UDC 616.98: 579.842.23 (571.15)
DOI: 10.21668/health.risk/2021.4.15.eng

Read online

Research article

EFFICIENCY OF DISINSECTION AND DERATIZATION AIMED AT REDUCING EPIDEMIOLOGIC RISKS IN GORNO-ALTAISKIY HIGH-MOUNTAIN NATURAL PLAGUE FOCUS

A.N. Matrosov[1], E.V. Chipanin[2], A.Ya. Nikitin[2], A.V. Denisov[3], A.I. Mishchenko[3], E.N. Rozhdestvensky[3], A.A. Kuznetsov[1], N.V. Popov[1]

[1]«Microbe» Russian Research Anti-Plague Institute, 46 Universitetskaya Str., Saratov, 410005, Russian Federation
[2]Irkutsk Research Anti-Plague Institute, 78 Trilisser Str., Irkutsk, 664047, Russian Federation
[3]Altai Plague Control Station, 2 Zavodskaya Str., Gorno-Altaysk, 649002, Republic of Altai, Russian Federation

Our research aim was to estimate efficiency of emergency disinsection and deratization that were accomplished to reduce risks of diseases among population in Gorno-Altaiskiy high-mountain natural plague focus.

The research was performed in 2016–2021 in Gorno-Altaiskiy high-mountain plague focus which is the northern part of Sailygem cross-border natural focus located both in Russia and Mongolia. Zoological, epizootologic, epidemiological and statistical research procedures as well as GIS-tools were applied to collect and analyze research data.

Epidemiologic surveillance over plague in the focus has been accomplished since 1961. Prior to 2011 only rhamnosopositive strains of the plague microbe with selective virulence were found here, belonging to the Central Asian subspecies Yersinia pestis altaica, circulating mainly in the population of the Ochotona pallassi. Given that, the focus was believed to have low epidemic potential. Since 2012 highly virulent strains of the basic plague microbe Yersinia pestis ssp. pestis started to occur in populations of Marmota baibacina and other carriers. As a result, starting from that period of time, epidemiologic status of the focus changed and it led to 3 cases of bubonic plague among humans in 2014–2016. Disinsection and deratization remained the major components in anti-epidemic activities aimed at non-specific plague prevention. In 2016–2021 fields disinsection covered a total square equal to 162.7 km^2; disinsection in settlements, 127.3 thousand m^2; deratization in settlements, 461.7 thousand m^2. An approach involving disinsection only on land spots that were considered epidemically hazardous was first implemented; such land spots were around livestock breeders' camps located within boundaries of detected epizooties. Efficiency of fields disinsection amounted to 94.6; disinsection in settlements, 100 %; deratization in settlements, 88.0 %. Population of plague vectors and carriers was controlled bearing in mind environmental aspects in regulating numbers of animals and compliance with environmental protection requirements.

Deratization and disinsection, together with other activities aimed at plague prevention, provide epidemiologic welfare in the focus and reduce its epizootic activity.

Key words: *plague, natural focus, plague vectors and carriers, risk factors, risk groups, risk time, risk territory, disinsection, deratization, epidemiologic welfare.*

Aleksander N. Matrosov – Doctor of Biological Sciences, Leading researcher at the Laboratory for Epizootiological Monitoring of Epidemiology Department (e-mail: anmatrosov@mail.ru; tel.: +7 (937) 630-40-98; ORCID: https://orcid.org/0000-0003-4893-7188).

Evgeniy V. Chipanin – Candidate of Biological Sciences, Senior Researcher at the Zoological and Parasitological Department (e-mail: adm@chumin.irkutsk.ru; tel.: +7 (395) 222-01-37; ORCID: https://orcid.org/0000-0001-6051-1409).

Aleksey Ya. Nikitin – Doctor of Biological Sciences, Leading Researcher at the Zoological and Parasitological Department (e-mail: adm@chumin.irkutsk.ru; tel.: +7 (395) 222-01-37; ORCID: https://orcid.org/0000-0002-3918-7832).

Aleksey V. Denisov – Candidate of Biological Sciences, Head of the Zoo-Parasitological Laboratory (e-mail: chumagorny@mail.ru; tel.: +7 (388) 226-42-39; ORCID: https://orcid.org/0000-0002-4678-2453).

Aleksander I. Mishchenko – Head of the Epidemiological Department (e-mail: chumagorny@mail.ru; tel.: +7 (388) 226-42-39; ORCID: https://orcid.org/0000-0002-7502-2429).

Evgeny N. Rozhdestvensky – Director (e-mail: chumagorny@mail.ru; tel.: +7 (388) 226-42-39; ORCID: https://orcid.org/0000-0002-6005-3783).

Aleksandr A. Kuznetsov – Doctor of Biological Sciences, Chief Researcher at the Laboratory for Epizootiological Monitoring of Epidemiology Department (e-mail: rusrapi@microbe.ru; tel.: +7 (845) 273-46-48; ORCID: https://orcid.org/0000-0002-0677-4846).

Nikolay V. Popov – Doctor of Biological Sciences, Chief Researcher at the Laboratory for Epizootiological Monitoring of Epidemiology Department (e-mail: rusrapi@microbe.ru; tel.: +7 (845) 251-52-10; ORCID: https://orcid.org/0000-0003-4099-9261).

Plague is still among the most dangerous natural foci diseases and is widely spread in the North and South America, Africa, and Eurasia [1–5]. According to the valid International Health Regulations (2005) plague is a socially significant and extremely dangerous infection that requires international control [6–11]. In 2000–2020 plague outbreaks were detected on 5 continents in 20 countries worldwide with a total number of cases being 28,082 and 2,504 (8.9 %) out of them were lethal ones [12–13].

In Russia, CIS member states, Mongolia and China natural plague foci that occur in mountain natural habitats of marmots and gophers have become more active over the last decade. Given that growing activity, there have been sporadic cases of bubonic plague among humans caused by dressing carcasses of hunted marmots [14–22][1]. In Russia three cases were registered in 2014–2016 in the Gorno-Altaiskiy high mountain natural plague focus which is the northern part of Saylugem cross-border natural plague focus [23, 24].

