

Migrations of Rodents in the Zone of Local Radioactive Contamination at Different Phases of Population Dynamics and Their Consequences

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Abstract—Migrations of rodents in the zone of local radioactive contamination (East Urals Radioactive Trace, Southern Urals) at different phases of population dynamics are analyzed for the first time. The absence of any isolation of the rodents in the zone of this radioactive trace is convincingly demonstrated and the migration distances are estimated. As is shown, migration decreases the probability for transfer and fixation of adaptations in the chain of generations in vagile rodent species and increases the within-population genetic diversity of animals in adjacent regions. The need to consider the migration factor in a wide range of studies on assessment of biological effects in the zones of local technogenic contamination is confirmed.

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INTRODUCTION

A necessary condition for the existence of vertebrate populations is animal dispersal and migration as its main factor. Migration or the spatial dispersal of individuals is a key characteristic in the life history of animals, which is related to demographic and evolutionary aspects of species (Blanquart and Gandon, 2014). Analysis of the relevant literature demonstrates that many issues in this problem have been studied well. Methods allowing for estimation of the sedentary and mobile population groups based on long-term trapping/labeling of small mammals are available (Luk'yanov, 1997), and the dependence of the share of migrants on population type, size, and the area of the species distribution range has been shown (Luk'yanov and Luk'yana, 2002). The effect of migrations on population structure has been illustrated (Bol'shakov et al., 1973; Lidicker, 1985), as have the species and genetic diversity (Slatkin, 1985; Theodorakis et al., 2001; Rakitin et al., 2016; Shchipanov, 2016). A classification of small mammals based on the population response to adverse impacts is proposed, and the issues associated with the role of activity of the nonresidential population in population stability and viability has been considered (Shchipanov, 2003). The capabilities of a population in adapting to the local natural (fires or floods) or anthropogenic (rat control) factors increasing the mortality rate of the species with different demographic responses have been discussed (Shchipanov, 2000). The share of the nonresidential population has been specially assessed by a case study of the pygmy wood mouse (Shchipanov et al., 1997).

It is currently believed (Kaidanov, 1996; Ronce, 2007) that vagility is an inherited trait and is associated with selection, which has an especially intricate effect on animal migrations in wildlife populations. This is determined by concurrent impacts of evolutionary factors, which can have opposite effects on migrations. A set of interactions brings about specific migratory patterns, which are regarded as an important element in the strategy of optimal fitness of a species to seasonal changes in the environment (Alerstam et al., 2003).

However, issues associated with research into rodent migrations as objects of monitoring in the zones of local technogenic contamination, in particular, East Urals Radioactive Trace (EURT), resulting from the Kyshtym nuclear accident (1957), have not been studied at all, yet they are relevant and of key importance. Characteristic of the EURT zone is a specific configuration, namely, a narrow, extended area with a sharply decreasing transverse gradient of radioactive contamination (*Atlas...*, 2013). The pygmy wood (*Sylvaemus uralensis* Pallas, 1811) and striped field (*Apodemus agrarius* Pallas, 1771) mice are common rodent species with a leading position in the rodent cenosis. They display a high migratory activity, labile types of spatial structure (Flint, 1997), and seasonal migrations between biotopes, caused by an insufficient number of shelters, irregular feed distribution, and some other factors. Their daily migrations in wildlife amount to 800–3000 m (Bol'shakov and Bazhenov, 1988; Shchipanov, 2003; Tolkachev, 2016a, 2016b).

Migrations lead to a considerable range of accumulation of technogenic pollutants/radionuclides in animals, as well as to a high variation in the biological characteristics. This was the reason why radioecologists (I'lenko, 1978) as early as the 1960s–1980s, understanding well the importance of this problem, attempted to assess the migrations of rodents in the EURT zone by radio- and individual labeling; however, their data were ambiguous and contradictory. Radioecological assessment of this most important population parameter is still ignored in radioecological studies; to a considerable degree, this is determined by methodological difficulties. The EURT zone is regarded as a sort of enclave with the animal population existing therein as a chain of generations for 60 years already, while the years since the nuclear accident are just multiplied by two generations. The established situation, that is, data interpretation without taking into account animal migrations, results in misinterpretation of the very results of research.

Studies of the migrations of rodents are important for solving ecological problems in contaminated local areas; adaptation and microevolution of the populations exposed to technogenic impacts; and assessment of the remote ecological and genetic consequences for animals inhabiting adjacent areas. All this determined the relevance of our study.

