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REVIEW

Adaptation to mountain γ-background: bacteria speciation

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ABSTRACT

Purpose: To study the adaptation of bacteria to the natural γ-background of mountains and anthropogenic emissions from nuclear power plants; to establish the main factors of variability and speciation of bacteria.

Method: Analysis of materials on the radiation background and its impact on living organisms in the landscape of Armenia, calculation of the absorbed dose by microbes due to rock radiation.

Results: The review shows the death, reproduction, radioresistance and speciation of bacteria in changing conditions of low variable natural and anthropogenic γ-background.

Conclusion: We assume that γ-rays from rocks activate cellular epigenetic mechanisms that regulate genome expression, signaling and, ultimately, variability of bacteria. Some of them have already been studied, others require research.

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Climate change; bacteria; migration; rodent accumulation; mountains; γ-background; natural radiation; human-generated radiation; epigenetic mechanisms; speciation

Introduction

Adaptation to environmental changes entails intracellular changes and possible movements to a more comfortable environment. Adaptation processes are associated with structural changes, diversity, reproduction, and death, which can be observed at all levels of life (Korogodina et al. 2013, 2016).

Global warming means higher average temperatures and rainfall droughts, and floods. Populations of animals, birds, and arthropods change their habitats; many will end up in the mountains. Bacteria move along with their carriers and vectors. Changes in environmental conditions affect population size (Danielyan et al. 2023). By 2070, over 3,000 mammal species are projected to change habitats (Carlson et al. 2022). There are shifts in the distribution and reproduction of insect populations. Warming affects the size of green leaves (Joswig et al. 2022) and leads to the spread of pests and the extinction of plants.

Changing environmental conditions and close contacts of different species contribute to genetic variability and the formation of new strains of microbes. Presumably, the SARS-CoV-2 coronavirus arose because of the resettlement and accumulation of many species of bats, carriers of coronaviruses, in new habitats (Beyer et al. 2021). So it was the origin of the plague bacillus *Yersinia pestis* from *Yersinia pseudotuberculosis* (Martínez-Chavarría and Vadyvaloo 2015), as well as observed in the spread of anthrax bacteria (Shakirzhanova et al. 2022).

A significant correlation is found between the abundance of the common vole and the activity of epizootics *F.tularensis* (Manucharyan 2023). The population density of microbial carriers contributes to their expansion and increases the activity of epizootics, expressed in the number of isolated bacterial strains. A periodic sharp increase of rodents (every 3–4 years) leads to wide diffused epizootics. The heterogeneity of cultures isolated in foci is increased in diffused foci (Kudryavtseva and Mokrievich 2022; Vodop'yanov et al. 2023). The strains differ in several specific single nucleotide substitutions and deletions (Kudryavtseva and Mokrievich 2022). The standard mechanism is visible here: increased population density, speciation, population growth and extinction. It usually works with environmental variability and is joined with epigenetic mechanisms.

The relationship between environmental conditions and genetic variability is obvious in mountain landscapes, where the radiation of rocks contributes to the formation of foci of pathogenic bacteria (Shagjjamba and Zuzaan 2006; Platonov et al. 2015), especially with climate change (Abakumov et al. 2022; Popov et al. 2022). The natural radiation background in the

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mountains is varied, as it is created by rocks containing ^{38}U, ^{232}Th, and ^{40}K (Pyuskyulyan et al. 2019; Abakumov et al. 2022).

Ionizing radiation always affects cells directly on DNA macromolecules or indirectly, inducing ROS through effects on various pathways, proteins, etc. (Gasch et al. 2000; Ragu et al. 2007; Hamanaka and Chandel 2010; Azzam et al. 2012). Radiation exposure leads to resistance or variability in unicellular bacteria (Byrne et al. 2014), as well as in Drosophila (Zarubin et al. 2021), animals, and plants (Korogodina et al. 2013, 2016).

Low doses of radiation initiate epigenetic mechanisms in cells (Mothersill and Seymour 2005, 2022; Mothersill et al. 2019). Epigenetic mechanisms control the bystander effect - cell signaling that stimulates gene expression. The dominant signal and the intracellular environment determine the final cell response (Mothersill et al. 2022a). The bystander effect expands the area of radiation risk and creates genomic instability in irradiated and non-irradiated cells. Signals are transmitted by different molecules (Du et al. 2020) and physically by photons emitted by irradiated cells (Gurwitsch 1988; Cohen et al. 2020). As a result of irradiation, physicochemical changes occur in atoms, accompanied by electromagnetic signals (Mothersill et al. 2022a).

In the mountains, rocks are a constant source of radiation background; their mosaic distribution creates an uneven γ-background (Arakelyan et al. 2023). Cosmic γ-rays and anthropogenic ^{137}Cs increase the intensity and diversity of the mountain radiation landscape. Gamma-ray background can represent a probabilistic distribution of γ-quanta (photons) or electromagnetic (EM) radiation. The highest dose rates can lead to genetic damage. Lower doses involve epigenetic mechanisms, signaling pathways, protein adaptation, and gene expression. The energy spectrum of the γ-background is diverse and variable, which leads to uncertainty in the adaptive response of the cell. The influence of background radiation in the mountains on the speciation of unicellular organisms (Platonov et al. 2015), plants (Sadoyan 2013), rodents (Manucharyan 2023), and carcinogenesis in humans (Belyaeva et al. 2019) is known.

