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East urals radioactive trace: Adaptive strategy of rodents' population

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Abstract. Population of small rodents in radiocontaminated environment is compelled to include more energy-intensive way of maintenance its ability to live — increasing of the proportion of mature young of the year (first pathway of ontogeny). Their reproductive characteristics — actual fecundity was higher, whereas embryonic mortality and the proportion of females with embryonic losses were significantly lower compared with neighboring areas. Abundance of mice in the impact zone was higher, age cross was revealed, which improves the adaptive possibility of the population. Preconditions for acceleration of evolutionary transformations of a population are created, but this process is restrained by both the local configuration of the polluted territory and migration of murine rodents. As a consequence, the population decreases the probability that certain changes will be fixed and inherited in a series of generations. Chronic low-dose radiation (stress) can be considered as the mechanism of switching of life history of cyclomorphic mammals. Thus, ontogenetic multiversality of small mammals is an important mechanism of protection strategy of population and decreasing the damaging action on biota in radiocontaminated environment. Functional approach makes it possible to reduce errors in assessing the radiological consequences and hence, can provide a reliable methodological basis for organization of biological monitoring.

1. INTRODUCTION

Nowadays a paradigm shifts have occurred in the field of radiation security: the anthropocentric principle of environmental protection against ionizing radiation has been replaced with the ecocentric perspective [1, 2]. This promotes the conduction of large-scale studies in the radioecology of indicator plant and animal species, a thorough analysis of the biological effects of radiation on their populations, and also determination of the permissible level of irradiation with account for the peculiarities of the specific radioecological situation. The East Urals Radioactive Trace (EURT) is the result of the most serious nuclear accidents took place at Kyshtym (Southern Urals, Russia) in 1957. This zone has the specific configuration that looks like a prolonged and narrow territory with rapidly decreasing gradient of radioactive contamination. Because of this rodents of mobile species (mice and voles) are able to pass through significant distances that are comparable with the cross-section size of EURT area. This leads to forming of a flowing population [3], i. e. a population with constantly changing set of individuals due to immigrants from adjacent unpolluted areas and emigrants from the polluted zone. The main dose load radionuclide in the EURT zone is ^{90}Sr (95%), which accumulates in the skeleton of vertebra and irradiates organs and tissues during the all life of animal.

Small mammal's populations are heterogeneous. Individuals of the same species living in the same community differ in many traits and may be divided into groups with respect to age, size, developmental rate, and other parameters responding to changes in the environment. Each individual at a certain moment may be characterized in two ways: (1) by the absolute age, or the period of time since the birth, (2) by the biological (physiological) age, which is much more difficult to determine. Moreover, each organism at each moment has a specific complex of features related to its physiological age. Cyclomorphic mammals are characterized by rhythmical changes in the most of biological parameters over a period of approximately one year, one-time serial reproduction, and generation overlap in

the presence of two alternative ontogenetic pathways (types). Both types of ontogeny fully manifest themselves in rodent populations inhabiting the temperate zone of the Northern Hemisphere and its Arctic periphery, where the climate is sharply continental.

The present paper compares numbers and the ratio of individuals of alternative types of ontogeny of small rodents captured both the EURT zone and the background area.

2. MATERIALS AND METHODS

2.1 Sampling and analysis

This work is based on the comparative analysis of data obtained in the course of long-term monitoring (2002–2010) mouse-like rodents populations in the Eastern Urals Reserve and the background plot, which was selected beyond the polluted area (the background γ-radiation level is 12 μR/h, and the β-radiation count is 12 cpm/cm^2). The impact plot lies on the EURT axis 13 km from the explosion epicenter, the density of soil pollution by ^{90}Sr is 182–451 Ci/km^2, the γ-radiation level at the soil surface varies from 22 to 76 μR/h, averaging 50 μR/h; the β-radiation count varies from 90 to 942 cpm/cm^2, averaging 380 cpm/cm^2.