The goal of this work was to describe the phenomenology of migrations of mouselike rodents in this zone of radioactive contamination at different phases of population dynamics and their consequences. The hypothesis that we tested assumes that the rodent population in the EURT zone is not isolated from the adjacent areas because of animal migrations in both directions.

MATERIALS AND METHODS

The object of our study was the rodent population inhabiting the EURT zone (Chelyabinsk oblast, Southern Urals). The average annual abundance of rodents was assessed according to the long-term monitoring data (2002–2015) based on surveys of the relative abundance (number of individuals per 100 trap-days; five–six trapping rounds per season) synchronously performed in the impacted and control sites. Rodents were trapped with Gero break-back traps (irreversible withdrawal).

The phenomenology of migrations in the EURT zone was studied by mass labeling of small rodents with tetracycline, which is widely used in zoological studies. This is a direct method for studying migratory activity, which is the most informative and makes it possible to assess the shares of sedentary and migrating individuals as well as the distance the migrants cover. Tetracycline (a qualitative label) is absent in wildlife and allows for mass nonselective labeling of animals. In the body, tetracycline antibiotics enter the calcified

tissues of growing skeletal regions and are retained there for a long time (Klevezal' and Mina, 1980). A single bait with tetracycline consumed by an animal guarantees distinct labeling in ultraviolet light. The animal trapped at the distance of the site where it was labeled is unambiguously identified according to the fluorescence of dental tissues.

The rodent population was labeled with tetracycline in the summer seasons of 2002–2005 at different phases of population dynamics according to the recommendations by Klevezal' and Mina (1980). The protocol and scheme of mass labeling of small mammals were described in detail earlier (Grigorkina and Olenev, 2013). The work included the following main stages. Small mammals were labeled in the EURT zone in a uniform biotope in different years in the center or periphery of the zone (Fig. 1). The central region (Berdenish, 55°46' N, 60°53' E) is 13 km from the epicenter of the Kyshtym nuclear accident. The content of radionuclides in the soil layer of 0–45 cm was 12851 kBq/m² of ⁹⁰Sr, 427 kBq/m² of ¹³⁷Cs, and 33.2 kBq/m² of ^{239,240}Pu (Molchanova et al., 2009). The peripheral labeling site was located at a distance of 1 km from the central site. The bait with tetracycline (pieces of dried rye bread with unrefined sunflower oil containing tetracycline powder) was placed with an interval of 3 m in plots of 30 × 300 m. Repeated labeling was performed at the same plots. Rodents were trapped with Gero traps on different dates (2 to 55 days) in the labeling site and at sites located at different distances from it (Fig. 1) in similar biotopes: EURT zone at a distance of 1 km (center–periphery) and 6.5 km (Uruskul'; 55°49' N, 60°55' E) with ⁹⁰Sr and ¹³⁷Cs contents in the 0–45 cm layer of 7625 and 225 kBq/m², respectively (Molchanova et al., 2009), and a control plot (Metlino; 55°48' N, 61°00' E) located at a distance of 9.3 km beyond the radiation reserve.

Migrations comprise the overall range of spatial translocations of animals beyond their territory. It is rather difficult to ascertain the status of a migrant; correspondingly, the term nonresident is proposed as an alternative to a sedentary lifestyle (Shchipanov, 2003), which refers to the individuals trapped at all distances from the labeling site. We believe that all labeled animals trapped at the sites located beyond the labeling plot in the EURT zone and in the control plot can be regarded as migrants. The rodents that remained in the initial area and were trapped in the labeling plot one month or more after the bait was left can be regarded as residents. The tetracycline label was recorded using an MBS-10 binocular microscope and an OSL-1 fluorescent illuminator with a filter according to yellow fluorescence in ultraviolet light (Milch et al., 1958) in longitudinal sections of the upper incisors.