In the Russian Federation and the CIS countries epidemiologic surveillance in natural plague foci involves epizootologic monitoring with its results giving grounds for planning and implementing prevention activities. In case an epidemic situation is deteriorating, strategies and tactics of surveillance over the dangerous infection are adjusted bearing in mind that all studies are epidemiologically oriented and aimed at preventing plague outbreaks [25]. In 2014–2021 a whole (integrated) set of anti-epidemic and prevention activities has been implemented in the Gorno-Altaiskiy high mountain, Tuvinskiy mountain, and Tien Shan high mountain natural plague foci. This set includes epizootologic examinations, epidemiologic monitoring, security and restrictive measures, sanitary-technical activities, informing and educational work with population, as well as disinfection in epidemic foci and on epizootic territories [26–28]. Insecticide and rodenticide treatments are the most radical measures aimed at inhibiting and eliminating epizooties. Reducing a number of carriers and vectors down to levels which put an end to an epizootic process allows minimizing risks of infection spread among people and provides epidemiologic welfare of population regarding this dangerous disease.

At present numbers of marmots are rapidly recovering and these animals are known to be basic plague carriers in mountain foci [18, 29][1]. This fur-bearing animal is traditionally hunted by locals. Despite marmot hunting is strictly prohibited in natural plague foci, local population hunt them all the same as a source of meat and fat which is usually used as a therapeutic mean. At present it is recommended to cease hunting this valuable and protected species since it will help inhibit plague epizooties in marmot habitats. As experience shows, ecological peculiarities of marmots related to their eating habits, places of living, and spatial-ethological features can't secure any reduction in their numbers without significant expenditure on organizing and accomplishing their extermination. Any attempts to regulate rodents' numbers without taking their population peculiarities into account are inefficient and ungrounded [30].

At present the greatest effects in inhibiting epizooties in plague foci are produced by eliminating fleas since these insects are specific vectors and keepers of the plague microbe. To do that, variable techniques are used including powder-based or wet disinsection or impregnation of materials with phosphor organic chemicals, pyrethroids, or phenylpyrazole [26, 31–33]. Their pulicide effects persist for 2–4 months; up to 6 months in some cases; and as it has been reported in some observations, even up to 3 years, probably, due to violated biocenosis in burrows. In case burrow holes of rodents or lagomorphs are to be treated with powder-like compounds, the most efficient way is to apply deep dusting with air blowers (motor dusters) or aerosol treatment using cold foggers.

[1] Abdel Z.Zh. Natural plague foci in the Tien Shan mountains in Kazakhstan and Kirgizia. Almaty, KNZKZI Publ., 2019, 168 p.

Emergency plague prevention in its natural foci is planned and implemented based on a systemic approach to contents of all applied activities. Only their integrated set can provide sustainable anti-epidemic effects. At the same time disinsection and deratization remain the most radical measures aimed at inhibiting and eliminating plague epizooties thus reducing risks of the infection spread among people [23].

Our research aim was to estimate efficiency of emergency disinsection and deratization that were accomplished to reduce risks of contagion among population in Gorno-Altaiskiy high-mountain natural plague focus.

Materials and methods. The research was accomplished in 2016–2021 in the Gorno-Altaiskiy high-mountain natural plague focus with its square being equal to 11,681 km^2. The focus is located within administrative boundaries of Kosh-Agachskiy district in Altai Republic (the Russian Federation). It is the northern part of Saylugem cross-border natural focus located both in Russia and Mongolia with its total square being 28,597 km^2. Over the last 5 years experts have examined 9,286 small mammals as typical plague carriers and 70,025 blood-sucking ectoparasites including fleas (57,919), lice, ticks and gamasite mites as primary and secondary plague vectors in the Gorno-Altaiskiy high-mountain natural plague focus. Overall, 146,665 burrows have been examined to detect fleas in them; all these burrows belonged to grey marmots (*Marmota baibacina*), Mongolian and Daurian pika (*Ochotona palassii* and *Ochotona dauurica*), and long-tailed (Siberian) souslik (*Spermophilus undulatus*). Also, 77 animal nests have been dug out.

Epidemic complications related to bubonic plague cases among people required restructuring the whole system of epidemiologic surveillance in the focus and its status changed after detecting highly virulent strains of the basic plague microbe [23, 34]. Given the existing situation, insecticide and rodenticide treatments increased in volumes and their tactics also changed. A new approach involved using small mobile teams (made up of 5 people) who worked on land spots with the highest epidemiologic risks around livestock breeders' camps located in epizootic areas. In one day such a team is able to accomplish barrier disinfection around 6–10 livestock breeder' camps located in mountains.

The Altai Plague Control Station got assistance in a period when the epidemiologic situation as per plague could deteriorate (from May to September) as 10–12 experts came there from the "Microbe" Russian Research Anti-Plague Institute (Saratov), Irkutsk Research Anti-Plague Institute and Stavropol Anti-Plague Institute [24, 28]. Experts from the prevention departments of the Center for Hygiene and Epidemiology in Altai Republic and Rospotrebnadzor Regional Office in Altai Republic took part in examining settlements and extermination activities in them. All the works were accomplished in accordance with the documents including "The Complex program of activities performed by Rospotrebnadzor and aimed at improving the epidemiologic situation in the Gorno-Altaiskiy high-mountain natural plague focus in Kosh-Agachskiy district of Altai Republic", "The activity program (roadmap) aimed at reducing risks of epidemiological complications in the Gorno-Altaiskiy high-mountain natural plague focus for 2019–2023" approved by the Order by the Altai Republic Government No. 2-r dated January 11, 2019, "The Program of disinsection and deratization in the Gorno-Altaiskiy high-mountain natural plague focus", and operation plans made up by the Altai Plague Control Station in 2016–2021.

