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Adaptation of bacteria in mountains: investigation of the relationship with background radiation and mountain landscape

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ABSTRACT

Purpose: Analysis of the influence of natural and anthropogenic background radiation on the variability of the causative agent of tularemia – the bacterium *Francisella tularensis* – in the mountainous landscapes of Armenia.

Materials and methods: Epizootic of tularemia in population of common vole (*Microtus arvalis*), PCR method, statistical methods, correlation and regression methods.

Results and discussion: A statistical analysis of the number of epizootics and the tularemia threshold revealed a correlation with the radiation dose absorbed by rodents and the altitude at which epizootics were localized. The analysis revealed a multi-year cycle of the common vole and tularemia bacteria. The reproduction of rodents is followed by a period of depression. During depression, the incidence of tularemia increases, and DNA structure can change. Under favorable conditions, a new reproductive cycle initiates in the rodent population, and a new subspecies can form in the bacterial community. In highlands, radiation background stimulates epigenetic mechanisms and genetic variability.

Conclusions: Factors affecting the variability and speciation of bacteria in the mountains are identified: the impact of γ -radiation on the epigenetic and genetic mechanisms of cells and the diversity of the mountain landscape influence bacterial speciation. Active bacterial reproduction occurs during the depression period of the rodent's long-term reproductive cycle.

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Introduction

The diverse environmental conditions in the mountains allow for the survival and reproduction of various species and subspecies of plants, animals, and insects, which are carriers and transmitters of microorganisms and ectoparasites. The terrain, rock diversity, flora, and fauna are all influenced by altitude. Altitude determines the viability and diversity of living organisms.

The mountains are home to many different pathogenic microorganisms, while in the valleys there are isolated outbreaks (Platonov et al. 2015; Myrtenäs et al. 2016; Popov et al. 2022; Manucharyan et al. 2023). It has been established that certain microbial foci can persist in soil for decades and centuries. Another form of microbial community existence is epizootics – animal populations in which pathogenic microorganisms live and reproduce. Epizootics are linked to the

soil microbiome (Myrtenäs et al. 2016). Microbes in epizootics are more susceptible to environmental influences when they travel with their hosts and vectors of various infections – animals, birds, and arthropods. Changes in environmental conditions lead to the death of some individuals and a reduction in the population (Danielyan et al. 2023; Manucharyan 2023). Due to biological adaptation mechanisms, part of the population changes and reproduces in new conditions.

A specific feature of the mountain landscape is the background radiation, which is formed by the radiation emitted by rocks, the spectrum and activity of which depend on their location. Rock radiation is supplemented by cosmic radiation and may include anthropogenic radionuclides Cs-137 (Pyuskyulyan et al. 2020). This creates variability in the radiation effects on microbes traveling with rodent hosts. Single-celled organisms are most susceptible to genetic

variation and speciation (Platonov et al. 2015), but the proximity of rocks to the earth's surface and mines increase the impact on the genetic variability and diversity of rodents (Manucharyan 2023), plants (Sadoyan 2013), and the risk of carcinogenesis in humans (Belyaeva et al. 2019).

Adaptation is associated with genetic variability (Korogodina et al. 2013), and speciation requires the reproduction of individuals (Koonin 2023). The main role in adaptation is played by epigenetic mechanisms that are induced by low doses of radiation (Mothersill and Seymour 2022). These are cellular communication signals – the so-called bystander effect – that influence gene expression. Epigenetic effects are often associated with quantum effects (Matarèse et al. 2023) that play a major role in cellular communication. The reproduction of mutants and speciation are linked to environmental diversity in the mountains.

Armenia is mountainous country, home to 350 bird species, 90 mammal species, 53 reptile species, 38 fish species, and eight amphibian species. One of the pathogenic microbes circulating in natural foci is the tularemia bacterium *Francisella tularensis*. Primary host of tularemia bacterium is the common vole *Microtus arvalis* (Manucharyan et al. 2023). Other small mammals and rodents, along with ectoparasites, are secondary carriers and transmitters of tularemia in nature.

Studies of the long-term cyclical patterns of microbes and small mammals have revealed similarities in their cycles. The first is a period of reproduction, during which external and internal factors do not cause damage; the second is a period of population aging and collapse, when structural changes and population decline occur. Then, the reproductive period returns (Korogodin 1964; Zhigalski and Troshin 2007). The cyclicity depends on the species. The external environment, particularly radiation, can influence variability, death and reproduction of the individuals.

The infection threshold for the tularemia pathogen in rodents characterizes the concentration of *F. tularensis* bacterial DNA in rodents. The tularemia bacterium primarily affects the lymphatic system, the eyes, and the lungs. The infection threshold for an epizootic is determined by quantitative PCR (qPCR) methods. The higher the PCR cycle threshold, the fewer bacteria are present in the sample. Increasing infection levels lower the tularemia threshold. An infection threshold of 20 or less is critical, identifying an active epizootic.