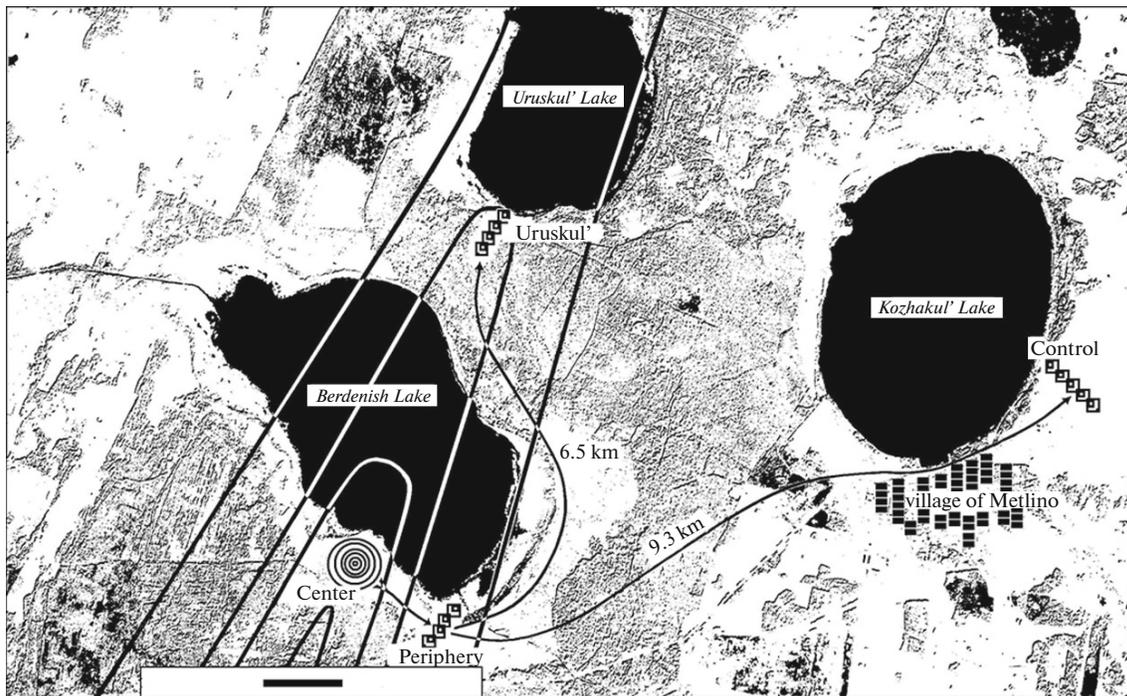


Fig. 1. Scheme of the labeling sites (center and periphery) and trapping of rodents. Isolines characterize the drastically decreasing gradient of radioactive contamination in the EURT zone. Scale, 1 km.

RESULTS

Long-term dynamics of the rodent population (2002–2015). Long-term monitoring covers different phases of the changes in the rodent population size (Fig. 2), the abundance of which in the examined habitats varied in a wide range. The amplitude of changes varied eight- to ninefold in the EURT zone and four- to fivefold in the control plot. The oscillation in abundance of the pygmy wood mouse *S. uralensis* Pallas, 1778 was even higher: 13-fold in the EURT zone and 8-fold in the control plot. *S. uralensis* was constantly prevalent in rodent communities, accounting for 40–60% of the harvest until 2009. After the drought of 2010, the rodent community in the EURT zone turned into a monodominant one represented by *S. uralensis* alone (Olenev and Grigorkina, 2016). The population dynamics curves at both sites changed in a synchronous manner. Population peaks were recorded in 2002, 2003, 2005, 2006, 2008, 2009, and 2012 (Fig. 2). Note similar abundances in the EURT zone in the years adjacent to population size peaks, which are separated by periods of drastic population decreases (2004, 2011, and 2014) and even a deep depression (2007).

Migration of rodents at different phases of population dynamics. In total, 963 animals belonging to eight species of mice (pygmy wood *S. uralensis* Pallas, 1811 and striped field *A. agrarius* Pallas, 1771 mice and red-backed vole *Clethrionomys rutilus* Pallas, 1779; European water vole *Arvicola terrestris* Linnaeus, 1758; tun-

dra vole *Microtus oeconomus* Pallas, 1776; common vole *M. arvalis*, Pallas, 1778; narrow-headed vole *M. gregalis* Pallas, 1779; and field vole *M. agrestis* Linnaeus, 1761) were trapped when studying their migration; 364 trapped animals (38%) carried the label. The rate of labeled animals in the years examined varied from 35 to 40%. Animals of different species and different trophic specialization ate the bait with tetracy-