Data were collected and analyzed using zoological, epizootological, epidemiological, and statistical procedures as well as GIS-tools [20]. The latter were applied when managerial decisions were being taken based on "Management of restoration activities in the Gorno-Altaiskiy high-mountain natural plague focus" interactive electronic map.

Results and discussion. From 1961 to 2021 only the plague microbe belonging to the Central Asian sub-species *Yersiniapestis* ssp. *Altaica* was detected in the Gorno-Altaiskiy high-mountain natural plague focus in Kosh-

Agachskiy district of Altai Republic. The microbe circulated in habitats of Mongolian (*Ochotona pallassii*) and Daurian (*O. daurica*) pika, long-tailed (Siberian) souslik (*Spermophilus undulatus*), and flat-headed vole (*Alticola strelzowi*). These plague microbe strains are highly virulent for white mice but weakly or even anti-virulent for guinea pigs [2]. Given that, the epidemic potential of the focus was considered to be low regardless of its permanent epizootic activity: plague was not registered among people for 50 years. In 2012 a strain of the highly virulent basic plague microbe *Y. pestiss* ssp. *pestis* was detected in the focus for the first time in a carcass of a long-tail souslik. Over the next few years this strain started to be detected regularly in grey marmots (*Marmota baibacina*) and long-tailed sousliks (*Spermophilus undulatus*) as well as in a wide range of fleas and other ectoparasites [18, 31]. Overall, in 1961–2021 2,601 cultures of the plague microbe were isolated in the focus; 2,438 out of them belonged to the Altai subspecies and 163 to the basic one (160 strains were detected in the field and 3 were isolated in clinics).

Epizootologic monitoring established there were seasonal and yearly changes in numbers of plague carriers including such background rodents and lagomorphs as grey marmots, Mongolian and Daurian pika, long-tailed souslik and flat-headed vole. At present marmot populations are rather dense and biotopes inhabited by this rodent have become larger. A number of occupied burrows varies from 0.3 to 2.0 per 1 hectare or 0.8 on average per 1 hectare. Numbers and habitats of Mongolian pika and long-tailed souslik are rather stable: average density of pika colonies amounts to 4.8 per 1 hectare in spring and 6.7 per 1 hectare in autumn; souslik population density is 3.8 and 5.7 animals per 1 hectare in spring and autumn accordingly. Average long-term number of flat-headed vole that lives in rock outcrops and scatterings in mountain ranges all around Chutskaya steppe on average amounts to 11.25 % in spring and 29.7 % in autumn if measured as per a number of entrapped animals.

A number of synanthropic rodents remains low. House mouse (*Mus musculus*) prevails in 11 large settlements in the focus; an average share of animals entrapped in mashers amounts to 2.6 in spring and to 3.3 in autumn. Flat-headed vole is easily found in buildings within high mountain livestock breeders' camps; its numbers vary from 4.0 % in spring to 7.1 % of entrapped animals in autumn. A lot of such camps are surrounded by habitats with a lot of various species living there including marmots, sousliks, and pikas.

Fleas that live in the focus and participate in the plague microbe circulation belong to 54 species and subspecies; 29 out of them were registered in 2016–2021. 17 species are mass ones and they are fleas typical for marmot, souslik, pika and vole. Indices of abundance (IA) of ectoparasites in animals' fur are quite stable over time and amount to 0.7 insects on grey marmot; 2.0, long-tailed souslik; 7.7, Mongolian pika; 1.9, flat-headed vole. In 2016–2020 IA for fleas amounted to 0.16 ± 0.03 insects on average in burrow holes. At present an overall number of fleas prevailing on Mongolian pika amounts to 190 insects per 1 hectare in spring and grows twice in autumn up to 390 insects per 1 hectare. *Oropsylla silantiewi* fleas prevail on grey marmots; *Amphalius runatus*, *Ctenophyllus hirticrus*, *Frontopsylla hetera*, *Paradoxopsyllus scorodumovi*, *P. scalonae*, *P. dashidorzhii*, *P. hesperius kalabukhovi*, *Amphipsylla primaris* and *Rhadinopsylla dahurica*, on pika and in its colonies; *Citellophilus tesquorum*, *Oropsylla alaskensis*, on long-tailed souslik.

Most cultures of the plague microbe belonging to the Altai subspecies were isolated from pikas and fleas that were specific for them; cultures of the basic plague microbe were isolated from grey marmots and long-tailed sousliks and their ectoparasites (94 %). The plague microbe of the Altai subspecies circulates at heights varying from 1,800 to 2,600 meters above the sea level; the basic plague microbe, 2,200–2,700 meters. Habitats of *Y. p. altaica* и *Y. p. Pestis* are overlapped on the major part of the focus territory.

Factors, contingents, time, and risky territories in terms of possible contagion with plague among population were analyzed thoroughly and analysis results were estimated to give grounds for building up a map showing levels of epidemiological hazard (risk) of plague contagion in the focus. The map is checked up and, if necessary, adjusted every year (Figure 1). This cartographic basis is used in planning and implementing examinations and prevention activities thus making them more targeted.

The Gorno-Altaiskiy high mountain natural plague focus is unique due to two independent adjacent plague foci occurring on its territory that are different as per their biocoenotic and spatial structure. The plague microbe of Altai subspecies is established to circulate in three meso-foci, Ulandrykskiy, Tarkhatinskiy and Kuraiskiy ones, which are territorially and functionally linked to Mongolian pika populations of the same name [34]. An area where epizootic events caused by *Y. p.* ssp *altaica* were detected amounts to 2,317.2 km^2 and it coincides with the Mongolian pika habitat completely. Results of several studies indicate that the aforementioned foci are relatively independent in their functioning [16, 35].