This article analyzes factors in Armenia's mountainous landscape that may lead to genetic changes and speciation in *F. tularensis* bacteria. The main environmental factors are the altitude of epizootic localization, which determines the landscape, and the background radiation of the area. Both of these mountainous landscape characteristics influence the incidence of epizootics and the infection threshold for epizootics with *F. tularensis*. The article discusses the main patterns of bacterial adaptation and speciation in the mountains.

Materials and methods

Research object

This study examined the occurrence and activity of tularemia epizootics in common vole (*Microtus arvalis*) populations in

different Armenian landscape zones. The causative agent of tularemia is the small gram-negative bacterium *Francisella tularensis*. The bacterium can persist in the natural environment in soil, grass, and animal carcasses. The study determined the abundance and density of common voles in control plots and the number of infected rodents. To document the genetic variability of the bacterium, the tularemia threshold in epizootics was determined.

25 active epizootic research sites

The sites were classified by altitude and radiation level. Geolocation was conducted using the GPS system, and radiation levels were determined using CENS data (Pyuskyulyan et al. 2020; Movsisyan et al. 2022). The sites can cover a large area and can be divided into three sectors based on altitude and radioactivity. The boundaries of sectors with minimum (min), maximum (max), and average ((min + max)/2) altitude and radioactivity were determined for 25 sites. The sector boundaries overlap: 1400–2680; 1840–3100; 1960–3560 m above sea level.

Calculation of absorbed dose rate

To analyze the relationship between the variability of bacterial cells and the γ -background, the authors determined the absorbed dose rate by living organisms. The study used methods described in ICRP (2017), the Program BiotaDC ver. 1.5.2 (a complement to ICRP Publication 136) allows to determine the absorbed dose rate of γ -radiation by radionuclides (Ra-226, Th-232, Cs-137) in the atmosphere and in soil by representatives of flora and fauna.

Common vole (*Microtus arvalis*) with bacteria community

The absorbed dose rate of external radiation of tularemia bacteria was determined for the common vole since low radiation exposure to a rodent will necessarily affect the bacterial community living in it. For a mammal, it is insignificant. In the highlands, the radiation of rocks and the human-generated radionuclide Cs-137 deposited in the soil of Mount Aragats because of the Chernobyl disaster and nuclear tests were taken into account. The absorbed dose rate of external exposure of the common vole was calculated using the formula (ICRP 2017):

$$D_{ext} = DC \times f \times A(2),$$

where D_{ext} is the absorbed dose rate of external exposure, mGy/day; DC is the dose coefficient, (μ Gy/h)/(Bq/kg) according to the Program BiotaDC ver. 1.5.2.; DC is the dose coefficient, μ Gy/h (ICRP 2017); A is the activity concentration of radionuclide, Bq/kg; f is the occupancy factor (0.5 over soil, 0.5 in soil). Calculation of the coefficient <http://biotadc.icrp.org/> for Common vole: head to body: 97–128 mm, tail: 27–44 mm, and weight: 22–67 g.

Trapping rodents and collecting samples

Rodent populations, primarily of the genus *Microtus* spp, were captured alive using Sherman traps for five days at each site. Sample types: blood, spleen, liver, and lymph node tissue were collected after euthanasia under sterile conditions. Ectoparasites (fleas, ticks) were also collected; they were preserved in 70% ethanol to screen for potential pathogens.

Detection of *Francisella tularensis*

DNA extraction was performed using Qiagen DNeasy Blood & Tissue Kits (Venlo, The Netherlands). Real-time PCR was used to detect the presence of *Fr. tularensis*.

Determination of correlation coefficients

The correlation coefficient R between the biological indicator (number of epizootics, tularemia threshold) and habitat data (altitude above sea level, radioactivity) was determined using the formula

$$R = \frac{\sum (x - x_m) * (y - y_m)}{\sqrt{\sum (x - x_m)^2 \sum (y - y_m)^2}}$$

where for each site, parameter x is the number of epizootics or the tularemia threshold; x_m is their average values across all sites. For each site, parameter y is the altitude or radioactivity; y_m is their average values. Summation is performed over all sites.

Partial correlation coefficient $r_{xy/z}$ between the indicators x , y , excluding the influence of the indicator z , is determined by the formula:

$$r_{xy/z} = \frac{R_{xy} - R_{xz} R_{yz}}{\sqrt{1 - R_{xz}^2} \sqrt{1 - R_{yz}^2}}$$

where R_{xy} , R_{xz} , R_{yz} are the correlation coefficients between the number of epizootics and altitude, the number of epizootics with radiation, the tularemia threshold with altitude, and the tularemia threshold with radiation.