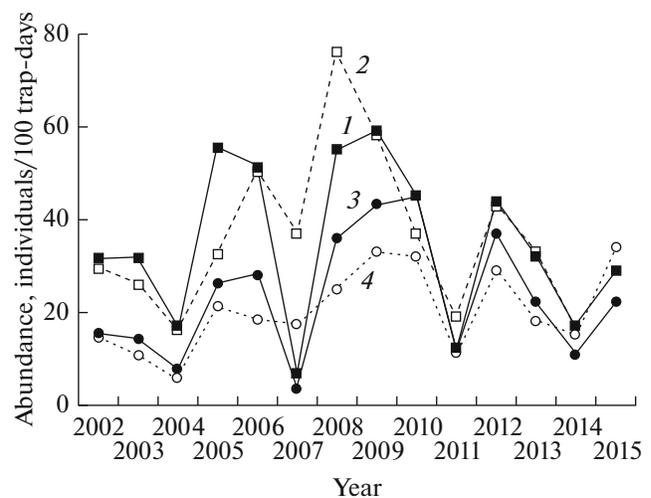


Fig. 2. Population dynamics of mouselike rodents in the key sites (EURT–control) in 2002–2015 (annual average values): (1 and 2) rodents and (3 and 4) pygmy wood mouse (EURT–control).

Table 1. Data on trapping of rodents at various distances from the labeling site (2002; abundance, 31 individuals/100 trap-days)

Individuals	Time of trapping, days after labeling						
	2	40–45			50		
	0*	0*	1*	9.3*	0*	1*	9.3*
<i>Sylvaemus uralensis</i>	4/5	8/27	2/2	3/36	6/21	–	4/18
<i>Apodemus agrarius</i>	2/2	2/5	2/2	2/10	1/9	8/10	4/21
<i>Clethrionomys rutilus</i>	–	–	2/2	1/19	1/1	–	0/17
<i>Arvicola terrestris</i>	–	4/4	4/4	–	3/3	–	–
<i>Microtus oeconomus</i>	4/4	10/16	1/1	–	9/11	–	–
<i>M. arvalis</i>	–	–	–	–	1/1	–	–
Total**	10/12(83)	24/53(45)	11/11(100)	6/65(10)	21/46(46)	8/10(80)	8/37(22)

For Tables 1–4: Numerator, the number of animals with label; denominator, total number of trapped individuals; (–) no data; * distance from labeling site, km; and ** the share of labeled individuals is in parentheses.

Table 2. Data on trapping of rodents at various distances from the labeling site (2003; abundance, 32 individuals/100 trap-days)

Individuals	Time of trapping, days after labeling				
	45–50		50–55		
	0*	9.3*	0*	1*	9.3*
<i>Sylvaemus uralensis</i>	3/11	2/5	6/13	3/3	5/22
<i>Apodemus agrarius</i>	–	0/8	2/10	2/2	3/11
<i>Clethrionomys rutilus</i>	–	–	0/3	1/2	1/6
<i>Arvicola terrestris</i>	–	–	1/1	–	–
<i>Microtus oeconomus</i>	6/17	0/2	9/14	1/2	–
<i>M. agrestis</i>	–	–	–	1/1	–
Total**	9/28 (32)	2/15 (13)	18/41(44)	8/10(80)	9/39(23)

cline, including *Microtus* voles and the water vole. This made it possible to trace the distances covered by mouse-like rodents in their migrations in the area of the radiation reserve and beyond it (Tables 1–4).

Total dynamic pattern of migrations. The rate of labeled individuals was rather high as early as 2–3 days after labeling (Tables 1, 3), which demonstrated that the bait used was efficient. With time (in 30–55 days), the number of labeled animals decreased in a regular manner, while their share at a distance increased. The share of residents in the labeling plots was the highest after 30–35 days and varied from 32 to 50% in different years (Tables 1, 2, 4). Wood and field mice accounted for the main part of these residents (28–33 and 69%, respectively; Tables 1, 4). A considerable share of residential individuals in 2005 (Table 4) was determined by a high abundance of rodents of these particular species (35 and 31 individuals/100 trap-days). Note also that a considerable share of labeled young animals (body weight, 9–12 g), which had recently left their burrows and started independent

feeding, was present in the harvests of September. It is possible that they received tetracycline with breast milk during the suckling period. This transmission route was experimentally shown for ground squirrels (Lobkov, 1984). A similar pattern was described for the tetracycline labeling of animal population in an urban environment (Tolkachev, 2016b). In addition to *S. uralensis* and *A. agrarius*, tundra voles of different sex and age cohorts accounted for a considerable share (42%) of residential individuals (Table 1). The water voles of different functional statuses from the habitats associated with near-aquatic biotopes were labeled at a rate of 100% (Tables 1, 2); note that residential individuals were recorded both in the labeling plot and at a distance of 1 km.