An area where *Y. p. pestis* was established to circulate in 2021 amounts to 2,015.7 km^2 whereas the whole habitat of grey marmot amounts to 4,120 km^2. It can be considered as a future opportunity for the highly virulent subspecies to spread over larger areas in this focus. There is a partial overlap in the focus regarding epizootic events caused by two different subspecies of the plague microbe since strains of them both are detected on an area being equal to 950.0 km^2. Therefore, the total area here plague epizooties are detected amounts to 3,383.0 km^2 or 29.0 % of the whole focus (Figure 2).

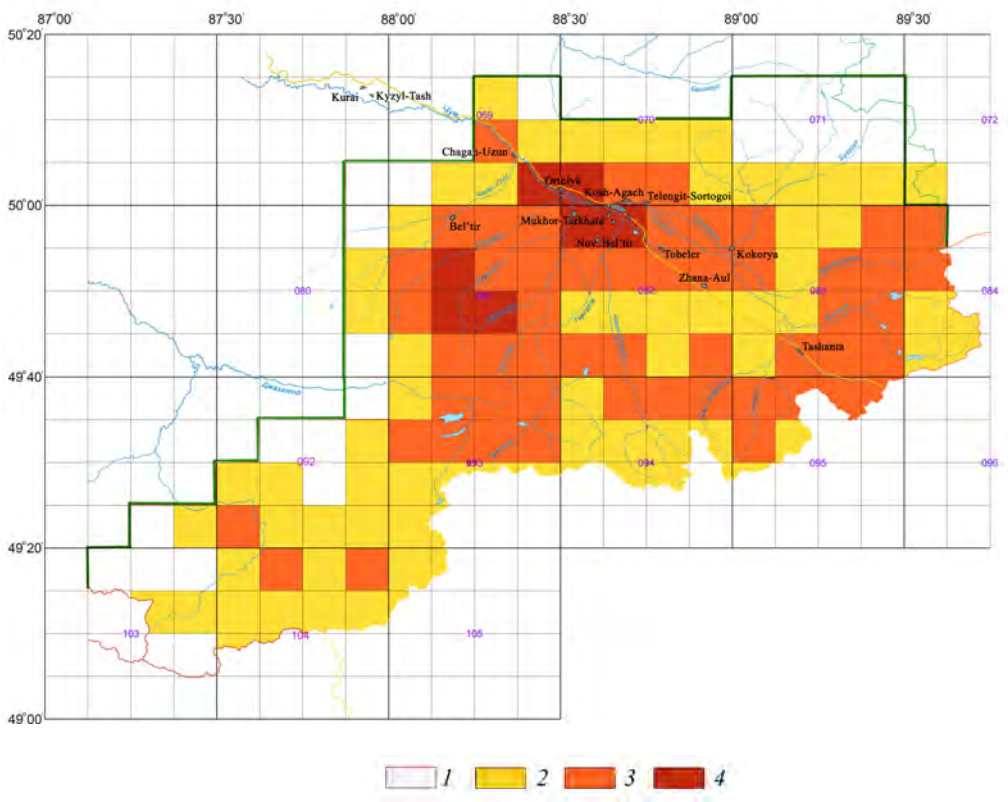

Figure 1. Levels of epidemiologic risks in the Gorno-Altaiskiy high mountain natural plague focus
1 is low; ***2***, moderate; ***3***, high; ***4***, extremely high

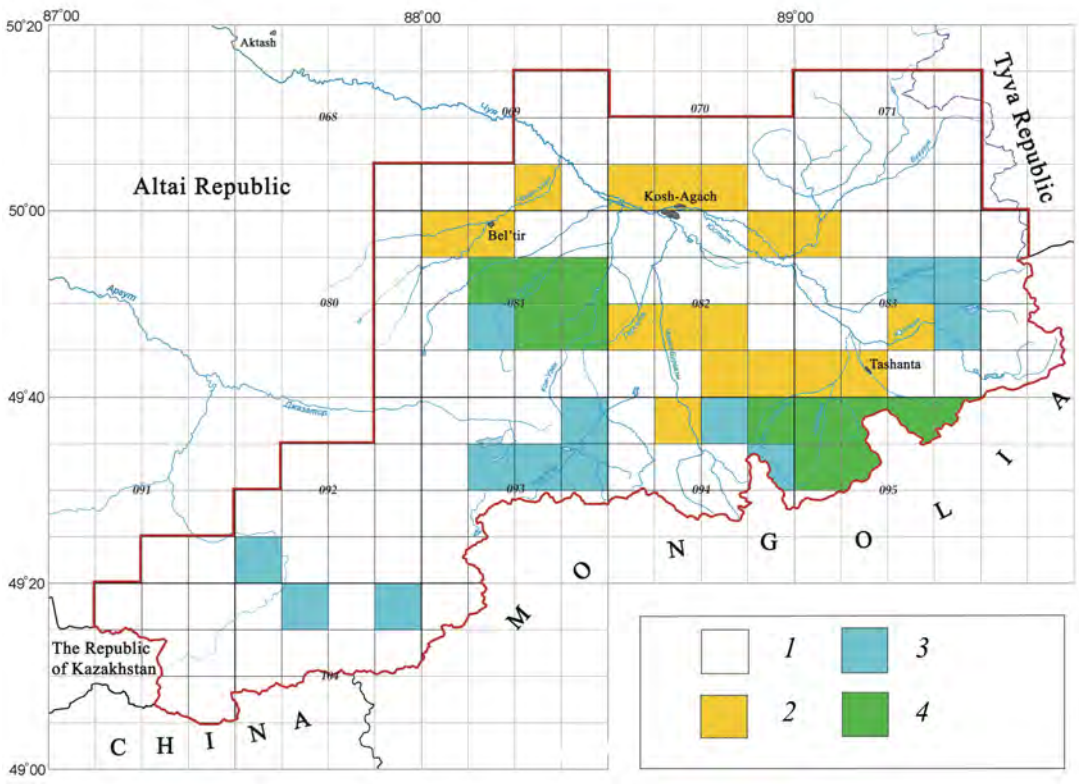

Figure 2. Places where plague cultures were isolated in the Gorno-Altaiskiy high mountain focus Sectors: ***1*** means cultures were not isolated; ***2***, only *Y. p. ssp. altaica* strains; ***3***, only *Y. p. ssp. pestis* strains; ***4***, both strains were isolated

Disinsection and deratization remained primary anti-epidemic activities. Reducing numbers of plague carriers and vectors down to levels at which an epizootic process stops provides epidemiologic safety regarding this dangerous infection. Growing volumes of operative insecticide and rodenticide activities that were relevant to the existing situation with plague were provided by attracting additional resources from anti-plague institutions in Russia.