Results

Tularemia outbreaks in mountainous landscapes

A large natural focus of tularemia is located in the southeast of Armenia, spread across four landscape-geographic zones: mountain-steppe, meadow-steppe, forest, and subalpine. The primary carrier of the tularemia bacterium *Fr. tularensis* is the common vole *Microtus arvalis*. Figure 1 (Table S1) presents the annual number of voles (1968–2022) per square kilometer of their habitat and the frequency of infection among them. The high number of voles in the period 1978–1990 is explained by extensive research conducted during this period. Changes in research methods do not disrupt the

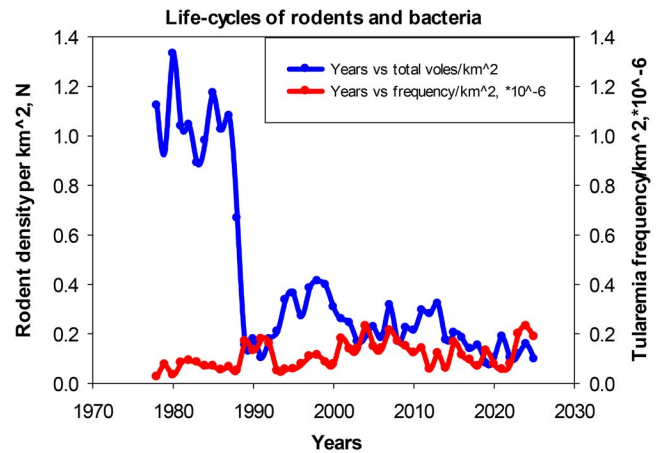


Figure 1. Rodent population density in Armenia N/km^2 and the frequency of n rodents infected with *F. tularensis* n/N . Registration years: 1978–2025. Total area of the highlands: $19,736 \text{ km}^2$. The x-axis: years of registration; y-axis (left): rodent density, N ; y-axis (right): frequency of tularemia infection, n/N . The high vole population in the period 1978–1990 is explained by a more detailed study of the area, which did not affect the frequency of rodent infections.

long-term cyclical pattern of reproduction, extinction, and infection of voles (13–14 years). Reproduction is followed by a period of depression and an increase in the frequency of tularemia incidents.

Environmental conditions in the mountain-steppe zone and highlands have different impacts on rodent numbers and incident rates. In the observed sites of the mountain-steppe zone, only isolated cases of tularemia epizootics have been reported. In the highland zone, new epizootics are being recorded (Manucharyan 2023), and the incidence of infected rodents is high.

Summary. The reproduction of rodents, the decline in their numbers and the incidence of tularemia are cyclical in nature. Extinction and infection of rodents follow the proliferation of the rodent population.

The relationship between mountain landscapes and radiation

Armenia is a mountainous country, with an altitude ranging from 340 to 4090 m above sea level. Figure 2 shows the location of epizootic control sites on a map of Armenia.

All epizootic areas located above 3000 m above sea level can be classified as highlands, and below 3000 m – as mountain-steppe zone. These zones correspond to the total radioactivity of Cs-137 + Ra-226 + Th-232 radionuclides in the mountainous landscape in the highlands $\text{Rad} > 480 \text{ Bq/kg}$ and in the mountain-steppe zone $\text{Rad} < 480 \text{ Bq/kg}$. Data on the altitude and background radiation for 25 epizootic areas are presented in Table S2. It shows the dependence of radiation activity on the altitude above sea level of epizootic foci (Figure 3(a)) and the correlation coefficient between radiation and altitude values (Figure 3(b)).

In the mountains, radiation varies due to the diversity of the landscape and the γ -spectrum of rocks, cosmic radiation and anthropogenic radionuclides Cs-137 (Pyuskyulyan et al. 2020; Movsisyan et al. 2022). The mosaic nature of the