In general, the group of labeled animals reflects the balance of species in harvests containing the dominant (*S. uralensis*) and codominants (*A. agrarius* and *M. oeconomus*) as well as the species occurring not every year or displaying a low abundance (Tables 1–4). These animals include solitary individuals of *Microtus*

Table 3. Data on trapping of rodents at various distances from the labeling site (2004; abundance, 17 individuals/100 trap-days)

Individuals	Time of trapping, days after labeling						
	3		30–35		50–55		
	0.8*	1*	6.5*	9.3*	0.8*	1*	9.3*
<i>Sylvaemus uralensis</i>	–	15/24	1/6	0/6	–	9/24	1/9
<i>Apodemus agrarius</i>	–	1/1	0/4	0/1	–	4/14	0/1
<i>Clethrionomys rutilus</i>	10/10	–	1/2	–	2/3	–	0/4
<i>Microtus oeconomus</i>	–	5/13	–	0/4	–	1/1	–
<i>M. arvalis</i>	1/1	–	–	0/6	–	0/1	–
<i>M. agrestis</i>	–	–	–	0/1	–	–	0/6
Total**	11/11	21/38(55)	2/12(17)	0/18(0)	2/3	14/40(35)	1/20(5)

Table 4. Data on trapping of rodents at various distances from the labeling site (2005; abundance, 55.4 individuals/100 trap-days)

Individuals	Time of trapping, days after labeling						
	35		20–25				
	1*	9.3*	0*	1*	6.5*	9.3*	9.3*, ***
<i>Sylvaemus uralensis</i>	33/48	3/33	14/28	5/9	2/23	1/5	5/17
<i>Apodemus agrarius</i>	36/69	1/6	38/77	6/10	4/31	4/13	10/29
<i>Clethrionomys rutilus</i>	0/1	0/7	1/1	3/5	1/7	1/3	3/13
<i>Microtus oeconomus</i>	1/1	–	1/2	–	–	–	–
<i>M. arvalis</i>	1/4	–	1/1	–	–	–	–
<i>M. agrestis</i>	–	–	0/1	–	–	–	–
<i>M. gregalis</i>	2/3	–	–	3/5	–	–	–
Total**	73/128(53)	4/46(9)	55/110(50)	17/29(59)	7/66(11)	6/21(29)	18/59(31)

*** Sample of rodents shipped to vivarium for laboratory assays.

voles (field, common, and narrow-headed voles). The red-backed vole has low abundance in the EURT zone; these species during the years of labeling were recorded annually. The spring trappings are represented exclusively by overwintered mice (*S. uralensis*), while the other members of this rodent cenosis appear in the mid-summer harvests. Repeated labeling in all years examined made it possible to take into account all migrants of the species living there. Labeled animals were trapped at a distance of 1 km as early as on days 3–4 after labeling; moreover, a highway crossing the area was not a serious landscape barrier preventing their migration (Table 3). Study of migrations of small mammals in urban environment using tetracycline labeling demonstrates that mice and wood voles can successfully cross unpaved and asphalt roads with intensive vehicle traffic as well as other landscape barriers (Tolkachev, 2016a, 2016b).

Animal dispersal pattern in vast uniform biotopes. It was initially assumed that a diffuse migration would be

characteristic of the area examined and that the share of trapped labeled animals would be lower because of equiprobable differently directed migrations. The harvests from birch stands (a monotonic biotope) westward of labeling plots (Fig. 1) contained labeled wood mice. This biotope could be regarded as an ideal model test site when studying migrations; however, it appeared rather inappropriate for constant habitation of rodents because of the low feeding potential and poor shelter conditions. The intensity of dispersals to this biotope was decreased, and the animals were in low abundance there in the years examined. Interestingly, this biotope is actively used by overwintered animals in early spring (end of April), when the main site examined was just freed of snow cover, housed winter-depressed vegetation, and had no shelters at all. Mice move to the birch stand, thus migrating in spring to another biotope where they find shelters from predators until development of the grass cover in their main biotope with mixed herbs and nettle. This is demonstrated by April harvests, when the local abundance of

overwintered *S. uralensis* in the ecotonic habitat reached 50 individuals/100 trap-days. This emphasizes that the spatial distribution of the rodent population in the EURT zone depends on a wide range of environmental factors.