The purpose of the review is to study the adaptation of bacteria in the mountains caused by rodent migration and to establish the main factors influencing the variability and speciation of bacteria. The variability of the environment in the mountains is represented by the variability of γ-spectra, which affects the structure of cells. Rodent population density promotes intercellular signaling. Epigenetic mechanisms of the cell regulate bacterial adaptation.

To study the effects of natural and anthropogenic radionuclides on cells, we chose single-cellular bacteria, tularemia, and the mountains of Armenia. Armenian scientists conducted most of the research on dosimetry and radioecology presented in the article.

Methods and calculation of absorbed dose rate

The material for investigations

To study the adaptation of bacteria in the radiation landscape of Armenia, we used data on the movement of rodent epizootics into the mountains (Danielyan et al. 2023), as well as studies of the variability of soil bacteria (Khachatryan et al. 2017) and of low-growing Tradescantia plants (Aroutiounian 2006) in the surrounding area of the Armenian Metsamor Nuclear Power Plant (ANPP). The results and methods for studying the epizootics and variability of soil bacteria and plant cells are published in their articles.

Armenian scientists have studied the radiation background caused by rocks and deposits of ^{137}Cs radionuclide in the soil after the Chernobyl accident and nuclear tests (Pyuskyulyan et al. 2019; Movsisyan et al. 2022); natural cosmic γ-radiation (Chilingarian et al. 2022); emissions from the Metsamor ANPP (Aroutiounian 2006; Khachatryan et al. 2017). Their results, methods, and standard errors are published in their articles.

Calculation of absorbed dose

To analyze the relationship between the variability of bacterial and plant cells and the γ-background, the authors determined the absorbed dose 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 of γ-radiation by radionuclides (^{226}Ra, ^{232}Th, ^{40}K, ^{137}Cs) in the atmosphere and in soil by representatives of flora and fauna.

Statistical methods

The standard deviation (Stddev) of the calculated absorbed dose exceeds the standard errors due to great differences in the γ-spectra of the rocks. We determined the Stddev of absorbed dose, taking into account the minimum and maximum radiation activity in highlands published in Pyuskyulyan et al. (2019):

$$\sigma = \sqrt{\left(\left((a-\mu)^2 + (b-\mu)^2\right)/2\right)} \qquad (1),$$

where σ is the Stddev of absorbed dose, μ is the average absorbed dose, and a and b are the minimum and maximum absorbed doses. Thus, the standard deviation varies from ±(50–60)% in the soil to ±(20–35)% above the soil. Radiation activity in the three regions of the Ararat Valley differs little (Table 1), and we assume that Stddev of the average absorbed dose in the Ararat Valley does not exceed that in the highlands of Aragats. We represent the radiation landscape in terms of average absorbed dose values to understand possible ways in which γ-background influences speciation.

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 on it. For a mammal, it is insignificant. In the highlands, the radiation of rocks and the

Table 1. Averaged γ-activity and absorbed dose of natural and human-generated radiation in Armenia.

Averaged γ-activity, Bq/kg				Averaged absorbed dose, μGy/h (x10^{-2})				
^{226}Ra	^{232}Th	^{40}K	^{137}Cs	^{226}Ra	^{232}Th	^{40}K	^{137}Cs	Σ*
Aragats, 3000–3500 m. a.s.l., highland[a]				Common vole and its bacteria community				
31.0	30.0	371.0	62.0	1.84	6.29×10^{-2}	2.00	1.35	5.63[e]
				Soil bacteria community				
31.0	30.0	371.0	62.0	2.73	9.20×10^{-2}	3.00	1.89	7.71
Aragats, 1000 m. a.s.l., Ararat Valley[b]				Common vole and its bacteria community				
62.0	45.0	654.0	12.0	3.68	9.43×10^{-2}	3.53	0.26	7.56
Ararat Valley, 3-5 km from the ANPP[c]				Tradescantia plant population				
62.0	45.0	654.0	19.4	2.02	5.13×10^{-2}	1.92	0.22	4.21
Ararat Valley, 2.5 km from the ANPP[d]				Soil bacteria community				
62.0	45.0	654.0	14.0	5.46	0.14	5.28	0.43	11.31

*Σ: natural + human-generated + cosmic γ-rays. The range of changes in the total absorbed dose is 20%–50%.