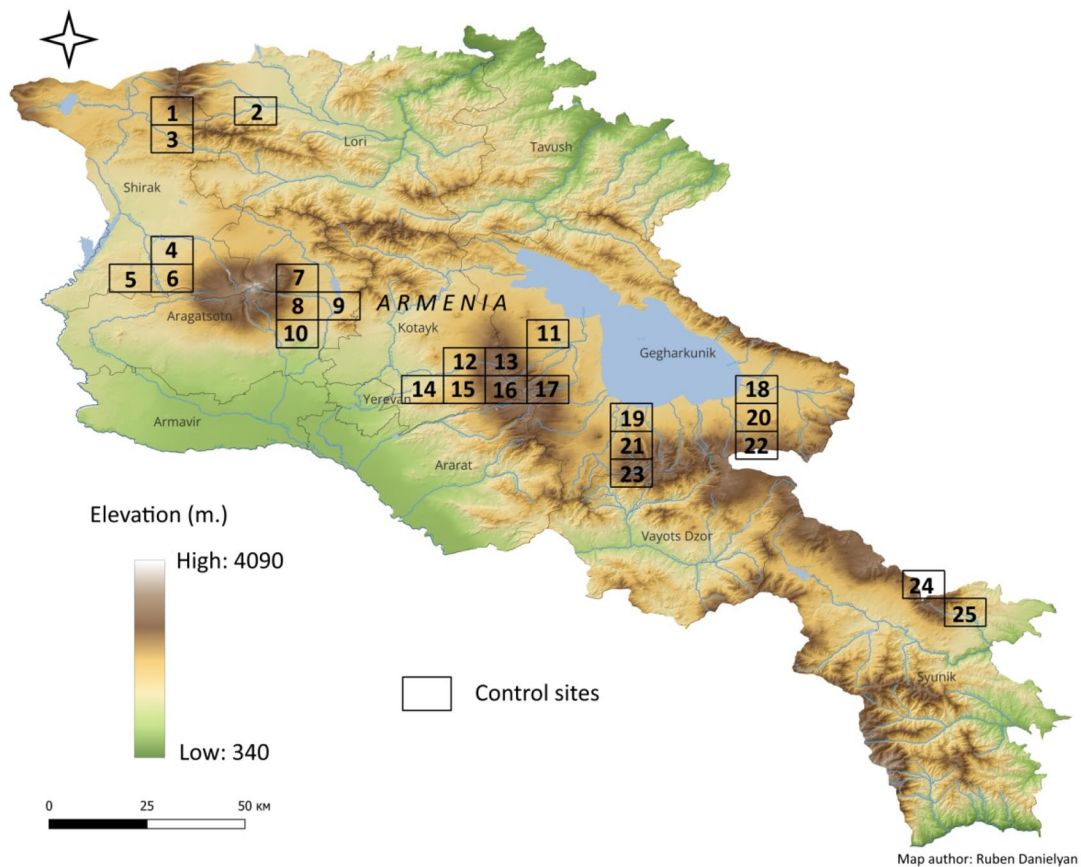


Figure 2. Location of control sites with epizooties in Armenia.

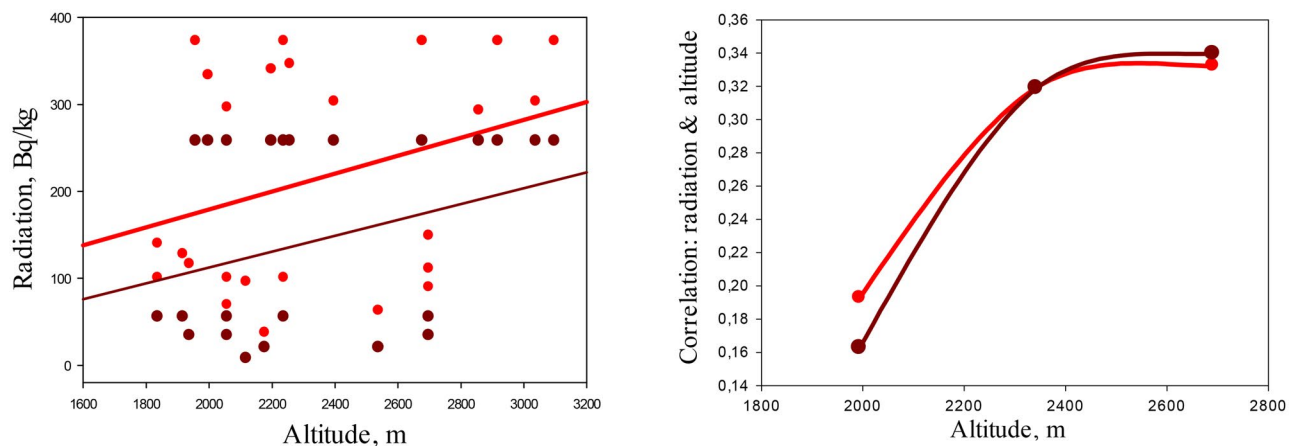


Figure 3. (a) Distributions of epizootic sites and their regressions. The x-axis is altitude; the y-axis is radioactivity. Points and curves: Cs-137 + Ra-226 + Th-232 – red; Cs-137 – brown. Linear regression, confidence interval: 95%. (b) Distribution of correlation coefficient of altitude and radiation. The x-axis is altitude; the y-axis is correlation coefficient. Points: min; (min + max)/2; max points and curves: Cs-137 + Ra-226 + Th-232 – red; Cs-137 – brown.

gamma background and the heterogeneity of radiation exposure in the mountains may be a factor in genetic variability. The number of epizootics in certain areas varies from 1 to 26, and their locations can span a wide range of mountain landscape variability (Figure 2). For this reason, the correlation coefficient between the altitude of epizootic localization and landscape radioactivity is no more than 0.41.