Migrations in an inhomogeneous landscape environment. High landscape mosaicism is characteristic of the EURT zone. In their migrations, animals utilize definite (compulsory) migratory routes. The lakes residing at the axis of the radioactive trace are natural insurmountable barriers; when reaching these lakes, rodents have to continue their way along the shore (i.e., across the EURT zone), which we took into account when selecting the trapping sites. The animal density increases in the case of such “concentrating migrations,” making the trapping more efficient. As has been shown, wood voles, wood mice (Krylov, 1992; Shchipanov et al., 1997), and house mice (Shchipanov, 2003) have definite routes they use for migrations. An analogous fact is described for migrations of animals belonging to the same species in a fragmented landscape (Tolkachev, 2016a), where a “corridor” between lines, represented by a wasteland crossed by two roads, the so-called landscape conduct, was observed (Corridor..., 2006).

As has been observed, all rodent species migrated within the EURT zone to a distance of 1 km (Tables 1–4). The nonresidents (migrants) trapped at a considerable distance from labeling sites within the EURT zone (6.5 km, Uruskul’, and 9.3 km, control) belonged to wood mice, field mice, and red-backed voles (Tables 3, 4). In the year of a low rodent abundance, the share of migrants in the area adjacent to the EURT zone was 5% versus 20–30% in the years of high abundance. The nonresidents trapped at large distances were represented by overwintered individuals, both mature and immature underyearlings. Note that overwintered male *S. uralensis*, *A. agrarius*, and *C. rutilus* individuals were recorded in August harvests (Tables 1, 4).

DISCUSSION

Our data of four years of labeling the animal population in the EURT zone demonstrate that migrants were present in remote sites in all years of study. The migratory activity has been determined by the specific ecological features of individual species. Wood and field mice as well as red-backed voles are the most active migrants. The rodents of these species covered distances severalfold exceeding the cross dimension of the narrow stretched EURT zone. Animals of all sex and age cohorts and all functional groups were trapped in the control plot.

Analysis of the long-term population dynamics of rodents demonstrates that the abundance in 2006 and 2008 was comparable to that in 2005 and even exceeded it in 2009 (59 individuals/100 trap-days;

Fig. 2). The peak abundance of the absolute dominant (*S. uralensis*) was recorded in the dry year of 2010. Labeling has demonstrated that the share of nonresidential individuals in the years with a high abundance varied from 9 to 13% in summer harvests and increased to 30% in fall harvests (Tables 1, 2, 4). Pygmy wood mice as the most abundant species in the area examined accounted for the main part of migrants. Presumably, migration in subsequent years with a high abundance was comparable to that in 2005 and/or even higher. Beyond the experimental plots, labeled mice and red-backed voles were trapped at all distances in all trapping sites. As was demonstrated earlier, *S. uralensis* individuals formed within-population groups performing alternative functions (control and restoration) and displayed either stable or variable population composition (Shchipanov et al., 1997, 2003). It is possible that we observed in the EURT zone such functional units of the pygmy wood mouse that are able to respond to changes in animal abundance.

Consequences of migrations in the EURT zone. It is logical to assume that even a short-term visit of animals to the zone of radioactive contamination has certain consequences for their genomic profile. If this event ends in reproduction, a consequence of migrations is gene flow and the related natural selection (Kaidanov, 1996; Altukhov, 2003; Blanquart and Gandon, 2014). The isolation caused by distance between the EURT–control sites is excluded since the distance between them is only 9 km. This is suggested by the presence of migrants (wood mice, field mice, and red-backed voles) in the background site; according to labeling, their share increased in the years with a high abundance. A consequence of animal migration is the transfer of the biological effects induced by ionizing radiation beyond the radiation reserve, which contributes to genetic diversity of the animals living in adjacent areas. This is illustrated by molecular genetic data on the variation of microsatellite DNA loci, which we studied in the red-backed voles trapped in the same sites in 2006, the year of peak abundance (Rakitin et al., 2016). As has emerged, some characteristics of genetic diversity (the number of unique alleles and the allelic diversity index taking into account sample sizes) were maximal in the voles from the control plot. The level of between-population genetic differentiation assessed based on the variance of allelic frequencies of microsatellite loci (AMOVA, F_{ST}) was rather low, and the share of variance determined by this differentiation amounted to 1.34% ($p = 0.005$). The differences between the EURT–control samples were at the boundary of the 5% confidence level, i.e., comparable to the within-population differences. Presumably, the observed effects are associated with the free exchange of migrants and, correspondingly, with a certain exchange of genetic information, which do not bring about any significant differentiation of groups according to the parameters studied.

