier is a great gerbil (*Rhombomys opimus*).

Originally, the Betpakdala desert was used as a seasonal pasture by livestock breeders keeping cattle to the south, in the Moyinkum desert and on the foothill plains. Cattle tracks passed through Betpakdala, along which cattle were driven north in the spring to the vast steppes of Saryarka, south of the Kazakh small-scale field, and back to the sands of Moyinkum in the autumn. Thanks to the millions of herds of saiga (*Saiga tatarica*), in the past, a hunting industry developed here. Since the 1970s, the mining of uranium, gold and other minerals began in the Betpakdala Desert. However, against the background of global warming, anthropogenic impact or partial aridization in some parts of the territory, the great gerbil population is progressing due to the coverage of the territories of the Ulytau and Karaganda regions of Kazakhstan beyond the 47^{th} parallel of northern latitude. The active study of rodents in the Betpakdala desert began in the 30-60s of the 20^{th} century and continues to the present time, where a large amount of material was collected [5-20].

Unfortunately, to date, there are insufficient data on the settlements of the great gerbil on a cartographic basis in Betpakdal, and for a number of reasons, the distribution of the great gerbil in the territory is devoid of detail [7,15]. Therefore, our task was to concretize all known gerbil settlements by 2022 with a brief description of them within the western part of the Betpakdala desert of Kazakhstan.

Thus, the significant persistence and transformation of natural plague foci, the variety of mechanisms and ways of transmission of the causative agent of infection, the spread of the pathogen by carriers in nature, the involvement in its circulation of a large number of homoiotherm animals and arthropods, and an increase in the risk of human infection with plague determine the importance of improving monitoring of natural foci. Delineation of the modern range of the great gerbil (*Rhombomys opimus*) is the basis of epizootological examination and is necessary to clarify the boundaries of the natural focus of the plague to develop effective monitoring and preventive measures to ensure biological safety and epidemic well-being of the country's population as a whole.

MATERIALS AND METHODS

Epizootological monitoring and collection of field material

The research was carried out according to generally accepted methods of epizootological monitoring using modern tools of the GPS system and GIS technology [21,22]. The experimental base of the study was the Shymkent Anti-Plague Station branch and the Central Reference Laboratory of Masgut Aikimbayev's National Scientific Center for Especially Dangerous Infections of the Ministry of Health of the Republic of Kazakhstan (NSCEDI, MoH of the RK).

Field and laboratory studies were carried out on the basis of the Resolution of the Chief State Sanitary Doctor of the Ministry of Health of the Republic of Kazakhstan "On carrying out sanitary and anti-epidemic and sanitary-preventive measures on the enzootic plague territory of the Republic of Kazakhstan for 2021-2025" No 8 from 26.02.2021, in accordance with Article 36 of the Code of the Republic of Kazakhstan "On public health and healthcare system", taking into account the requirements of the International Health Regulations (2005) to ensure epidemiological well-being for plague on the territory of the Republic of Kazakhstan and approved by the Bioethics Committee of the NSCEDI of the MoH of the RK.

The materials are based on accumulated long-term observations (2009-2022) in the process of epizootological examination within the Turkestan region (Sozak district) and Ulytau region (Ulytau district) of Kazakhstan. The survey area in the south passed along the Shu River in the north to the Zhideli sands. The length was approximately 300 km. In the west, the border was the Sarysu River, and in the east, the survey area reached the border with the Zhambyl region of Kazakhstan, which was approximately 200 km from west to east. The survey area was more than 50.0 thousand km^2. In total, 36203 mammals and 486173 ectoparasites were studied during the analyzed period (total-522376 samples).

Study of the properties of isolated strains

To study phenotypic and molecular genetic studies (Polymerase Chain Reaction test-PCR) of this, 49 strains of *Yersinia pestis* were used, isolated from the Betpakdala autonomous plague focus of Kazakhstan obtained from the depository and museum of living cultures of the NSCEDI. All manipulations with *Y. pestis* strains were carried out in accordance with biological safety standards and techniques for working with pathogens [23,24]. DNA extraction of *Y. pestis* strains was carried out using the QIAamp® DNA Mini Kit (Qiagen, USA). Genotyping of *Y. pestis* was carried out using whole genome sequencing. DNA sample preparation was performed using the Nextera® XT DNA Library Preparation Kit (catalog number: FC-131-1024) according to the manufacturer's instructions. Sequencing was performed on a high-performance MiSeq sequencer, Illumina platform, and a set of chemical reagents MiSeq® Reagent Kit v3, 600 cycles (catalog number: MS-102-3003) according to the manufacturers' instructions.

Research quality control

Quality control was ensured by testing control strains deposited in the museum of living cultures of the NSCEDI: Reference strains of *Y. pestis* from various autonomous foci of Kazakhstan, *Y. pestis* EV strain, *Y. pseudotuberculosis* strain, and fragments of loci of four well-studied strains representing the main biovars of the plague microbe were used as reference samples: Pestoides F (biovar Microtus/Antiqua), Nepal516 (biovar Antiqua), KIM10 + (biovar Mediaevalis) and CO92 (biovar Orientalis).