The highlands have a mosaic but stable distribution of radionuclides. Table 1 shows the minimum and maximum

radioactivity of the main radionuclides in the highlands (Pyuskyulyan et al. 2020; Movsisyan et al. 2022) and the absorbed dose rate of the vole with the bacterial population was calculated (ICRP 2017).

The absorbed dose rate by soil bacteria near the Metsamor NPP (Table S3) initiates the death, reproduction and mutagenesis of bacteria of different strains (Khachatryan et al. 2017). These data are consistent with laboratory experiments on the adaptive effects of weak radiation on cells (Bridgman

and Kimball 1954; Korogodin 1964; Korogodina 2026). The absorbed dose rate value by soil bacteria near the NPP is within the range of the average absorbed dose rate of voles in the highlands (Table 1). It can be assumed that the radiation background of the highlands also affects the structure of the genes of the vole bacteria.

Summary. The absorbed dose rate by the bacterial population near the Metsamor Nuclear Power Plant corresponds to the average absorbed dose rate of bacteria living on voles at high altitudes. It can be assumed that the background radiation at high altitudes also influences bacterial variability.

The influence of altitude and radiation in the mountains on the infection threshold and the number of epizootics

Epizootics at a single site can occur in highlands and mountain-steppe zones (Figure 2). These zones are distinct (Figure 3(b)) and epizootics can differ in their infection thresholds. The critical threshold is considered to be $Ct \leq 20$ cycles, when 80% of individuals are infected with tularemia;

a higher threshold indicates lower infection. Figure 4 shows the dependence of epizootic thresholds on altitude and radiation: in the mountains (a, d), in the mountain-steppe zone (b, e), and in the highlands (c, f).

In the mountain-steppe zone and at high altitudes, the low $Ct \leq 20$ threshold and the high $Ct > 20$ threshold change differently. The confidence interval widens in the mountain-steppe zone due to the variable localization of rodent epizootics (b, e). The low threshold $Ct \leq 20$ cycles appears only at an altitude of $h > 2600$ m (b) and becomes stable at high altitudes (c). The high threshold $Ct > 20$ cycles decreases with altitude at high altitudes (c). Radiation exposure is stable at high altitudes. The mosaic gamma background at high altitudes stimulates the occurrence of tularemia outbreaks, which widen the confidence interval of the regression graphs for both the low and high thresholds (f).

Table 2 shows the distribution of 122 epizootics by infection threshold in the highlands and mountain-steppe zone. The total number of epizootics N is higher in the observed high-altitude sites. In recent years, statistically higher epizootic intensity has been observed in high-altitude landscapes. Higher infection rates ($Ct \leq 20$ cycles) are observed in the highlands ($h > 3000$ m, $Rad > 480$ Bq/kg). The number of epizootics with low infection rates ($Ct > 20$ cycles) in the highlands of the high-altitude landscape ($h > 3000$ m) decreases ($N = 34$), while in the highlands of the radiation landscape ($R > 480$ Bq/kg) it increases ($N = 51$).

Table 1. Radiation landscape of the highlands.

	Averaged γ -activity, Bq/kg			Averaged absorbed dose rate, $\mu\text{Gy/h}$ ($\times 10^{-2}$)			
	Ra-226	Th-232	Cs-137	Ra-226	Th-232	Cs-137	Σ
3000–3500 m a.s.l., highland				Common vole and its bacteria community			
min	21.5	40.7	68.6	1.28	8.53×10^{-2}	1.49	2.85
max	70.1	97.6	445.7	4.16	20.4×10^{-2}	9.67	14.03

Cs-137 – fallout from Chernobyl.