We should note that seasonal schedules of livestock breeders' roaming were taken into account when volumes and places of field disinfections were determined. It was obligatory to treat all livestock breeders' camps located on land spots that were epizootic as per plague as it was detected in previous seasons or through operative field examinations. Major part of these barrier treatments was accomplished in May and this allowed reducing numbers of fleas and preventing development of plague epizooties around summer camps before a great number of people settled in them for a season.

Deratization and disinsection in settlements was basically accomplished by experts from the Department for preventive disinsection of the Center for Hygiene and Epidemiology in Altai Republic. Home mouse (*Mus musculus*) is the only synanthropic rodent living in large settlements in the focus. All buildings in livestock breeders' camps located in highlands are inhibited by flat-headed vole. Occasionally Mongolian pika or Campbell's dwarf hamster can also be found there. Regular monitoring allowed establishing that numbers of home mouse and its fleas were very low in settlements. Given that, in case there are indications that some extermination procedures are necessary, as a rule, rodents and ectoparasites are not detected after deratization and disinsection. Since these activities have been highly efficient so far, the result is lower epizootic activity in the focus as a number of isolated cultures belonging to the highly viru-

lent basic subspecies has been decreasing (Table). These activities, together with other preventive measures, gave an opportunity to provide epidemiologic welfare as per plague in the Gorno-Altaiskiy high mountain natural plague focus. Since 2017 and up to now there have been no plague cases registered among people.

From 2016 to 2021 the overall square of field disinsection in the Gorno-Altaiskiy high mountain focus amounted to 140.9 km^2; disinsection in settlements, 117.7 thousand meters^2; deratization in settlements, 393.2 thousand meters^2. Field deratization wasn't either planned or accomplished in the focus since it was considered inefficient to exterminate marmots in order to inhibit epizooties as well as due to the necessity to protect this valuable commercial species. Annually from 46 to 132 livestock breeders' camps as well as border stations were examined on epizootic areas. Disinsection was accomplished around each camp in multi-species settlements of pika, marmot, and souslik on a square varying from 0.3 to 1.0 km^2 as per results of epizootologic monitoring over territories that were endemic as per plague and depending on a lay of land. Density of burrows in multi-species animal settlements varied from 11 to 84 with its average value being 22.1 ± 3.2 per 1 hectare. Index of abundance (IA) for burrow fleas varied from 0.116 ± 0.02 to 0.197 ± ± 0.03 in different years around livestock breeders' camps on epizootic territories. IA for fleas fell from 0.007 to 0.003 after insecticide effects expired. On average, 5.5 kg of insecticide dust were spent on one camp. Treatment was accomplished by dusting burrow holes or deep dusting with TWISTER knapsack dusters and CIFARELLI motor (petroleum-driven) air blowers.

Deratization took place only in large settlements and livestock breeders' camps in the focus as well as in building at border stations. Given that house mice prevailed in settlements and flat-headed voles prevailed in buildings in highland livestock breeders' camps, it was quite efficient to use rodenticide baits in animas' shelters (burrows, cracks, containers, cellars, etc.).

Ready-made baits based on the second-generation anticoagulants were used as rodenticides to perform deratization in settlements in the Gorno-Altaiskiy high mountain natural plague focus; the examples are paraffin blocks "Blokada", "Brodifan" and "Zernotsin-blok" (based on 0.005 % *bromadiolone* and *brodifacoum*). Field disinsection was performed by using dust mixtures "Kaprin-F" (0.04 % *fenvalerate* + 4.0 % *boric acid*), "Fas-dubl'" (0.02 % *zete cipermetrina* + 0.01 % *fenvalerate*) and "Zelenyi dom" (0.2 % *ccipermetrina* + 0.2 % *sumithion*) based on synthetic pyrethroids and phosphor organic compounds. Wet disinsection in settlements was performed by using concentrated emulsion of "Fufanon-super" phosphor organic compound (44–57 % *malathione*).

Table

Epizootic activity, efficiency of deratization and disinsection in the Gorno-Altaiskiy high mountain natural plague focus in 2016–2021

Year	Number of isolated *Y. p. pestis*	Square of epizooties, km^2	Field disinsection		Deratization in settlements		Disinsection in settlements	
			km^2	eff., %	th. m^2	eff., %	th. m^2	eff., %
2016	65	930.6	30.4	86.0	102.9	81.1	72.8	100.0
2017	49	925.0	43.5	96.7	99.1	82.9	13.9	100.0
2018	11	670.4	32.7	94.5	77.7	80.5	12.9	100.0
2019	8	418.1	32.0	97.4	39.0	83.7	7.4	100.0
2020	5*	503.4**	2.3	–	74.5	100.0	10.7	100.0
2021	5	415.2	26.3	98.5	68.5	100.0	9.6	100.0
Total	138	3,383.0	167.2	94.6	461.7	88.0	127.3	100.0

N o t e : * means 3 out of 5 plague microbe strains were isolated on hard-to-reach spots in Ukok highlands which were not examined in 2016–2019; ** means square of epizooties in Ukok highlands is also included and amounts to 252.7 km^2.