[a] Movsisyan et al. (2023); Pyuskyulyan et al. (2019)

[b] Aroutiounian et al. (2006)

[c] Khachatryan et al. (2017)

[d] Chilingarian et al. (2022).

human-generated radionuclide ^{137}Cs deposited in the soil of Mount Aragats because of the Chernobyl disaster and nuclear tests were taken into account (Table 1). The absorbed dose rate of external exposure of the common vole was calculated using the formula (ICRP 2017):

$$\mathrm{Dext} = \mathrm{DC} \times f \times A \qquad (2),$$

where Dext – absorbed dose rate of external exposure, mGy/day; DC – dose coefficient, (μGy/h)/(Bq/kg) according to the Program BiotaDC ver. 1.5.2; A – the activity concentration of radionuclide (Table 1), Bq/kg; f – occupancy factor (0.5 over soil, 0.5 in soil). Average characteristics of common vole: weight 0.045 kg, height 0.1 m.

The number of cosmic γ-rays was determined on Aragats using a NaI spectrometer (Chilingarian et al. 2022). Every second, two γ-quanta with energies $E > 300$ keV passed through one cm^2 of the spectrometer. Therefore, two γ/cm^2 per sec $\approx 3.45\times10^{-10}$ J/h. The absorbed dose rate for common vole is 7.6×10^{-5} μGy/h. The rodent spends half the day underground, so the absorbed dose rate in air is 3.8×10^{-3} μGy/h. The total dose absorbed rate by a rodent of natural radiation from rocks, human-generated ^{135}Cs, and cosmic γ-rays is 5.63×10^{-2} μGy/h (Table 1).

The absorbed dose rate was determined for the common vole in the Ararat Valley by the methods (ICRP 2017). Rock and human-generated radionuclide activity concentrations are considered in the Ararat Valley at 1000 m above sea level (m a.s.l) (Table 1).

Soil bacteria

The absorbed dose rate for the soil bacteria was determined by the methods (ICRP 2017). The radionuclide activity concentrations of rocks in the Ararat Valley at an altitude of 1000 m a.s.l., 2.5 km from the nuclear power plant (ANPP), and the deposition of emissions from the Metsamor ANPP were taken into account (Table 1). We assume that the total mass of microorganisms in 1 kg of soil in the upper 5 cm layer is no more than 0.0002 kg.

Terrestrial plant

The absorbed dose rate of terrestrial plants (Tradescantia) is determined by the same methods (ICRP 2017) for terrestrial flora. The radionuclide activity concentrations of rocks (1000 m a.s.l. Ararat Valley, 3–5 km from the ANPP) and the deposition of emissions from the Metsamor APP were considered (Table 1). The absorbed dose rate was calculated for an herb layer with a 13.7 kg/m^3 density. External source exposure was considered in the upper 10 cm of soil and 1.0 m above the ground.

Investigations

Migration in the mountains

Most of the populations find their place in the mountains. In the mountains, the activity range of natural radionuclide concentrations and the absorbed dose rate vary widely. The absorbed dose rate depends on the organism and its habitat (ICRP 2017); in the mountains, the indicator approaches the upper value of the world average (Shagjjamba and Zuzaan 2006; Asvarova et al. 2012; Yordanova et al. 2015). In some countries, the human-generated radionuclide ^{137}Cs, a product of nuclear tests and accidents at nuclear power plants, is present in mountainous areas (Pyuskyulyan et al. 2019).

Radiation is a powerful variability factor; therefore, mountains are a source of diversity for unicellular organisms, including pathogenic bacteria. In the mountains, natural foci of plague are active in the Caucasus and Gorny Altai (Popov et al. 2022) and the Mongolian Altai Mountains (Platonov et al. 2015). In Bulgaria, active tularemia foci are located in the Balkans and the Pyrin Range (Myrtennäs et al. 2016); in Armenia, tularemia epizootics are recorded in the Aragats mountains and Syunik region (Danielyan et al. 2023).

In Armenia, global climate change is affecting the expansion of arid desert and semi-desert lands. Rodents migrate from the most densely populated areas of the meadow-steppe and lower subalpine belt to cooler places up the mountain slope by 250–400 m (Danielyan et al. 2023). The range of the common vole, a carrier of tularemia, plague, and other diseases, is predicted to shrink (Figure 1(a and b)). Environmental factors determine the abundance of voles (Zhigalski and Kshnyasev 2000; Dragomirov 2009).

Because of migration into the cool, barren highlands, vole populations have increased in density. Isolated cases of voles with tularemia have been recorded in the hot mountain-steppe belt, but no epizootics have been recorded. Diffuse and local epizootic foci are concentrated at an altitude of 1850–3300 m a.s.l. of Mount Aragats, along the Geghama and Karabakh ridges (Danielyan and Sahakyan 2019) (Figure 2). With an increase in temperature, the abundance of carriers of the plague bacillus *Yersinia pestis*, which are the girds *Meriones vinogradovi* and *Meriones persicus*, and their specific fleas *Xenopsilla conformis* and *Ctenophtalmus iranus* in the