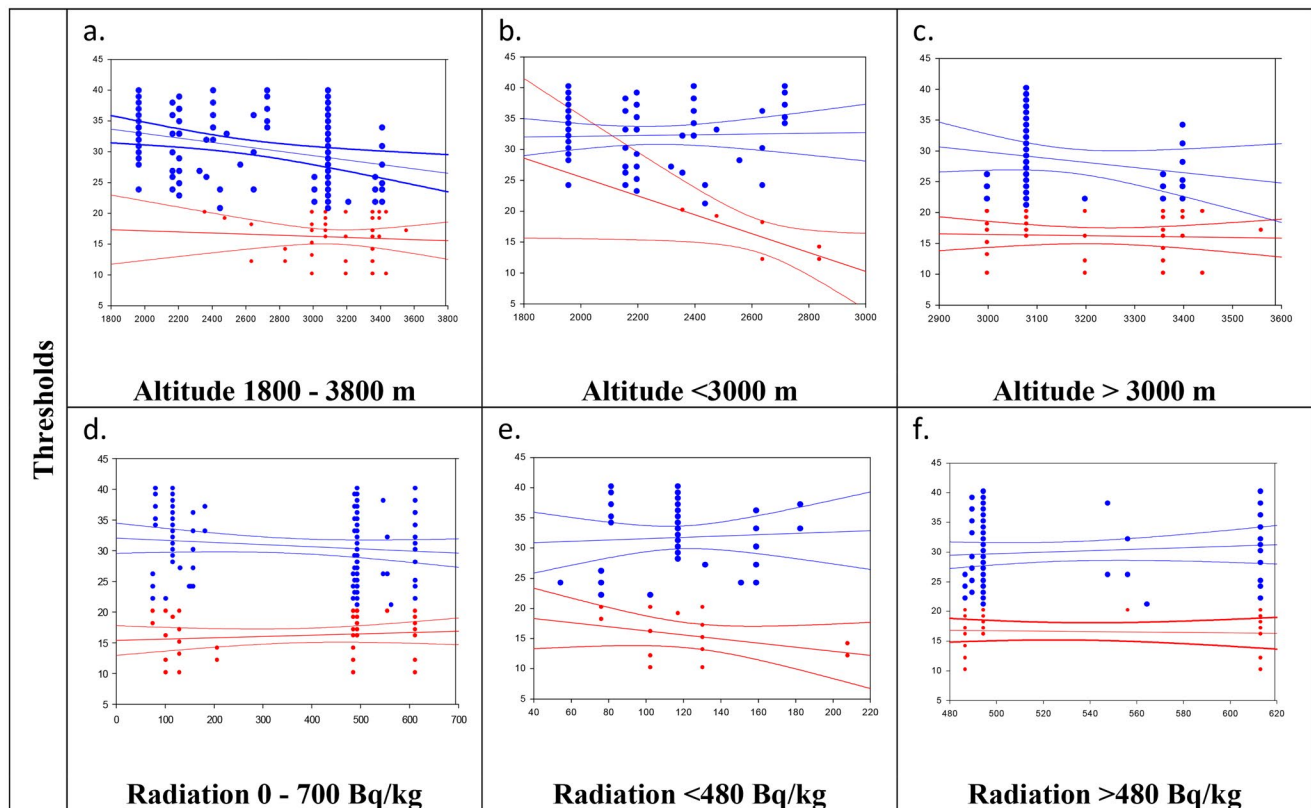


Figure 4. Dependence of tularemia threshold on epizootic localization in the mountain steppe zone and in the highlands. Thresholds and linear regression with confidence interval (95%): $Ct \leq 20$ (red); $Ct > 20$ (blue).

Table 2. Number of epizootics N with threshold C_t in the highlands and mountain-steppe zone.

Zone	Border	N	$N (C_t \leq 20)$	$N (C_t > 20)$
High-altitude landscape	$h > 3000$	64	30	34
	$h < 3000$	58	6	52
altitude above sea level, m				
Radiation landscape	$Rad > 480$	73	22	51
	$Rad < 480$	49	14	35
radiation, Bq/kg				
Total		122	36	86

The different dependence of the infection threshold (Figure 3) and the number of epizootics with low and high thresholds of tularemia on the altitude above sea level and background radiation indicate the independence of these factors of the mountain landscape.

Summary. Altitude and radiation landscapes in the mountains are independent and both are important for bacterial variability and speciation.

Low doses: epigenetic mechanisms and genomic changes

Adaptation induced by exposure to low doses of radiation is associated with epigenetic mechanisms and affects regulatory functions of the genome, including gene expression and the bystander effect (Mothersill and Seymour 2022; Chankova et al. 2023). Epigenetic mechanisms adapt cell populations to environmental changes (McCaw et al. 2020). These investigations suggest that low-dose irradiation will induce biophotonic communication and other epigenetic effects in soil bacteria near the Metsamor NPP (Table S3) and rodent bacteria in highlands (Table 1).

Armenian scientists who studied the impact of the Metsamor NPP on soil bacteria described cell communication in the soil (Khachatryan et al. 2017). They determined that the Cs-137 content in the top 5 cm soil layer was 14–19 Bq/kg (Table S3). Such radiation can damage individual bacterial cells and plant roots. However, proliferation and increased resistance in a subpopulation of one bacterial strain, and suppression of the population of another strain, have been observed. Mutations in plant branch cells have been recorded (Aroutiounian 2006), as the signal is transmitted from the roots to the shoots (Wang et al. 2012). In the atmosphere, signals can be transmitted between the cells of the leaves of the canopy (Gustova et al. 2016). It can be expected that the high-altitude radiation background will induce radiation effects in the bacterium *F. tularensis*, since the absorbed dose of soil bacteria near the ANPP $11.31 \times 10^{-2} \mu\text{Gy/h}$ (Table S3) corresponds to the range of the absorbed dose by the microbial community of voles in the highlands $(2.85\text{--}14.03) \times 10^{-2} \mu\text{Gy/h}$ (Table 1).