RESULTS

General characteristics of the desert zone

Betpakdala (Betpak-Dala, kaz. Betpak-unscrupulous, shameless, fierce, turk. batnak-swampy, turkic/kaz. Dala-plain) desert in the Ulytau, Karaganda, Turkestan and Zhambyl regions of Kazakhstan, located between the lower reaches of the Sarysu River, the Chu River and Lake Balkhash. In the North, it borders the Kazakh small hills. Betpakdala belongs to the gravelly clayey and clayey-salt deserts. The area is approximately 75,000 km^2, and the length from west to east is approximately 500 km, from north to south up to 170 km (Betpak-Dala, 2023).

Geographical characteristics and climatic conditions of the landscape

The Betpakdala Desert is a flat and gently undulating plain with average heights of 300-350 m and a general slope to the southwest. In the east, the heights are greater; in the southeast, there is a Zheltau elevation of up to 974 m (Zhambyl city). The western part of Betpakdala is composed of folded Mesozoic and horizontally lying Paleogene loose rocks (sands, sandstones, clays, pebbles), and the eastern part is a hilly part, has a folded structure and is composed of lower Paleozoic sedimentary-metamorphic strata and granites. Desert gray-brown saline and solonetzic soils predominate. The climate is sharply continental. Precipitation is 100-150 mm per year (of which only 15% occurs in summer). The region's climate exhibits sharp contrasts between winter and summer. Summers are dry and hot, winters are moderately cold and have little snow. The average temperature in January is -13°C-14°C. The average temperature in July is +23.0°C-24.5°C. The sum of temperatures above 10°C is 3100-3400°C, the hydrothermal coefficient of moisture availability is 0.2-0.3, and the duration of the period with air temperatures above 10°C is 170-177 days. In winter, the absolute minimum temperatures reach -42°C and -46°C. A stable snow cover is formed in the first ten days of December and lasts 2.5-3 months, but its height does not exceed 10-15 cm. Despite the large thermal resources, a significant lack of moisture limits the cultivation of agricultural crops [25].

Flora and fauna of the territory

significant part of the territory is covered with thickets of boyalych (Salsola arbuscula), in depressions replaced by wormwood-ephemeral and solyanka formations (black wormwood (*Artemisia pauciflora* f. Makara), gray wormwood, etc.). Solyanka formations are represented by boyalych (*Xylosalsola arbuscula*), Biyurgin (*Anabasis salsa*), Tasbiurgun (*Nanophyton erinaceum*), kokpek (*Atriplex cana*), itsigek sarsazan (*Halocnemum strobilaceum*), etc. There are many holophytes-soleros (Salicornia) and solyanka (*Salsola tragus*). Quite a lot of shrubs-tobylga (*Filipendula vulgaris*), karagany (Caragana), gingila (*Tamarix gallica*), meadowsweet (Spiraeanthus), buzzard (Calligonum). Occasionally, in the depressions, there are thickets of saxaul (*Haloxylon*), turangi (*Populus euphratica*), etc. Ephemera develop poorly in spring because at a time when the soil is best soaked due to the melting of seasonal snow and early spring precipitation, it does not have time to warm up enough yet. In spring, ferules, tulips, and onions develop, and ephemeral vegetation does not form on a dense cover [5-7,26]

Epizootological characteristics of the plague focus

The Betpakdala desert plague focus belongs to the Central Asian natural plague focus of Kazakhstan, focus code –42. The total area of the focus is 60,140 km^2. Epidemic manifestations of plague in a natural focus have not been registered. The focus area is divided into five Landscape-Epidemiological Regions (LERs) (42.1. Western Sholak-Espinsky; 42.2. Southern Kamkalinsky; 42.3. Eastern Akbakaysky; 42.4. Central Hilly; 42.5. Karakoinsky) [27].

The rodent fauna includes 26 species. The main carrier of plague in the focus is the great gerbil (*Rhombomys opimus*, Licht, 1823). The great gerbil is distributed sporadically, but the area of individual settlements is vast, and within their boundaries, the number of animals reaches high levels. On average, there is 400-1000 gerbils of this species per 1 sq. km, and in some places, their numbers reach more than 5,000 animals per 1 sq. km. Red-tailed gerbil populations are more evenly distributed over a wide area. On average, there are 400-1000 gerbils of this species per 1 sq. km, and in some places, their numbers reach more than 5,000 animals per 1 sq. km [26,27].

The fauna of fleas parasitizing rodents include 9 species: *Xenopsylla gerbilli minax, X. conformis, Nosopsyllus laeviceps, Citellophilus trispinus, Echidnophaga oschanini, Mesopsylla hebes, Oropsylla ilovaiskyi, Neopsylla setosa,* and *Coptopsylla lamellifer*. Flea abundance indices vary from 0.1 to 5.8 in the great gerbil and from 45 to 365 in burrows (Chulak-Espe level). The dominant ectoparasites are X. g. minax and X. conformis, the number of which ranges from 10,000 to 40,000 insects per 1 sq. km, in some places, X. skrjabini is numerous [26,27].