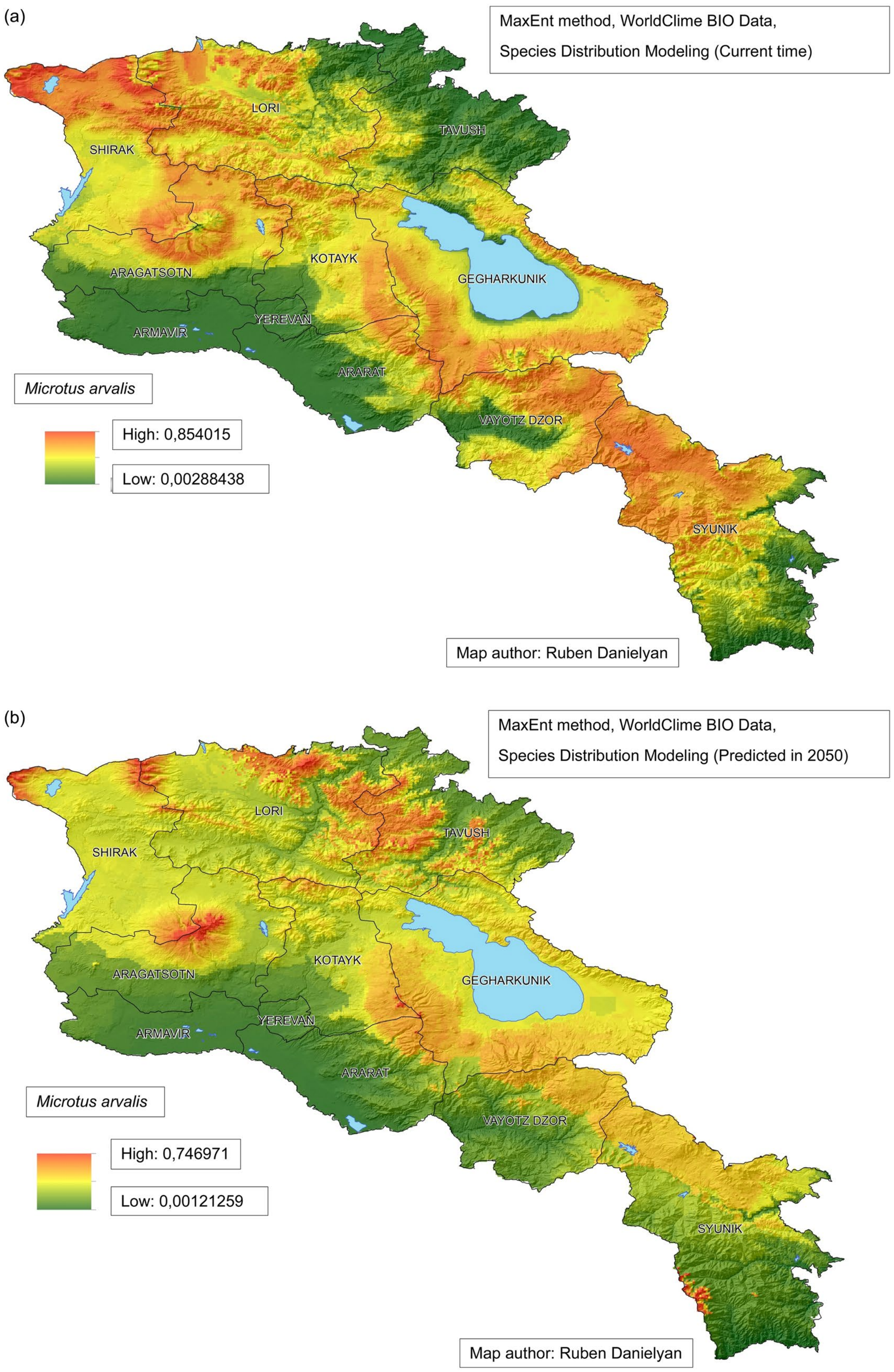

Figure 1. (a) Model (SDM, spatial distribution models, MaxEnt) of the distribution of the common vole (*Microtus arvalis*) using current climate data in Armenia (Danielyan et al. 2023). (b) Model (SDM, spatial distribution models, MaxEnt) of the distribution of the common vole (*Microtus arvalis*) using future climate data (2050) in Armenia (Danielyan et al. 2023).