Factors of epidemiologic risks related to plague contagion are to a great extent determined by epizootic activity of a natural focus. At present species structure, numbers, and specific distribution of vectors and carriers in the Gorno-Altaiskiy high mountain natural plague focus make for persistent circulation of the highly virulent basic plague microbe subspecies. It is either rather difficult or not advisable to exterminate small rodents that are plague carriers in natural biotopes given their environmental peculiarities [36]. Thus, grey marmot and pika are grass-eating animals and given that it seems rather inefficient to use ready-made traditional rodenticide baits. Besides, it is prohibited to exterminate grey marmots as they are a valuable commercial species and are protected by environmental legislation. Deratization is to be accomplished only in settlements where it is necessary to completely exterminate synanthropic and hemisynanthropic rodents. The up-to-date concept of disinsection and deratization in plague foci involves focusing on insecticide treatments against fleas in human settlements as well as in natural biotopes where basic plague carriers live. When a number of fleas as plague microbe vectors and keepers is reduced, it helps break an epizootic chain and, consequently, inhibit or eliminate an epizooty. Risks for people to get infected with plague are also reduced or prevented completely and it is exactly the main goal that epidemiologic surveillance over plague is to achieve.

Selecting a procedure for accounting numbers of fleas as plague vectors is a major task that has to be solved when assessing efficiency of accomplished insecticide treatments. Fleas that live on burrowing animals migrate rather poorly from depths to holes in highlands in the focus. At the same time all animal settlements located around and within livestock breeders' camps are mixed colonies with grey marmots, pikas, and sousliks living there; insects can be collected in such animal settlements during the whole season (from May to September) using a flannel band (or a hose).

Pulicide efficiency was estimated as per results of insecticide treatments accomplished in May–June around livestock breeders' camps; the estimation was based on flea abundance at burrow holes of plague carriers and indicated that efficiency amounted to 94.6 % on average in the focus varying from 86.0 to 97.7 % in different years. Indices of abundance for burrow flea went down by 20–40 times on different areas. To obtain correct data on efficiency of insecticide treatments against burrow fleas, experts performed simultaneous examinations on treated (test) land spots around livestock breeders' camps and on untreated (reference) ones. The examinations proved accomplished insecticide activities to be highly efficient. Test land spots around livestock breeders' camps were repeatedly examined in July and August to reveal that insecticide effects on fleas at burrow holes persisted for up to three months (observation periods). We should note that examinations also revealed either total absence of fleas or very low numbers of them in burrow holes on most land spots around livestock breeders' camps that were treated in the previous year. However, this fact can be due to not only persisting effects of applied insecticides one year after but also be a consequence of flea taxocenes recovering rather slowly by fleas penetrating from neighboring untreated areas given that insects were highly tessellated and highland biocenoses were relatively isolated.

Apart from providing satisfactory pulicide effects, we should also bear in mind that accomplished insecticide treatments also may have anti-epidemic and anti-epizootic effects. In 2017–2021 there have been no plague cases registered among people in the Gorno-Altaiskiy high mountain focus. Over the same period epizootic territories and a number of isolated cultures have also been going down.

Conclusions. Epidemiological anamnesis with data on people getting infected with plague in the Gorno-Altaiskiy high mountain natural plague focus is clear evidence that all cases when people got infected with bubonic plague were caused by dressing carcasses of sick marmots that were illegally hunted. Given that, informing and educational work with population becomes very important and people

should be aware of prevention activities against the dangerous infection; control over restrictions imposed on people's visits to epizootic areas is another vital issue. But at the same time a major task to be solved is to inhibit and eliminate plague epizooties in carriers' settlements including grey marmot, Mongolian pika and long-tailed souslik. It will allow reducing a probability that people would get infected on epizootic areas. Insecticide treatments performed on such areas as well as deratization within settlements and around them makes the focus territory healthier and, together with other prevention activities, reduces a number of possible contacts between people and infected animals.

Field disinsection as well as disinsection and deratization in settlements were proven to have high anti-epizootic efficiency; given that, volumes and territories to be treated were increased when emergency anti-plague activities were planned and implemented in order to make them relevant to the existing situation. In this relation, traditional experience accumulated by Rospotrebnadzor was applied involving providing additional resources of anti-plague stations and institutes in emergency situations.

A decrease in numbers of fleas as basic plague microbe vectors and keepers in natural biotopes resulted in inhibiting epizooties development in settlements of basic plague carriers (grey marmots, sousliks and pikas) and reducing risks of people getting infected in the focus. Deratization and disinsection in settlements provide eliminating rodents and their fleas (plague microbe carriers and vectors) in settlements and livestock breeders' camps. A set of prevention activities accomplished in 2017–2021 allowed providing epidemiologic welfare of population and reducing epizootic activity in the Gorno-Altaiskiy high mountain natural plague focus.

Unique experience in planning, organizing, and implementing a set of prevention activities in the Gorno-Altaiskiy high mountain natural plague focus should be examined and recommended to be applied in other natural plague foci in Russia and neighboring countries.

Funding. The research was not granted any sponsor support.

Conflict of interests. The authors declare there is no any conflict of interests.

References

1. Josko D. *Yersinia pestis*: still a plague in the 21st century. *Clin. Lab. Sci.*, 2004, vol. 17, no. 1, pp. 25–29.

2. Prirodnye ochagi chumy Kavkaza, Prikaspiya, Srednei Azii i Sibiri [Natural plague foci in the Caucasus, the Caspian sea, Central Asia and Siberia]. In: G.G. Onishchenko, V.A. Kutyrev eds. Moscow, «Meditsina», 2004, 192 p. (in Russian).