The study of rodents in the Betpakdala desert began in the 30-70s of the XX century [4-8]. An epizootic of plague in the Betpakdala focus was first registered in 1959; then, after a 24-year break, from the fall of 1983, the great gerbil began to be recorded annually in settlements, which required constant monitoring, the area of which was 30.0 thousand km^2 until 1990 [21]. In subsequent years, plague epizootics were noted of varying intensity with the isolation of strains of the plague microbe (1984–1987, 1989-1999, 2000-2006, 2009-2012) and registration from interepizootic periods [26], where no plague was registered among humans during this period. However, there are places of temporary settlements of nomads, pastures, tracts and wells with the names of plague, as evidenced by the historical names of geographical places-Karaoba (kaz. Kara-black; oba-plague), Kosoba (kos-double, couple, shack, etc.), Besoba (bes-five…), etc.

Due to the heterogeneity of landscapes, vegetation, and rodent settlements, as well as the peculiarities of the epizootic plague process and for the convenience of epizootological monitoring, the territory of the western part of Betpakdala (Western Sholak-Espinsky) was divided into 3 more Landscape-Epizootological districts (LERs) on the basis of long-term observations: Sholakespinsky, Western Betpakdala and Karakoyinsky [19].

In the study area, we identified 4 main types of settlements of the great gerbil: diffuse, band, island and solitary. Figure 1 shows a detailed diagram of the settlement of the main plague carrier in the western part of the autonomous plague focus of Betpakdala Figure 1 indicating the total occupied area and the enzootic plague territory of Kazakhstan.

Due to the rapid industrial development of the Betpakdala desert, global changes in climatic conditions and other factors over the past 30 years, the area of the natural focus has increased by 50.12% (60.14 thousand km^2), which has led to the expansion of plague epizootics among wild rodents, increasing the risk of human infection with the plague (Figure 1).

A large settlement of the great gerbil is located in the Inkuduk tract (area of the Zhalpak deposit), where it is represented in a diffuse form (Figure 1). The white spots in the picture are great gerbil colonies. The density of colonies ranges from 150 to 250 colonies, and in some places, it reaches 300 colonies per 1 km^2. Another settlement, but of an island type, is located in the southeast of the described territory) (Figure 1). Groups of colonies are outlined. Here, the density ranges from 50 to 200 colonies per 1 km^2. Ribbon settlements of the great gerbil run along the road from the village of Zhuantobe to the village of Kyzemshek and further to the turn to the Zhalpak deposit. They are found in areas along the Pavlodar-Shymkent oil pipeline, the Beineu-Bozoy-Shymkent gas pipeline, highways, etc.

Due to its ecological plasticity, the great gerbil is able to adapt to various natural conditions and has a great advantage over other rodent species. The gerbil actively inhabits emerging new roads, embankments, and various pipelines, which everywhere accompany the construction of new drilling sites and mining enterprises [17].

Even during the reconstruction of roads, colonies destroyed by heavy road equipment reappear within 2-3 years, and after a while, there are already solid colonies barely distinguishable only by the ecological center. The density in ribbon settlements reaches 8 or more colonies per 1 ha. There are also single colonies on the territory of the LER. They are so rare that only 1-2 colonies can be found at a distance of 5-7 km. However, as a rule, such colonies are large, 25-30 m in diameter, with a good ecological center, where at least 5-10 and sometimes more than 15 animals live. The density of colonies in such settlements is extremely difficult to determine.

The results of a long-term analysis showed a stable epizootic index, which depended on many factors, such as the number of carriers and vectors, the epizootic cycle, and the persistence of the pathogen in the interepizootic period.