Another example from the life of a microbial community is that foci of tularemia bacteria in the soil persist for many decades (Manucharyan 2023). Outbreaks of new isolated and diffuse epizootics are being recorded in the observed sites of the highlands (Myrtenäs et al. 2016; Danielyan and Sahakyan 2019). According to scientific research, tularemia

outbreaks are associated with genetic changes (Kantardjiev et al. 2006; Myrtenäs et al. 2016; Kudryavtseva and Mokrievich 2022; Vodop'yanov et al. 2023). Tularemia outbreaks in the highlands can be caused by higher background radiation levels than in the valley, which stimulates genetic changes in bacteria. Through biophotonic communication, the entire bacterial community is modified (Khachatryan et al. 2017). Infections in rodent populations, outbreaks, and the emergence of new epizootics occur in the natural environment of the mountain landscape.

Summary. Gamma radiation stimulates epigenetic changes in cells, causing the bystander effect and genetic variability. Mountain altitude determines environmental diversity and bacterial survival.

Cyclicity of rodent populations, host–bacteria system

Between 1968 and 2022, several 13–14-year rodent and bacterial reproduction cycles were recorded (Figure 1). Initially, a period of rodent reproduction is observed, followed by a rapid decline, depression, and recovery. During the depression period, an increase in the incidence of tularemia-infected rodents is observed. After the depression, a new rodent reproduction cycle begins. This cyclical pattern in small mammals has also been observed in the Urals (Zhigalski and Troshin 2007). The close relationship between the rodent organism and bacteria suggests the involvement of epigenetic and quantum mechanisms in the system of organisms. An examination of the rodent/bacteria community (Figure 1) shows that the frequency of infection (occurrence of tularemia bacteria) in the rodent population depends little on rodent population density, but rather fits into the rodent mortality/reproduction cycle.

Summary. A unified cycle of rodent population growth and decline is observed, along with the tularemia bacteria. Regression analysis suggests a link between this system and the external environment: renewal of the rodent/bacteria system, and a decrease and increase in the tularemia threshold.

Discussion

Tularemia outbreaks

Soil tularemia outbreaks are maintained by biophotonic communication (Kantardjiev et al. 2006; Myrtenäs et al. 2016; Khachatryan et al. 2017). New outbreaks of bacteria appear infrequently in the observed sites of plains. Only isolated cases are known in these sites of the mountain-steppe zone of Armenia. In the lowland Srebarna Nature Reserve in Bulgaria, a tularemia outbreak arose with the introduction of the bacterium by a muskrat in 1962 and an outbreak of related tularemia strains occurred between 1997 and 2005 due to agricultural reforms. New epizootics and outbreaks of tularemia arise from genetic changes that are rare in a stable soil microbiome.

Tularemia bacteria in rodent epizootics are associated with a long-term reproductive cycle in rodent populations,

lasting 13–14 years (Figure 1). The long-term cyclicity of small mammal populations was also noted in the article (Zhigalski and Troshin 2007). It can be assumed that the constancy of the life cycle of a population is associated with its structure and the genetic stability of its organisms. During periods of population depression and aging, destruction and death of organisms occur under environmental influences and bacterial infections. The connection between the decline in vole populations and the increase in tularemia infection rates is evident in Figure 1. It can be hypothesized that a new reproductive cycle is initiated by genetic variation during population aging, as aging is accompanied by the production of oxidants (Gasch et al. 2000). This is facilitated by radiation exposure and infection. Oxidative stress always accompanies radiation exposure (Alexandrou and Li 2014). When a rodent dies, organic structures are destroyed and energy and substances are released that are used by bacteria. Oxidants and energy are factors necessary for genetic changes. The tularemia bacterial community can be considered as a factor renewing the rodent population, along with aging and radiation. During the reproductive period, the effects of infection and the environment do not alter the population structure. Similar effects have been established in cycles of division and depression in single-celled organisms (Bridgman and Kimball 1954; Korogodin 1964).

Summary. The analysis revealed a link between rodent population cycles and tularemia bacteria. Increased tularemia rates in rodent populations occur during the period of population aging and depression. A new reproductive cycle occurs after a period of aging and depression. Infection and mountain radiation alter genetic structures during depression.