The data on genomic instability in the bone marrow cells of the common voles (*M. arvalis*) trapped in the area adjacent to the EURT zone (Gileva et al., 1996) also suggest the absence of isolation. An increased level of aberrant metaphases and mutant karyotypes was observable in these cells. The available information about the effect of microsatellite DNA on chromatin formation and the expression of mutator genes (Li et al., 2002) does not rule out that variation in microsatellite loci can modify the rate of chromosome aberrations in somatic cells of rodents and is positively correlated with it, being a marker of the overall genomic mutational background in the body.

Cytogenetic and molecular genetic data confirm the relation between impacted and control parts of the rodent population and suggest that the actual intensity of gene migrations is close to a genetically efficient one (Altukhov, 2003), which is measured by the contribution of migrants (periodic participation of males) to reproduction and formation of the gene pool for generations. Only male migrants of the red-backed vole with different functional statuses were present in the harvests at the control site in different years of labeling.

According to our long-term data, the share of wood mice that emigrated from the EURT zone as indicated by a radioactive label (^{90}Sr in the bone tissue of rodents is an indirect migration marker) in different trapping years and seasons varied from 17 to 40% (Grigorkina and Olenev, 2013). The spring control samples, containing overwintered individuals, almost always contained nonresidential *S. uralensis*; they were identified according to the radioactive label, which displayed specific β -activity in the bone tissue several orders of magnitude higher as compared with the background and approximately matched the parameters of radionuclide accumulation in the rodents inhabiting the EURT zone. Males represented the main part of migrants, whereas females were considerably fewer; females at early stages of gestation were recorded twice in May harvests. The data on labeling demonstrate that the two labels (tetracycline as qualitative and ^{90}Sr as quantitative labels) give similar results on the share of nonresidents (migrants) and confirm the absence of isolation of the animal population in the zone of local radioactive contamination. This means that the areas adjacent to the EURT zone is a kind of a test site for assessing the role of increased mutation frequency in the microevolution of natural populations caused by refilling of the mutation pool by gene flows brought by migrants from the contaminated zone (Gileva et al., 1996; Rakitin et al., 2016). Our data confirm the absence of any spatial and functional isolation of the animal population residing in the EURT zone as a result of its specific configuration and the contribution of efficient migration (Altukhov, 2003) to the genetic diversity in adjacent areas. The impact zone with a specific population carrying the consequences of contacting a pollutant is established around the con-

taminated zone (the pollutants can be of different natures; what is important is that they cause biological effects) as an extension of the contaminated zone at the level of biological effects.

The basic role of migrations in the formation of genetic diversity was demonstrated in a population of kangaroo rats (*Dipodomis merriami*) trapped in radioactively polluted and reference sites in Nevada, United States (Theodorakis et al., 2001). However, no distinct association between the distribution of mtDNA haplotypes and the contaminated or reference sites was observed. The authors explained the topology of the phylogenetic tree taking into account the migrations of animals. The direction of migrations was determined for 23 of the 27 cases recorded: 13 individuals (57%) migrated from “clean” to contaminated sites; six individuals (26%), in the opposite direction; and the remaining 17% migrated between either two contaminated sites or two reference sites. This suggested that migrations of rodents influence the results of ecological and genetic studies associated with the varying composition of the animal population for the sites analyzed. Migrations mask the genotoxic effects of radiation exposure on the residents of contaminated sites and decrease the rates of their unique alleles, which is an effective marker of genetic exchange (Slatkin, 1985).