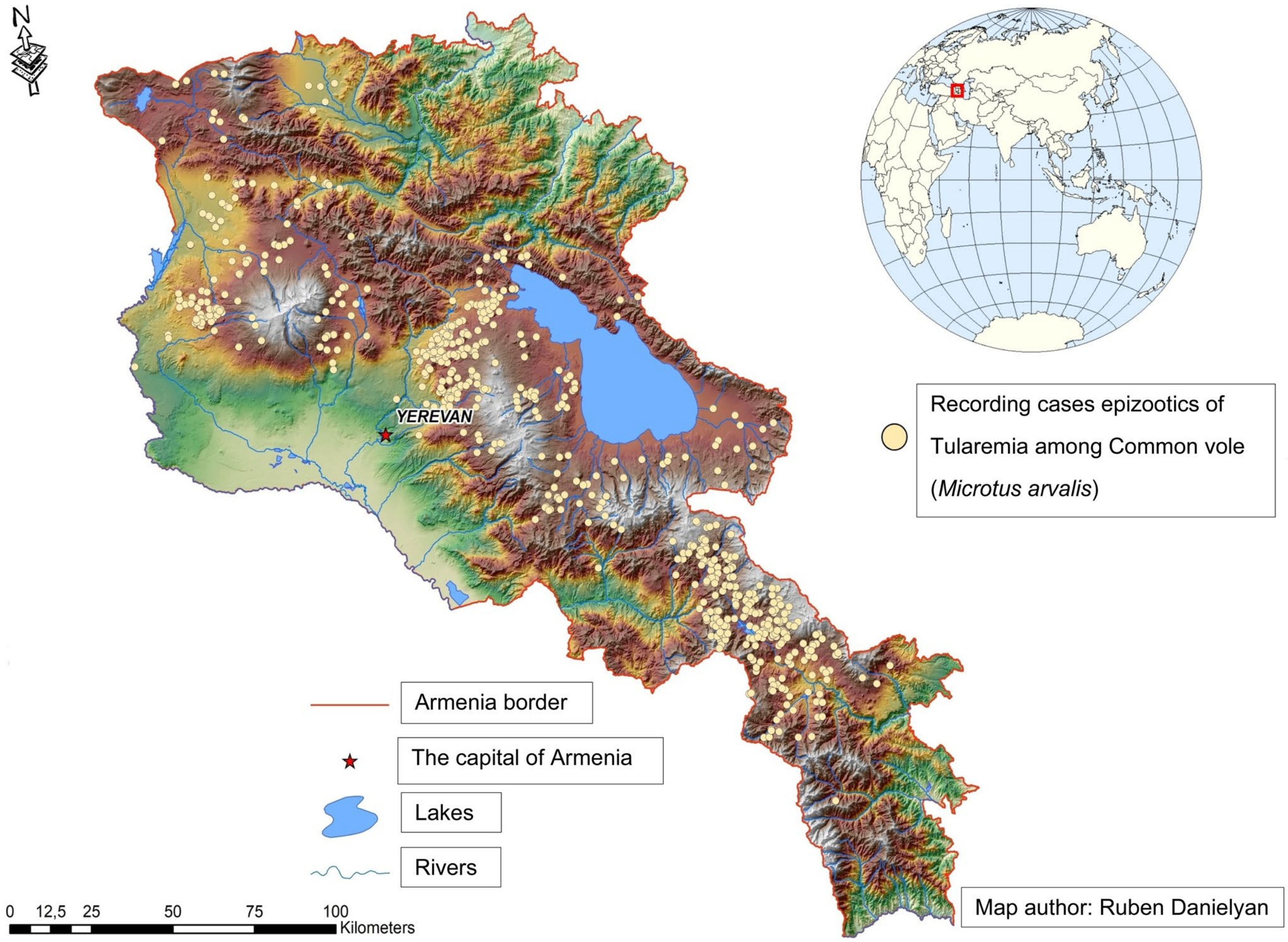

Figure 2. Map of the distribution of tularemia epizootics in Armenia from 1981 to 2017 (Danielyan and Sahanyan 2019).

Armenian dry mountain-steppe and semi-desert zones, decreases (Manucharyan et al. 2023). Plague foci are moving into the mountains of the Caucasus and the Altai Mountains (Popov et al. 2022).

Warming has moved epizootics to the mountains, while population densities have increased and the number of rodents has decreased.

Radiation background in the armenian landscape

The mountain landscape is varied, with large differences in altitude. Scientists of the Center for Econospheric Studies of Armenia studied the radiation activity of the soil and the fallout of the human-generated radionuclide ^{137}Cs on the slopes of Mount Aragats and in the Ararat Valley (Belyaeva et al. 2019; Pyuskyulyan et al. 2019; Movsisyan et al. 2022). Cosmic radiation is studied by scientists from AANL(YerPhI) in Aragats (Chilingarian et al. 2022). The diversity of the radiation landscape is described in the article (Arakelyan et al. 2023).

Modern methods (UNSCEAR 2000) make it possible to determine the range of variability of the absorbed dose rate of natural radionuclides for biota (Table 1). In Armenia, it exceeds the average values around the world (Belyaeva et al. 2019). A feature of the Armenian landscape is the presence of the ^{137}Cs radionuclide, registered after nuclear weapons tests (1957) and the accident at the Chernobyl NPP (1986). The radionuclide ^{137}Cs is deposited in the soil, and its content depends on the height a.s.l. (Belyaeva et al. 2019; Movsisyan et al. 2022). The absorbed dose rate gradually decreases toward the foot of Mount Aragats from 1.35×10^{-2} to 2.60×10^{-3} μGy/h (Table 1). The Armenian NPP is located in the Ararat Valley, and variations in its emissions do not exceed, on average, the natural radiation background of Armenia ($0.1-0.2$ μGy/h) (Pyuskyulyan et al. 2019). The maximum value content of ^{137}Cs in soil was determined at a distance of 2.5 km (Khachatryan et al. 2017). The cosmic γ-background at an altitude of 3000–3500 m a.s.l. is approximately 0.38×10^{-2} μGy/h (Chilingarian et al. 2022); it is taken into account in the general level of radiation in the atmosphere in the highlands. Table 2 and Figure 3 show the energy spectra of the main natural radionuclides and cosmic rays in the highlands of Aragats.