Highlands: a place of genetic change and speciation in bacteria

Epizootics of tularemia among rodents often occur in the mountains (Myrtenäs et al. 2016; Kudryavtseva et al. 2018; Danielyan et al. 2023; Manucharyan et al. 2023), especially in the highlands. It can be assumed that the cause of the genetic variability of bacteria and the emergence of new foci of tularemia in high altitude areas is the background radiation, which includes γ -rays from rocks, cosmic radiation, and anthropogenic radionuclides Cs-137 (Arakelyan et al. 2023; Korogodina et al. 2024). Low doses of radiation adapt populations by stimulating epigenetic mechanisms and cellular communication. The diversity of adaptation mechanisms and the wide range of epizootic localizations across the study sites (Table 1) explain the increased incidence of low-threshold and high-threshold epizootics (Table 2), along with their low correlation with radiation and altitude (0.4).

In the mountains, background radiation and the diversity of the mountain landscape facilitate the variability and proliferation of new bacterial species and subspecies. High-altitude radiation activates the bystander effect of microbial cells, epigenetic mechanisms, and genetic variability. The diversity of the mountain landscape facilitates the survival and proliferation of microbial cells. With global warming, carriers and vectors of microbes migrate uphill

(Popov et al. 2022; Danielyan et al. 2023). Close contact between animals increases the connectivity of bacterial communities.

Summary. The high-altitude radiation background preserves and activates foci of tularemia in the soil, lowers the infection threshold for epizootics, and regularly causes outbreaks of tularemia.

Basic patterns of variability and speciation in bacteria

An analysis of the dependence of the infection threshold and the incidence of epizootics on altitude and background radiation in epizootic areas allows us to identify the main environmental factors that contribute to the variability and speciation of microbes in the mountains. The mountain environment is highly diverse and influences bacterial variability.

The primary factor initiating genetic modifications in tularemia bacteria is high-altitude radiation. High-altitude radiation levels are the cause of tularemia outbreaks and the emergence of new foci, as they stimulate epigenetic and genetic variability. Gamma radiation stimulates biophotonic cellular communication, which adapts cellular function. This facilitates cellular communication in tularemia outbreaks, thereby lowering the infection threshold in rodent epizootics. Soil radiation stimulates cellular communication, preserving microbial populations and communities in tularemia outbreaks.

The second essential environmental factor is the mountainous landscape. In a diverse environment, Darwinian selection takes place, organisms reproduce, and new bacterial species and subspecies with altered virulence emerge (Smirnova et al. 2020).

Summary. In the mountains, background radiation, which stimulates epigenetic mechanisms and cellular communication, is a factor in bacterial genetic variability. Low doses of background radiation adapt the cell population. The diversity of the mountain landscape is a factor in the survival and reproduction of new species and subspecies.

Conclusions

We can identify the main factors that influence and maintain the microbial community in the soil and during epizootics. Biological factors include epigenetic mechanisms and biophotonic signaling, which maintain the microbial community in the soil for many years. The external environment is unstable, so epizootics among carriers and vectors of the *F. tularensis* bacterium are more variable but remain associated with soil foci. The reservoir and biological carriers of the tularemia pathogen in Armenia are small mammals, as well as blood-sucking arthropods parasitizing them, which ensure the circulation and transmission of *Francisella tularensis* in natural foci.

The general multi-year population cycle of rodents, including those that cause tularemia, is 13–14 years (Figure 1). This cycle consists of a reproductive period and a period of depression. Rodents are constantly exposed to radiation and

infections, but during aging and population depression, radiation-induced changes can lead to structural damage, and the bacterial community rapidly proliferates. These processes lead to the death of the rodents. A new reproductive cycle then begins. It can be assumed that this new reproductive cycle involves genetic changes in the organisms of both microbes and rodents. The radiobiologists have observed these processes of radiation exposure on microbes (Bridgman and Kimball 1954; Korogodin 1964).

Tularemia outbreaks and new foci are indicators of genetic changes of bacteria; they often occur in highland, where background radiation in the mountainous landscape is variable (Table 1) and promotes bacterial genetic variability. Outbreaks expand the confidence interval for the regression of tularemia thresholds at highlands (Figure 4(c,f)). Background radiation also stimulates communication between cells, contributing to a decrease in the infection threshold in epizootics with a threshold of Ct >20. The diversity of the mountainous landscape implements Darwinian selection for effective mutations in the external environment. Thus, background radiation and the mountainous landscape are environmental factors in the variability and speciation of bacteria in the mountains. Biological factors in cellular variability are epigenetic mechanisms and biophotonic signaling, which maintain the microbial community in the soil and in the rodent body.

In the future, it would be advisable to conduct a molecular analysis of tularemia bacteria during the depression period. We hypothesize that during this period, genetic changes occur and the microbes multiply.

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Author contributions

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Data availability statement

F. tularensis strains are housed in the living culture museum of the reference laboratory at NCDPC; all carrier and vector samples, as well as field and laboratory research databases, are stored in the NCDPC Laboratory of Epizootiology of Natural Foci of Infection Diseases.

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