3. Duplantier J.M., Duchemin J.B., Chanteau S., Carniel E. From the recent lessons of the Malagasy foci towards a global understanding of the factors involved in plague reemergence. *Vet. Res.*, 2005, vol. 36, no. 3, pp. 437–453. DOI: 10.1051/vetres: 2005007

4. Luo H., Dong X., Li F., Xie X., Song Z., Shao Z., Li Z., Tong Z. [et al.]. Cluster of primary pneumonic plague transmitted in a truck cab in a new enzootic focus in China. *Am. J. Trop. Med. Hyg.*, 2013, vol. 88, no. 5, pp. 923–928. DOI: 10.4269/ajtmh.12-0163

5. Andrianaivoarimanana V., Piola P., Wagner D.M., Rakotomanana F., Maheriniaina V., Andrianalimanana S., Chanteau S., Rahalison L. [et al.]. Trends of human plague, Madagascar, 1998–2016. *Emerg. Infect. Dis.*, 2019, vol. 5, no. 2, pp. 220–228. DOI: 10.3201/eid2502.171974

6. Gage K.L., Kosoy M.Y. Natural history of plague perspectives from more than a century of research. *Annu. Rev. Entomol.*, 2005, vol. 50, pp. 505–528. DOI: 10.1146/annurev.ento.50.071803.130337

7. Bertherat E. Plague around the world, 2010–2015. *Wkly Epidemiol. Rec.*, 2016, vol. 91, no. 8, pp. 89–93.

8. Bramanti B., Stenseth N.C., Walle L., Lei X. Plague: A disease which changed the path of human civilization. *Yersinia pestis: Retrospective and Perspective*. Dordrecht, Springer, 2016, pp. 1–26.

9. *Yersinia pestis*: Retrospective and Perspective. In: R. Yang, A. Anisimov eds. *Advanced in Experimental Medicine and Biology*, 2016, vol. 918, 397 p.

10. Obespechenie epidemiologicheskogo blagopoluchiya v prirodnykh ochagakh chumy na territorii stran SNG i Mongolii v sovremennykh usloviyakh. [Provision of epidemiological welfare in the natural plague foci in the UIS countries and Mongolia under current conditions]. In: A.Yu. Popova, V.V. Kutyrev eds. Izhevsk, OOO «Print», 2018, 336 p. (in Russian).

11. Campbell S.B., Nelson C.A., Hinckley A.F., Kugeler K.J. Animal exposure and human plague, United States, 1970–2017. *Emerg. Infect. Dis.*, 2019, vol. 5, no. 12, pp. 2270–2273. DOI: 10.3201/eid2512.191081

12. Bertherat E. Plague around the world in 2019. *Wkly Epidemiol. Rec.*, 2019, vol. 94, no. 25, pp. 289–292.

13. Popov N.V., Eroshenko G.A., Karnaukhov I.G., Kuznetsov A.A., Matrosov A.N., Ivanova A.V., Porshakov A.M., Lyapin M.N. [et al.]. Epidemiological and epizootic situation on plague in the Russian Federation and forecast for its development for 2020–2025. *Problemy osobo opasnykh infektsii*, 2020, no. 1, pp. 43–45. DOI: 10.21055/0370-1069-2020-1-43-50 (in Russian).

14. Reihm J.M., Vergnaud G., Kiefer D., Damdindorj T., Dashdavaa O., Khurelsukh T., Zöller L., Wölfel R. [et al.]. *Yersinia pestis* lineages in Mongolia. *PLoS One*, 2012, vol. 7, no. 2, pp. e30624. DOI: 10.1371/journal.pone.0030624

15. Adjaasuren Z., Tserennorov D., Myagmar J., Ganhuyag C., Otgonbayar D., Bayar T., Verzhutsky D.B., Ganbold D., Balakhonov S.V. Current situation in the natural plague foci of Mongolia. *Dal'nevostochnyi zhurnal infektsionnoi patologii*, 2014, vol. 25, no. 25, pp. 22–25 (in Russian).

16. Zhao S.-S., Pulati Y., Yin X.-P., Li W., Wang B.-J., Yang K., Chen C.-F., Wang Y.-Z. Wildlife plague surveillance near the China–Kazakhstan border: 2012–2015. *Transbound. Emerg. Dis.*, 2017, vol. 64, no. 6, pp. e48–e51. DOI: 10.1111/tbed.12603

17.Abdikarimov S.T., Ibragimov E.S., Egembergenov Ch.E. Current epizootic condition of natural plague foci in Kyrgyz Republic and measures aimed at provision of epidemiological welfare as regards plague. *Problemy osobo opasnykh infektsii*, 2018, no. 2, pp. 45–48. DOI: 10.21055/0370-1069-2018-2-45-48 (in Russian).

18.Verzhutskiy D.B. Activation of the plague natural foci in Central Asia: groundless apprehensions or a real threat. *Priroda vnutrennei Azii* (*Nature of inner Asia*), 2018, vol. 6, no. 1, pp. 7–18. DOI: 10.18101/2542-0623-2018-1-7-18 (in Russian).

19. Jones S.D., Atshabar B., Schmid B.V., Zuk M., Amramina A., Stenseth N.C. Living with plague: Lessons from the Soviet Union's antiplague system. *Proc. Natl. Acad. Sci. USA*, 2019, vol. 116, no. 19, pp. 9155–9163. DOI: 10.1073/pnas.1817339116

20. Kuznetsov A.A., Matrosov A.N., Porshakov A.M., Sludsky A.A., Kovalevskaya A.A., Toporkov V.P. Principles of cartographic differentiation and epidemiologic zoning of natural plague foci applied to assess and minimize population health risks. *Health Risk Analysis*, 2018, no. 4, pp. 96–104. DOI: 10.21668/health.risk/2018.4.11.eng

21.Verzhutsky D.B., Adiyasuren Z. Natural plague foci in Mongolia: annotated list. *Baikal'skii zoologicheskii zhurnal*, 2019, vol. 25, no. 2, pp. 92–103 (in Russian).

22. The Atlas of plague and its environment in the People's Republic of China. China, Science Press, 2004, 221 p.

23. Popova A.Yu., Kutyrev V.V., Balakhonov S.V., Ezhlova E.B., DeminaYu.V., Pakskina N.D., Shchuchinov L.V., Popov N.V. [et al.]. Coordination of measures of plague control institutions, aimed at rehabilitation and sanitation of Gorno-Altai high-mountain natural plague focus in 2016. *Problemy osobo opasnykh infektsii*, 2016, no. 4, pp. 5–10. DOI: 10.21055/0370-1069-2016-4-5-10 (in Russian).