There is also no doubt that the factor of migrations plays a decisive role in adaptation of the rodent population in the local radioactive contamination zone since migrations decrease the likelihood of transfer and fixation of adaptations in the chain of generations of vagile rodent species (Grigorkina and Olenev, 2009, 2013). This confirms our data on the higher rate of chromosome aberrations and micronuclei in the bone marrow cells (Yalkovskaya et al., 2010) as well as considerable differences in the hematopoietic and immune systems between the wood and field mice from the EURT zone and reference sites (Grigorkina and Pashinina, 2007). An increase in variation of the hematopoietic system in the rodents residing in the gradient of chemical pollution (heavy metals) was described earlier (Tarakhtii and Mukhacheva, 2011). An even more intricate situation is possible when assessing the biological effects in small mammals inhabiting areas with numerous nuclear explosion traces (Semipalatinsk Test Site, Kazakhstan), where local radioactive traces have formed beyond this site in the adjacent area. Correspondingly, researchers working in a zone of local radioactive contamination or any other technogenic pollution with a similar configuration should keep in mind that the samples collected will undoubtedly be heterogeneous, i.e., the animal samples will contain both “clean” animals and individuals exposed to pollutants, which influences the variation of the traits assessed.

An illustrative example of the role of migrations in genetic adaptation of small mammals to the radioac-

tive environment is a sedentary species, the northern mole vole *Ellobius talpinus* Pallas, 1770 many generations of which have lived in the EURT zone. These rodents live up to six years, are adapted to underground life, and seldom move to new territories, rather staying within a colony (Evdokimov, 2001). Their colonies are represented by families living for many years on a limited area. The colony of northern mole voles in the EURT zone is regarded as isolated and localized to the periphery of its distribution range. No cytogenetic abnormalities were detected in the *Ellobius* rodents of the EURT zone (Gileva, 2002) and a radiation-induced adaptive response was observed (Grigorkina, 2010), which is convincing evidence for their adaptation to long-term radiation exposure in the chain of generations. Note that specific ecological and physiological features of this species, namely, their underground colonial life habit and low migratory activity, enhanced their successful adaptation to radiation exposure.

CONCLUSIONS

The EURT zone, which has been examined by numerous researchers, in its current boundaries does not differ from the adjacent territories in the specific features of its vegetation and relief as well as its fauna. The differences concern the abundance of game species. In this case, the regulations on nature reserve status play the key role. The EURT zone is distinguished by its contamination with long-lived radionuclides. The geographic boundaries of the radioactive reserve do not coincide with the boundaries at the level of biological effects (in total, the latter areas are larger than the contamination zone).

Our data demonstrate that the EURT zone houses an animal population with the composition varying owing to efficient emigration of individuals from the contaminated area and immigration from background territories. This is convincing evidence for the absence of genetic isolation. The share of migrants from the EURT zone to adjacent territories in the years with different abundances of rodents varied from 5 to 30%, increasing in the years with a high abundance. Similar to other technogenic areas with an analogous configuration, the EURT zone in the level of migratory activity and intermixing of mouselike rodents does not differ considerably from the background. However, the variability of the population composition here is of key importance since animal migration significantly decreases the likelihood of transfer and fixation of adaptations in the chain of generations. A pronounced dispersal of rodents in both the contaminated area and the regions beyond the radiation reserve contributes to a change in the genetic composition of the animal population owing to dilution of the gene pool by the gene flow carried by individuals from clean areas to the contaminated zone and spreading of radiation-induced effects from the EURT zone. This is con-

firmed by the data on genetic diversity (according to the variation of microsatellite DNA loci) in the red-backed vole in the year of their peak abundance.

Evidently, it is necessary to continue molecular genetic studies because the corresponding data will deepen the insight into the biological foundations of the phenomenon of radiation-induced genome instability. Presumably, it would be useful to use the data on other vagile (actively migrating) species (pygmy wood mouse). It is also possible that the use of other molecular markers in addition to nuclear ones, such as mtDNA, may be efficient for this purpose, since together they are indicative of an adverse impact on the genome.

Thus, our data confirm the tested hypothesis on the absence of isolation of the rodent population living in the EURT zone. Analysis of the available and newly obtained data suggests a special role of migrations and configuration of the contaminated zone in the animal adaptation to radiation exposure and formation of genetic diversity of the populations in adjacent territories. The reported data allow for revision of the current concept stating the isolation of the rodent population in the EURT zone and a basically new explanation for the processes taking place in local contaminated areas. They also unambiguously confirm that the migration factor should be taken into account in a wide range of studies in technogenic territories of similar configurations.

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