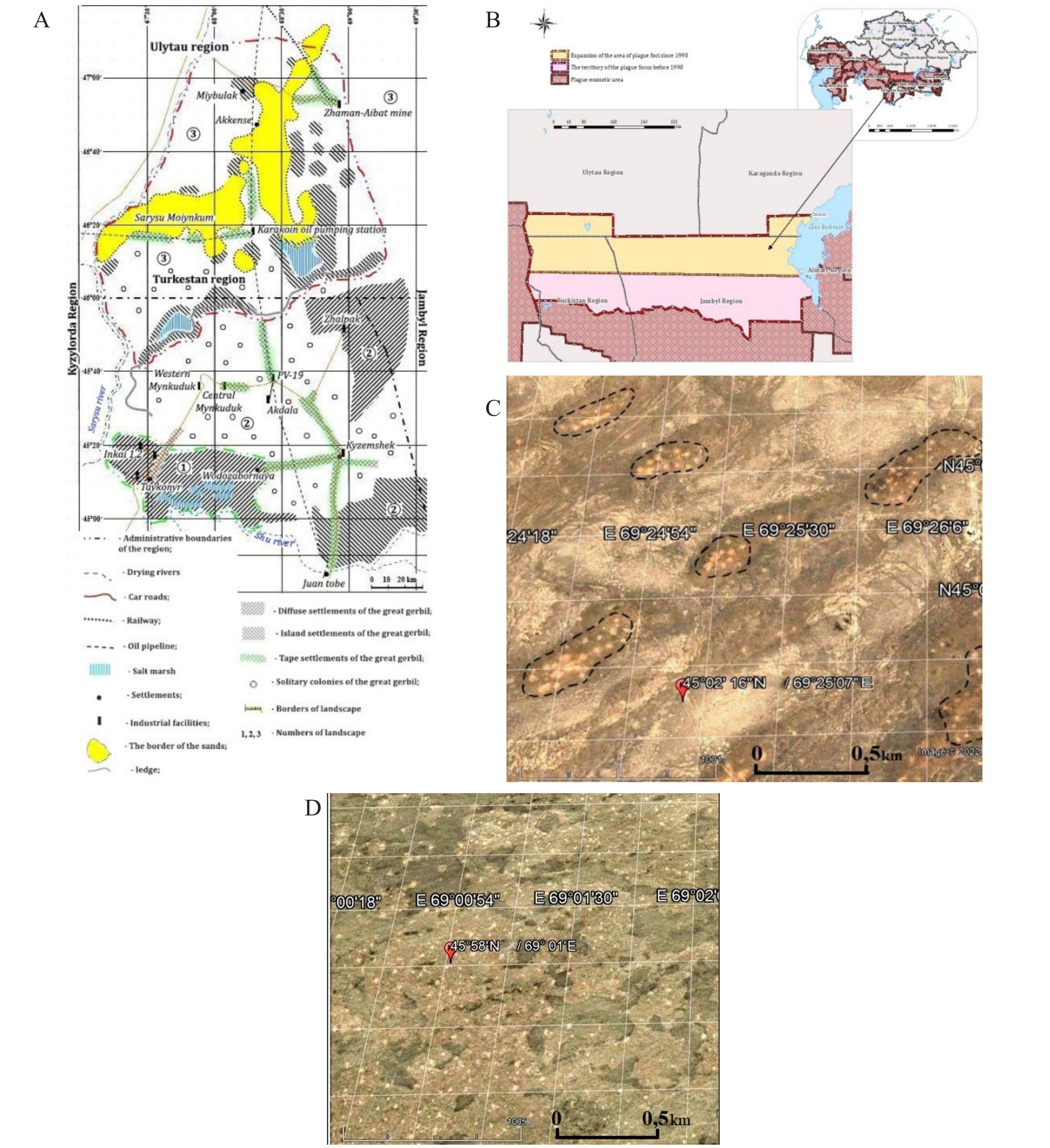

Figure 1: Distribution area, types of settlements of the great gerbil (*Rhombomys opimus*) in the western part of the autonomous plague focus Betpakdala of the Central Asian desert plague focus of Kazakhstan: A)-Settlements of the great gerbil in the territory of the Ulytau and Turkestan regions of Kazakhstan; D)-General border of the Betpakdala plague focus; C)-Island settlements of the great gerbil; D)-Diffuse settlement of the great gerbil. Figures c-d is made based on images from the Google Earth Pro application in the public domain.

Characteristics of plague microbe strains

Based on cultural, morphological, biochemical, enzymatic properties, and sensitivity to plague and pseudotuberculosis phages, the strains isolated in the focus belong to the typical sandy variant of the main subspecies *Yersinia pestis* subsp. Pestis [26]. During the analyzed period (2009-2022), a total of 48 strains of *Yersinia pestis* were isolated and studied, of which 26 were from the great gerbil, 2 were from the red-tailed gerbil, 20 were from fleas, and 1 was from ticks. The microbial population of the plague microbe has typical properties characteristic of the populations of the Central Asian desert focus of Kazakhstan. All strains ferment glycerol, glucose, mannitol, maltose, and arabinose and do not ferment rhamnose or pesticides and do not have denitrifying ability. All strains produced fraction 1. The strains are highly virulent for laboratory animals: The LD50 for guinea pigs is 1.0 × 106 microbial cells (m.c.), for white mice, the LD50 was 1.6-9.0 × 104 m.c., and for white mice, the LD50 of arginine auxotrophs was 1.1 × 103 m.c. All strains of the plaque microbe were sensitive to antibacterial drugs. No antibiotic-resistant or phage-resistant strains were found in the focus.

As a result of a comprehensive analysis of the results obtained by specialists of our scientific center [27-30] and during their own molecular genetic studies, including genome-wide sequencing of *Y. pestis* strains circulating in the autonomous plague center of Betpakdal in Kazakhstan according to the phylogenetic branch of the strain *Yersinia pestis*, they were assigned to the Medieval 2. MED1 biovar.