The radiation landscape of Armenia is diverse due to different sources of γ-rays. The main component is the natural background of rocks. All sites have different γ-spectra due

Table 2. Energy of γ-background of highlands of Aragats.

	^{226}Ra	^{232}Th(^{212}Pb)	^{40}K	^{137}Cs	Cosmic rays
Energy, γ-rays, Kev	186	239 (43.3%)	1460	661	>300
Absorbed dose, μGy/h ($\times10^{-2}$)	1.84	6.29×10^{-2}	2.00	1.35	≤0.38

*Cosmic rays: isotopes ^{214}Pb: ~300 keV (54.3 %) and ^{214}Bi: 609 keV (44.8%) of the uranium-radium chains.

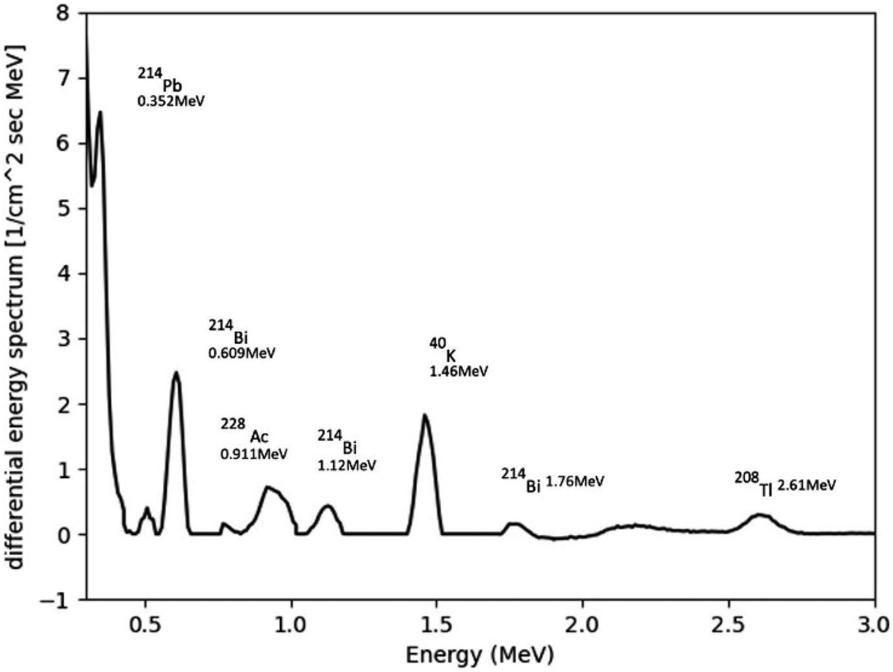

Figure 3. Natural γ-rays differential energy spectrum. Cosmic ray division, AANL, Aragats (Chilingarian et al. 2022).

Table 3. Data on total number of microorganisms in 1 g of dry soil in the direction of action of the wind rose (method accuracy 5–10%).

Region	Distance from ANPP, km	^{137}Cs activities in soil, Bq/kg	Total number of microorganisms in 1g of soil, ($\times10^7$)
Oshakan*	17	63.0	1.34
Aghavnatun	10	16.2	2.30
Aragats	5	16.5	2.29
Tsaghkunk	2.5	15.9	2.39
ANPP	0	17.8	2.39
M-1**	2.5	20.3	2.63
Metsamor**	5	19.4	2.71
Mrgashat	10	15.7	2.51
Nor Armavir	17	14.06	2.33
t. Vedi	57	16.2	2.37

*^{137}Cs deposition due to Chernobyl accident

**^{137}Cs deposition due to ANPP emissions.

Table 4. Data on the quantitative content of radiosensitive bacteria of the genus *Pseudomonas* and radioresistant bacilli *B.mesentericus* in the direction of predominant wind movement. Increasing the radioresistance (D_0) of radiosensitive bacteria *P.fluorescens*.

Region	^{137}Cs activities in soil, Bq/kg	Number of colony-forming cells *B.mesentericus* in 1g soil ($\times10^5$)	*Pseudomonas* in 1g soil, ($\times10^6$)	Radioresistance D_0, bacteria *P. fluorescens*
Oshakan*	63.0	2.0	3.0	14.0
Aghavnatun	16.2	3.8	5.0	11.0
Aragats	16.5	4.1	5.6	11.0
Tsaghkunk	15.9	4.0	3.5	11.0
ANPP	17.8	2.0	3.8	11.0
M-1**	20.3	1.4	1.6	12.5
Metsamor**	19.4	1.5	2.0	11.0
Mrgashat	15.7	1.8	4.1	11.0
Nor Armavir	14.06	2.2	5.0	11.0

*^{137}Cs deposition due to Chernobyl accident

**^{137}Cs deposition due to ANPP emissions.

to differences in natural radionuclides. Radionuclides have different energy γ-rays and affect the cell differently. Cell changes depend on the radionuclide energy spectrum and its γ-ray quality (Korogodin et al. 1996).