The object of our investigation is widespread specie - pigmy wood mice *(Sylvaemus uralensis* Pallas, 1811). Both conventional and original methods of field studies were used: the method of irreversible removal by snap traps, a modified method for determining the absolute age of animals, and the method of morphophysiological indicators. Numbers of rodents was assessed from the first-day of catch per 100 trap–days and presented by the mean value in each year (6–8 catches from April to November). To estimate the ratio between the types of ontogeny data obtained in June and July of each year were used, so in midsummer all intrapopulational groups are present and the proportion of reproductive young of the year reaches a peak. Data were processed statistically with the EXCEL 6.0 and STATISTICA 6.0 program packages.

2.2 Functional-ontogeny approach

We used the functional-ontogeny approach [4], as a methodological basis for analyzing age structure of population. This approach supposes to divide natural population into groups of individuals with the same functional status, i. e. with the uniform patterns of growth and/or maturation rate as well as whether they participate in reproduction (scheme of two alternative pathways of mouse-like rodents' ontogenetic development presented early [3]. Individuals of different types of ontogeny (functional status) manifest significantly diverse radioresistance [5]. Such diversity is based on the differences in metabolic intensity of animals.

Mature young of the year. The first type of ontogeny. Monophasic growth. Most animals (usually 70–90%) belong to the first cohorts (fig. 1). They rapidly grow, mature, and enter reproduction upon reaching the definitive body size and weight characteristic of overwintered animals (25 g), they fall into the same. These animals have a high metabolic rate, rapidly grow, old, and die in the year of birth. Life span ranges from three to five months. Behavior is characterized by some manifestations of aggressiveness. Their function is increase in population numbers.

Immature young of the year are more resistant part of population. The second type of ontogeny the first phase. Biphasic growth. Most animals are from the last cohorts, but there is always a considerable proportion from the first cohort animals remaining nonreproductive in the year of birth (fig. 1). These individuals have body mass 16–18 g, growth is suspended, do not mature, characterized by both low metabolism and aging (two times). Life span is 13–14 months. Their behavior is not aggressive. Their function is to preserve the corresponding part of the population (a state of "preserved youth") until the next spring with the smallest possible losses and, in the status of overwintered adults, to begin the cycle of population renewal.

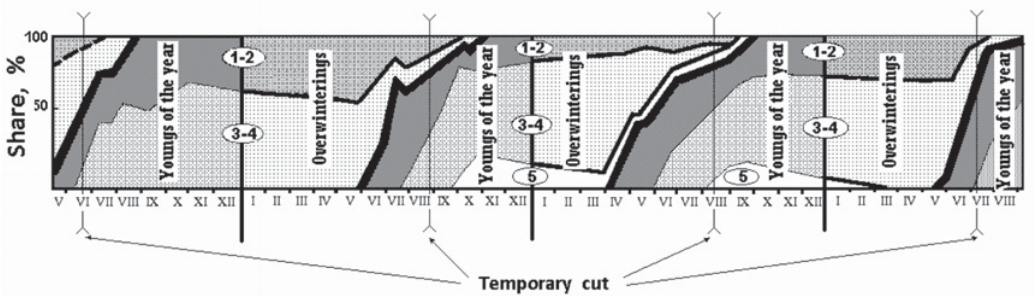

Figure 1. Age structure dynamics of *S. uralensis* from natural population: share of individuals and life span of different cohorts (examples of four years).

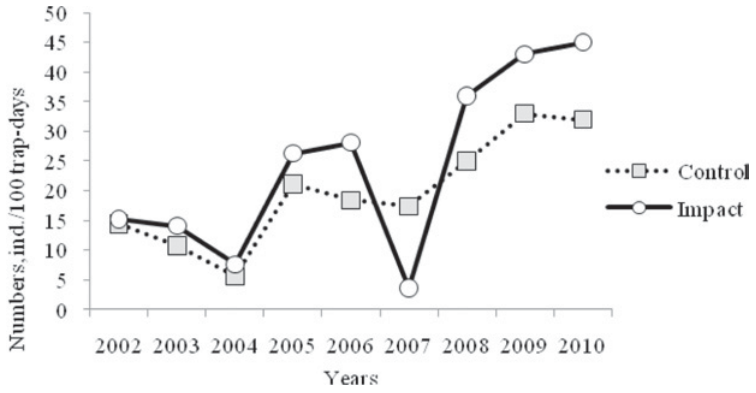

Figure 2. Numbers of *S. uralensis* in the impact and background plots (2002–2010, annual average values).