Modern characteristics of the plague focus and differentiation according to the level of epidemic danger and epizootic activity

Based on the results of epizootological monitoring, a comprehensive meta-analysis of the comparative characteristics of the data obtained was carried out, and the territory of the plague focus was differentiated according to the level of epidemic danger and epizootic activity. The results of samples of field material were summarized, and the extensiveness and intensity of the epizootic process of plague among great gerbils and their fleas were determined, taking into account the number of isolated strains of the plague microbe and registration of seropositive animals for plague infection for the period 2009 2022 (Figure 2) [31-34].

As a result of the analysis during the study period, it was found that plague epizootics among wild animals in this focus area were registered on an area of 15,600 km^2 (26.0%) of the total focus area (60,140 km^2) from 2009 to 2015, and in subsequent years, the interepizootic period began 7 (seven) years ago. Plague epizootics occurred in a local form with low intensity in the southern and central regions of the autonomous plague focus of Betpakdala in Kazakhstan. During the analyzed period, a total of 48 strains of *Y. pestis* were isolated, including 26 pieces from great gerbils, 2 pieces from red-tailed gerbils, 20 pieces from fleas and 1 piece from ticks.

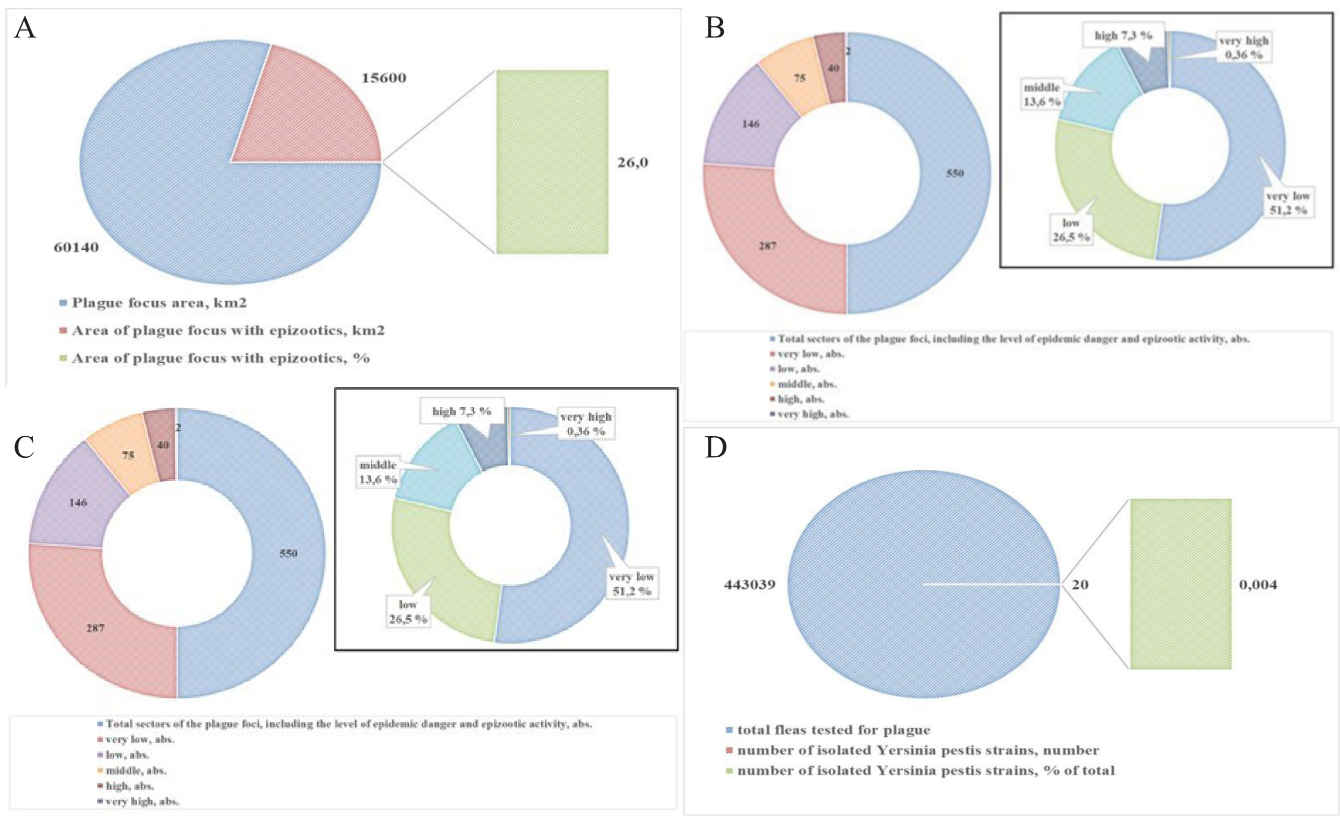

Figure 2: Results of meta-analysis of the epizootic characteristics and differentiation of the autonomous focus of Betpakdala in Kazakhstan for the period 2009-2022 for the plague: A)-The total area of the autonomous focus of the plague and of them with epizootic manifestations; B)-The number of sectors with different levels of epidemic danger with epizootic activity; C)-The results of the studied great gerbils and the number of isolated strains of the plague microbe; D)-The results of the fleas studied and the number of isolated strains of the plague microbe.