Epigenetic adaptation mechanisms in the Ararat Valley

In the Ararat Valley, emissions from the Metsamor ANPP create a variable γ-background of ^{137}Cs, which differs in energy spectrum from the stable natural background. Studies of soil microbiota (Khachatryan et al. 2017) were carried out in the 30-km zone of the ANPP (Table 3). The sites M-1 and the town Metsamor are located at a distance of 2.5 km on the leeward side of the ANPP, which generates ^{137}Cs emissions. The city of Oshakan is on the windward side of the ANPP, and the chronic deposition of the Chernobyl accident trace explains the content of ^{137}Cs in the soil. Studies have shown that, along with an increase in the absorbed dose rate of ^{137}Cs, there is a decrease in the total number of soil bacteria in Oshakan and their increase (Table 3) near the ANPP. This is clear because the Chernobyl fallout causes chronic radiation and the death of bacteria. However, the emissions from the ANPP create variable

Table 5. The frequency of point mutations, tetrads with micronucleus (MN) and MN in tradescantia in the vicinity of the Armenian NPP.

Region	^{137}Cs, Bq/kg	Tetrads with MN, %	MN in tetrads, %
Metsamor**	19.4	15.87 ± 0.67	26.90 ± 0.81
Aghavnatun	15.3	15.13 ± 0.65	24.20 ± 0.78
Armavir	15.7	14.72 ± 0.65	21.80 ± 0.75
Oshakan*	65.6	32.0 ± 0.85	61.0 ± 0.89
Control	12.0	9.8 ± 0.54	13.40 ± 0.62

*^{137}Cs deposition due to Chernobyl accident

**^{137}Cs deposition due to ANPP emissions.

irradiation, causing heterogeneity and the reproduction of survived bacteria. ANPP emissions affect cellular structures, causing radioresistance and reproduction (Table 4) (Khachatryan et al. 2017). These effects are impossible without activation of epigenetic mechanisms, given the small amount of ^{137}Cs absorbed dose rate by the microbiota (4.27×10^{-3} μGy/h, Table 1) and the low probability of activation of all bacteria by γ-rays without signaling. Interaction between soil bacteria is necessary. Signaling between microbes in the soil should be assumed.

The influence of ^{137}Cs at a distance of 3–5 km on the leeward from the ANPP on terrestrial plants of Tradescantia (clone 02) (Table 5) causes the appearance of point mutations (Aroutiounian 2006). A low absorbed dose rate of ^{137}Cs suggests activation of the bystander effect in the soil and between plant root cells; transmission of signals from the roots to the shoots of plants (Wang et al. 2012), as well as from the air to the cells of the crown leaves (Gustova et al. 2015).

Adaptation epigenetic mechanisms in the highlands

Epizootic foci are concentrated at 1850–3300 m a.s.l. of Mount Aragats, along the Geghama and Karabakh ridges (Danielyan and Sahakyan 2019) (Figure 2). Table 1 shows an approximately equal absorbed dose rate by rodents in the highlands of 3000–3500 m a.s.l. and the Ararat Valley (1000 m). In the Ararat Valley, radiation exposure leads to diversity and homogeneity, which depend on the duration of irradiation and the genotype of the cells.

The Aragats volcanic massif was formed in stages; its structure is heterogeneous. Radionuclides are distributed very unevenly: low and high concentrations are adjacent for ^{40}K (122.3; 1149.0 Bq/kg), ^{226}Ra (9.0; 134.0 Bq/kg), ^{232}Th (15.1; 93.3 Bq/kg), and ^{137}Cs (26.2; 147.7 Bq/kg) (Movsisyan et al. 2023). This creates high variability in radiation exposure for voles since family colonies of common voles usually include 3–4 generations and occupy 1200–1500 m^2 (Malygin 1983). The high density of rodents and their contacts (Danielyan et al. 2023) promotes the formation of local and diffuse epizootics (Danielyan and Sahakyan 2019). It is established that the energy spectrum of γ-radiation from different sources (Gustova et al. 2022) and in different sites (Asvarova et al. 2012; Abakumov et al. 2022) are different, and different spectra of radionuclides have different effects on epigenetic processes (Mothersill et al. 2022a) in bacterial cells traveling with rodents. The variability of soil bacteria (Khachatryan et al. 2017) and Tradescantia cells (Aroutiounian 2006) was recorded under variable exposure to ANPP emissions. Chronic and long-term exposure increases radioresistance, while variable exposure leads to diversity (Korogodina et al. 2013, 2016). Cell types and genotypes influence the adaptive response (Chankova et al. 2023; Todorova et al. 2023).

The diversity of the γ-spectrum of the mountain landscape and the epigenetic mechanisms of the cell give rise to cell variability. At high altitudes, closer contacts facilitate and enhance signaling, hence gene expression. Darwinian selection and the high probability of reproduction of modified cells in diverse conditions of the mountain landscape contribute to the emergence of subspecies and species.

Discussion

Why do mountains play an important role in speciation?