24. Popova A.Yu., Balakhonov S.V., Shchuchinov L.V., Matrosov A.N., Mikhaylov E.P., Mishchenko A.I., Denisov A.V., Shefer V.V. [et al.]. Organization of plague control and prevention measures on the territory of Kosh-Agach district of the Altai Republic and estimation of their effectiveness. *Infektsionnye bolezni*, 2018, vol. 16, no. 4, pp. 5–15. DOI: 10.20953/1729-9225-2018-4-5-15 (in Russian).

25. Kadastr epidemicheskikh i epizooticheskikh proyavlenii chumy na territorii Rossiiskoi Federatsii i stran blizhnego zarubezh'ya s 1876 po 2016 god [Inventory of epidemic and episodic manifestations of plague in the territory of the Russian Federation and the neighboring countries from 1876 to 2016]. In: V.V. Kutyrev, A.Yu. Popova eds. Saratov, OOO «Amirit», 2016, 248 p. (in Russian).

26. Meka-Mechenko V.G., Sarayev F.A., Belyayev A.I., Kulemin M.V., Sazhnev Yu.S., Nauruzbaev E.O. The history of non-specific prevention of plague in the Republic of Kazakhstan and its current state. *Karantinnye i zoonoznye infektsii v Kazakhstane*, 2020, vol. 41, no. 2, pp. 23–38 (in Russian).

27. Verzhutski D.B., Nikitin A.Ya., Kovaleva N.I., Galatsevich N.F., Chumakova N.A., Tkachenko S.V., Chumakov A.V. Main results of preventive disinfestation measures in the Sagil valley (Tyva natural plague focus). *Dal'nevostochnyi zhurnal infektsionnoi patologii*, 2014, no. 25, pp. 18–22 (in Russian).

28. Balakhonov S.V., Schuchinov L.V., Mischenko A.I., Matrosov A.N., Denisov A.V., Rozhdestvensky E.N., Korzun V.M., Kosilko S.A. [et al.]. Organization of preventive, anti-epidemic actions to decrease risks of epidemic situation complications for plague in Republic Altai. *Zhurnal mikrobiologii, epidemiologii i immunologii*, 2018, no. 6, pp. 85–94. DOI: 10.36233/0372-9311-2018-6-85-94 (in Russian).

29. Ibragimov E.Sh. Non-specific prophylaxis in the Tien Shan high-mountain natural plague focus: past and present. *Problemy osobo opasnykh infektsii*, 2015, no. 4, pp. 18–21 (in Russian).

30. Shilova S.A. Biologicheskoe raznoobrazie i kontrol' chislennosti «problemnykh» vidov zhivotnykh: kompromissy, protivorechiya, perspektivy [Biological diversity and population control over "problematic" animal species: compromises, contradictions, prospects]. *RET-info*, 2005, vol. 56, no. 4, pp. 8–10 (in Russian).

31. Metzger M.E., Rust M.K. Laboratory evaluation of Fipronil and Imidacloprid Topical Insecticides for control of the plague vector *Oropsylla montana* (Siphonaptera: Ceratophyllidae) on California Ground Squirrels (Rodentia: Sciuridae). *J. Med. Entomol.*, 2002, vol. 39, no. 1, pp. 152–161. DOI: 10.1603/0022-2585-39.1.152

32. Nikitin A.Ya., Kardash A.I. Vozmozhnost' ispol'zovaniya nekotorykh piretroidov dlya profilaktiki chumy v prirodnykh ochagakh Sibiri suslikovogo tipa [The possibility of using some pyrethroids to prevent plague in natural foci of Siberian gopher type]. *Meditsinskaya parazitologiya i parazitarnye bolezni*, 2009, no. 4, pp. 42–44 (in Russian).

33. Burdelov L.A., Zhumadilova Z.B., Meka-Mechenko V.G., Sazhnev Yu.S., Akimbaev B.A., Saylaubekuly R., Abdukarimov N., Belyayev A.I. [et al.]. Results of three-year field testing of aerosolization of the great gerbil (*Rhombomys Opimus*) burrows with ultra-small doses of pesticides. *Karantinnye i zoonoznye infektsii v Kazakhstane*, 2014, vol. 29, no. 1, pp. 14–21 (in Russian).

34. Gorno-Altaiskii prirodnyi ochag chumy: Retrospektivnyi analiz, epizootologicheskii monitoring, sovremennoe sostoyanie [Gorno-Altai natural plague outbreak: Retrospective analysis, epizootological monitoring, current status]. In: S.V. Balakhonov, V.M. Korzun eds. Novosibirsk, Nauka-Tsentr, 2014, 272 p. (in Russian).

35. Yarygina M.B., Korzun V.M., Balakhonov S.V. Genotypical structuring of *Yersinia pestis* ssp. *altaica* in Gorno-Altai high-mountainous natural plague focus. *Dal'nevostochnyi zhurnal infektsionnoi patologii*, 2019, vol. 37, no. 37, pp. 86–87 (in Russian).

36. Singleton G.R., Leirs H., Hinds L.A., Zhang Z. Ecologically-based management of rodent pest: reevaluating our approach to an old problem. *Ecologically-based Rodent Management*, 1999, pp. 17–29.

Matrosov A.N., Chipanin E.V., Nikitin A.Ya., Denisov A.V., Mishchenko A.I., Rozhdestvensky E.N., Kuznetsov A.A., Popov N.V. Efficiency of disinsection and deratization aimed at reducing epidemiologic risks in Gorno-Altaiskiy high-mountain natural plague focus. Health Risk Analysis, 2021, no. 4, pp. 136–145. DOI: 10.21668/health.risk/2021.4.15.eng

Received: 25.08.2021
Accepted: 18.11.2021
Published: 30.12.2021