It is well known that when conducting an epizootological survey of natural plague foci and their fragments within natural boundaries, the formal territorial principle of dividing the earth's surface into georeferenced data or into formalized accounting units (sectors and primary areas) is used. The area of the autonomous plague focus of Betpakdala (60,140 km^2) is divided into 550 sectors. When differentiating this focus according to the criteria of levels of epidemic danger and epizootic activity, it was very low-287 sectors (51.2%), low-146 s (26.5%), average-75 s (13.6%), high-40 s (7.3%), and very high-2 sectors (0.36%).

An analysis of the population organization of the great gerbil and their border populations showed that the peripheral population of the rodent is subject to permanent variability and depends on climatic-geographical and anthropogenic factors. Under the influence of these factors, in the peripheral zone of the foci, a mosaic distribution (diffuse, island and band settlement) of populations of the great gerbil is observed, and in some places, the formation of a sparse population density of the main carrier is observed.

Natural sandworm foci of the plague in Kazakhstan are characterized by high epizootic activity and require constant monitoring. The significant persistence of natural plague foci, the variety of mechanisms and routes of transmission of the infectious agent, the wide distribution of the pathogen in nature, and the involvement of a large number of warm-blooded animals and arthropods in its circulation determine the importance of improving monitoring of these foci [27].

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DISCUSSION

Changes in the structure and functioning of natural foci of plague in Kazakhstan are under constant monitoring by the anti-plague service of Kazakhstan using GIS technology tools, in connection with which new strategies and tactics of epidemiological surveillance of plague, new principles of planning and carrying out preventive measures are used. An important stage of this work is epizootological monitoring with landscape-epizootological zoning according to international standards, which makes it possible to take into account the results of the survey and registration of the epizootic process among wild animals in a differentiated way and ensures compliance with the unity of approaches to differentiation of the controlled territory.

An epizootic process is a complex continuous process of the emergence and spread of infectious diseases associated with the chain transmission of pathogens from infected animals to susceptible healthy animals. The epizootic process always develops under the influence of both natural and anthropogenic (that is, related to human activity) conditions. Thus, human migrations can have a significant impact on the development of the epizootic process-activating it, increasing the epidemiological potential; on the contrary, isolation of a territory or farm prevents the development of an epizootic process [35].

The revealed trend of expanding the boundaries of the foci occurred against the background of increased anthropogenic impact on natural landscapes, climate change (global warming) and other factors, which gives every reason to assume the possibility of further expansion of the boundaries of the great gerbil's range.

From the mid-1970s to the early 1980s, the industrial development of Western Betpakdala [36] began, which continues today. First, settlements such as the villages of Kyzemshek, Taikonyr, and Appak were founded and expanded. The Pavlodar-Shymkent oil pipeline was stretched across the entire territory, and then the deposits of a number of industrial ore mining enterprises were developed. In December 2010, construction began on the Beineu-Bozoy-Shymkent gas pipeline, designed to transport gas from the fields of western Kazakhstan to supply the south of the republic with its own natural gas, as well as export gas supplies to the Kazakhstan-China gas pipeline. As a result, the total length of all roads, embankments, oil and water pipelines in western Betpakdala is more than 600 kilometers in total. The bulk and ridge soil of the base of roads and pipelines is always less dense than in the surrounding areas, which favors the construction of burrows. Betpakdala produces coal, gypsum, uranium, lead and iron ores, quartzites, salt, rock crystals, marble, etc. [37-41].

The territory of Betpak-Dala is used as spring and autumn pastures. Through it, cattle are driven from the summer pastures of the semi-desert of the Kazakh small hills (Saryarka steppe) to the winter pastures of the Chui Valley and the Moyynkum sands and back. In addition, there are large geological villages of Kyzemshek (4230 people) and Taikonyr (2000 people), which belong to the Sozak district of the South Kazakhstan region. Currently, there are approximately a dozen uranium mining enterprises operating on a rotational basis in Western Betpakdala. The number of employees exceeds 2,500 people. Rotational camps are staffed in different regions of Kazakhstan and even in neighboring countries, which creates a real danger of the plague infection being carried beyond the focus if their employees become ill. In addition, large geological villages of Kyzemshek (4,230 people) and Taikonyr (2,000 people) are located here. In the eastern part of the territory, approximately 23,000 people live in villages, railway stations and crossings in the Zhambyl and Karaganda regions. In the eastern part of the focus are enterprises for the extraction of barite, asbestos, marble, gold, etc. All these settlements are in close proximity to colonies of great and red-tailed gerbils [37-41].