Migration means a change in environment and adaptation to new conditions. The accumulation of animals, birds, and insects in a suitable place (Danielyan et al. 2023) activates regulatory epigenetic processes of the bystander effect, protein folding, and gene expression (Mothersill and Seymour 2005), which can lead to mutation (Gasch et al. 2000). Migration processes occur constantly in nature and lead to diversity of biota, especially in the world of microbes (Kudryavtseva and Mokrievich 2022).

However, why are mountain landscapes associated with epizootics? The diverse and unstable background of rock radiation, cosmic rays, and, in the case of Armenia, human-generated ^{137}Cs background characterizes the cool highlands and affects the microbial community (Tables 1 and 2). The radiation background of the Aragats highlands is a changing factor that determines the absorbed dose rate (5.26×10^{-2} μGy/h) for moving rodents and regulates epigenetic processes in bacterial cells. It can be assumed that the activity of the local and diffuse epizootics of the highlands (Danielyan and Sahanyan 2019) indicates the presence of tularemia strains.

Here, we see that the source of changes in the cellular structure of soil bacteria and Tradescantia in the Ararat Valley are variable emissions from the ANPP; on the contrary, the natural background of rocks and old deposits of ^{137}Cs create a chronic effect on soil bacteria and plant roots. On Mount Aragats, the γ-background is varied, and the movement of rodents can cause changes in cellular structures. Radiosensitive cells die, mutate, and multiply. Radioresistant cells become more resistant. We hypothesize that lab studies of epigenetic mechanisms of bystander effects and gene expression can be used to explain these phenomena in soil, in the air, and between cells of different organisms.

The mountain landscape performs two functions: it induces genetic variability due to background radiation, a high density of running rodents at its site, and a high probability of positive Darwinian selection due to the diversity of natural conditions. Some species and subspecies of organisms disappear when the environment changes, but new species appear that form new ecosystems.

Basic laws underlying speciation under climate change

Radiobiologists' and radioecologists' investigations are well formulated within the framework of the laws of physics and thermodynamics. With a change in environmental conditions, populations suffer losses, grouping into a denser structure (Beyer et al. 2021). Such transitions must be compatible with intracellular structures and the environment. A coordinated change in the internal parameters of biological systems with environmental parameters occurs by Le Chatelier's principle, which allows one to study the thermodynamic limits of adaptation (Allahverdyan 2023).

The low γ-background in the mountains influences bacterial cells through epigenetic effects. The hit cell not only reacts to electromagnetic radiation but, in return, sends biological, chemical, physical, and acoustic signals to the external environment (Matarèse et al. 2022; Mothersill et al. 2022a) that can be represented in terms of quantum biology (Matarèse et al. 2023). The researchers believe that the influence of the γ-background on the population of bacteria shows the possibility of a systematic approach to the analysis of the connection between the reaction of the entire population of cells and the basic characteristics of the external environment. A correlation between background radiation parameters and epigenetic effects is possible in this case.

Adaptation is based on the laws of non-equilibrium thermodynamics and natural selection. The basic principle of evolution is multilevel learning, including replication of genetic material and minimizing losses during learning (Koonin 2023). With climate change, animals, birds, insects, and microbes densely populate sites suitable for life, suffering losses (Danielyan and Sahakyan 2019; Popov et al. 2022) and forming new species (Beyer et al. 2021). Such constant learning, losses, and reproduction of viable cells are observed in bacteria exposed to constantly changing conditions. Climatic changes can lead not only to adaptation but also to evolutionary shifts. New species will create new habitat niches (Xue et al. 2020). New species and subspecies, strains will spread rapidly in new conditions.

In the mountains, the influence of the γ-background plays a major role in the adaptive response of the cell because EM signals initiate reactive oxygen species (ROS) pathways and membrane changes in ion channels (Mothersill et al. 2022a). This explains that the transmission of EM signals plays a primary role in communication both in the air and in the soil: in populations of soil bacteria (Khachatryan et al. 2017) and in rodents (Danielyan et al. 2023). EM signaling in the soil has the same effect on plant root cells and signal transmission to the crown (Aroutiounian 2006; Wang et al. 2012). Signaling causes hormesis (Matarèse et al. 2023) and adaptation of the entire population (Khachatryan et al. 2017; Danielyan et al. 2023).

In the future, it is planned to study the participation of epigenetic mechanisms in microbes' adaptation to natural and anthropogenic background radiation. Molecular analysis will show changes in methylation of the genome and transcriptome of cells depending on background radiation characteristics and cell structure. These studies will show under what conditions microbes acquire resistance or variability, polymorphism, and new strains appear. The data obtained can be used to study further the effect of low doses of radiation therapy on epigenetic mechanisms of carcinogenesis.

Conclusion

Background radiation activates microbes' adaptation and speciation in the mountains. Natural radiation from rocks and cosmic rays affects cells and activates epigenetic mechanisms. Epigenetic effects determine the overall response of the cell and population. Population grouping and density contribute to the efficiency of the population's response to external influences.

The main factors contributing to the variability of microbial cells under climate change are γ-background in the mountains and its energy spectrum, the grouping of populations under climate change, and epigenetic mechanisms.

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