It should be noted that in recent decades, there have been significant global climate changes. They affect not only the atmosphere but also the biosphere, hydrosphere, and cryosphere and have a noticeable impact on many aspects of human life (South Kazakhstan Region Development Program for 2016-2020, 2016). In accordance with the linear trend of air temperature anomalies (against the base period of 1961-1990), indicating a steady increase in air temperature in Kazakhstan from 1941 to 2015, global climate change caused changes in the biosphere of the planet as a whole [42].

The scientific work on climate change and water resources in Central Asia noted that the effects of climate change will be observed in all regions of the planet, and Central Asia is no exception in this regard. Intense climate warming is observed throughout Central Asia [42]. As proof of this, the results of estimating the average annual temperature obtained from Berkeley Earth and 5 other research groups that estimate the surface temperature are shown in Figure 3.

The trend towards warmer winters and drier summers in many parts of the region provokes the retreat of glaciers and the melting of permafrost in the Pamir and Tien Shan mountains. The risk of heavy precipitation, drought, floods and mudflows increases. It was noted here that in the spring, the amount of precipitation decreased in the southern desert regions of Central Asia and increased at the same time in the northern steppe regions, where the northern borders of the Aryskum-Dariyalyktakyr, Balkhash and Betpakdal autonomous plague foci are located [42].

The main negative impacts of climate change with an assessment of the probability of their manifestation according to the Fifth Assessment Report of the IPCC were as follows: Changes in hydrological systems affecting water resources in terms of their quantity and quality (medium confidence) are observed; many terrestrial, freshwater and marine species have changed their geographical ranges, seasonal activity, migration patterns, abundance and interaction with other species (high degree of reliability), etc. (South 43 Kazakhstan Region Development Program for 2016-2020, 2016, IPCC, 2015). As a result, the gradual development of rodents of the northern borders, to a greater extent, by the great gerbil, continues not only in the Betpakdalinsky autonomous plague foci of Kazakhstan but also in two other border autonomous plague foci, such as Aryskum-Dariyalyktakyrsky and Balkhashsky.

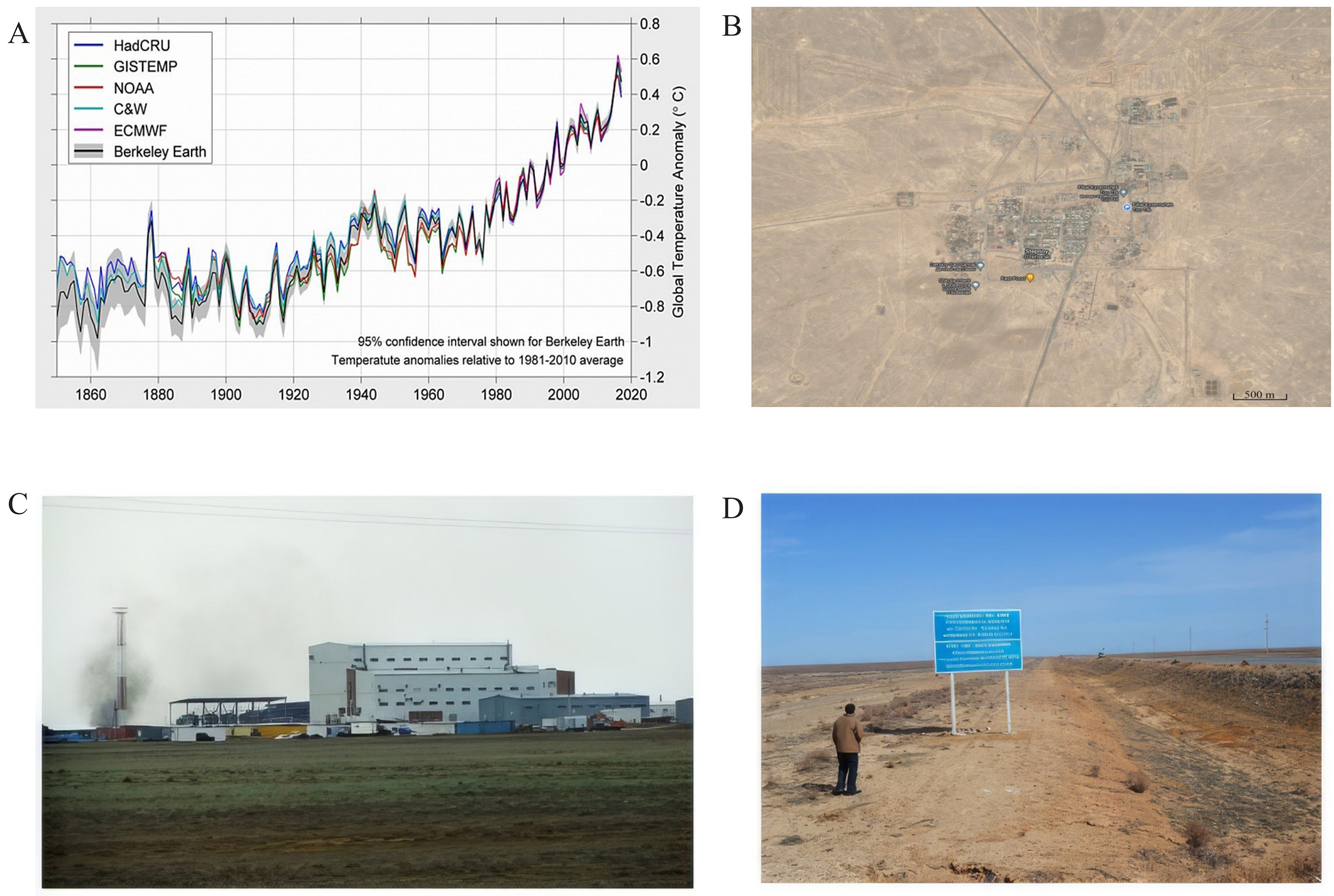

Figure 3: Climatic influences and anthropogenic impacts on natural plague foci of Kazakhstan: A)-Results of the assessment of the average annual temperature in Central Asia, Berkeley Earth, 2017; B)-Refining workshop of a uranium mining plant. LER Western Betpakdala, South Kazakhstan Region (2017); C)-Satellite image (Google, 2018) of the working village of Kyzemshek (Steppe). A dense network of roads, pipelines and patches of great gerbil colonies are visible. LER of Western Betpakdala, South Kazakhstan; D)-Linear settlements of the great gerbil along the highway. LER West Betpakdala, South Kazakhstan. (Turkestan region, 2019).

Thus, the above examples prove that at present, there are many industrial enterprises and zones with stationary buildings or modules located in the plague-enzootic territory. Paved roads and electric lines are connected to all enterprises. There are many access roads and pipelines, including water pipes, laid around the mines themselves. The total length of roads, oil and water pipelines is currently more than 600 km only in Western Betpakdal (Electronic Agricultural Knowledge Library, 2023) [35]. All members of biocenoses, especially plant communities and rodents, react quickly to changes in indigenous landscapes. The attractiveness of roads and embankments of water and oil pipelines for rodents is due to the abundance of ephemera and various shrubs along the sides of embankments and ditches, the herbage of which, even in dry years, usually remains richer than on the surrounding plain. In addition, the towering embankment of roads and various pipelines saves their inhabitants from flooding with meltwater and rainwater. The bulk and upland soil of the base of roads and pipelines is always less dense than in the surrounding areas, which favors the construction of rodent burrows (Figure 3).

It should be noted that the concentration of rodents along highways and other elevations of anthropogenic origin determines here a higher number of blood-sucking ectoparasites as carriers of various pathogens of infectious diseases. The issues of transformation of the borders of autonomous plague foci to clarify, increase and decrease the area of the main carrier, as well as the formation of a new focal area for the plague in Kazakhstan, have been repeatedly brought up for discussion in the academic council of our scientific center and in the scientific and production councils of the country's anti-plague services, whose decisions were published in the form of articles in atlases and domestic and foreign periodicals publications.

CONCLUSION

The total area of the Betpakdala plague focus in Kazakhstan at 01.01.1990 was 30,000 km^2. The northern part of the hearth did not go beyond the 46th parallel of the territory of Kazakhstan; however, against the background of global warming, anthropogenic impact or partial aridization in other parts of the area, the great gerbil settlement is progressing due to the coverage of the territories of the Karaganda region (beyond the 47th parallel of northern latitude), and taking into account the Balkhash zone may exceed this value. Over the past 30 years, the area of the great gerbil and, accordingly, the area of the plague-enzootic territory has increased by 50.12% (60.14 thousand km^2), which was confirmed with the isolation of the causative agent of the plague and the detection of seropositive animals for plague infection.

As a result of the analysis, it was revealed that plague epizootics in this area of focus were registered in the period 2009-2015 with coverage of 26.0% of the total area of the focus, and in subsequent years (seven), the interepizootic period came. During this period, the plague epizootics proceeded in a local form with low intensity in the southern and central regions of the autonomous plague center of Betpakdal in Kazakhstan. When differentiating this plague focus (550 sectors) according to the criteria of the levels of epidemic danger and epizootic activity, the following were distributed according to the degree of danger: Very low-51.2%, low-26.5%, average-13.6%, high-7.3%, and very high-0.36%.

The analysis of the population organization of the great gerbil and their border populations showed that the peripheral settlement of the rodent is under permanent variability and is dependent on climatogeographic and anthropogenic factors. Under the influence of these factors, a mosaic distribution (diffuse, island and ribbon settlement) of populations of the great gerbil is observed in the peripheral zone of foci and, in some places, the formation of a sparse population density of the main carrier.

Over the following decades, there have been changes in the structure and functioning of natural plague foci in Kazakhstan, in connection with which new strategies and tactics of epidemiological monitoring of the plague, new principles of planning and carrying out preventive measures using GIS technology tools have been proposed. Knowledge of the peculiarities of the distribution of the great gerbil in Betpakdala is of both scientific and practical importance for carrying out the necessary preventive anti-epidemic measures.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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