Overwintered animals. The second type of ontogeny the second phase. This phase begins in next spring, when the animals resume growing after the "conservation" period and mature within two to three weeks. Their body weight stabilizes again upon increasing to 24–26 g (the definitive value for the species). The rates of metabolism and senescence are similar to those in the first pathway of ontogeny, although the absolute age of overwintered animals is much greater. The duration of this phase is 120–200 days. The behavior of animals has some elements of aggressiveness. The main function of this group is to begin the cycle of population renewal, notwithstanding any adverse influences.

3. RESULTS AND DISCUSSION

3.1 Numbers

Pigmy wood mice are highly mobile, concentrated in spring mainly in ecotonal habitats and birch forest with suitable food and shelter conditions. They are numerical, dominate in both plots (from 40 to 100% in catches of different years), therefore the data presented below concern mainly this specie.

The observations covered different period of rodent population dynamics (fig. 2). Total abundance of mice varied by years in the EURT with 12-fold amplitude, in the background plot – almost 6 times. Numbers of mice in the EURT zone was consistently higher than in the control one during almost the all years of monitoring ($p \leq 0.05$) it changed in both sites synchronously, reached the maximal values in 2010.

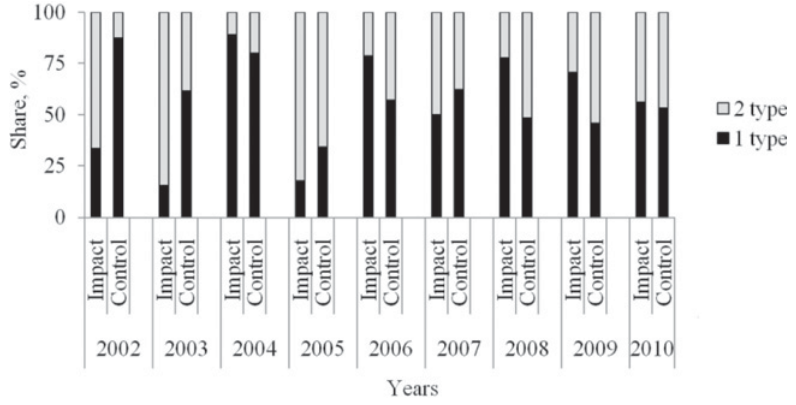

Figure 3. Ratio dynamics between ontogeny types in analyzed plots (2002–2010).

Abundance of *S. uralensis* in both plots was low in 2004 – 7.6 and 5.6 ind. /100 trap–days (impact – control), in the EURT zone was the lowest one in 2007 – 3.6 and the highest in 2010 – 45 ind. /100 trap–days. 2010 was unusual year - in both plots there were registered only *S. uralensis*.

The seasonal dynamics of population structure and abundance in mice were of the same type. The abundance of overwintered animals (the initial number of spawners) at the beginning of the breeding season in all years did not differ significantly and varied in the EURT zone from 4 to 18 and in the control plot from 5 to 12 ind. /100 trap-days.

According results of long-term ZEUS experiments (zoological environment under stress), conducted by Mihok et al. [6, 7], no effects on population characteristics were detected up in a gradient of gamma radiation (chronic external exposure rate 10–100 mGy/d) of red-backed voles (*Clethrionomys gapperi*) and meadow voles (*Microtus pennsilvanicus*). These levels of exposures to low-LET external radiation are insufficient to cause population effects (numbers, reproduction, survival, growth and demography structure of voles), even if some effects on individuals occur.

3.2 Ratio dynamics between ontogeny types

Owing to continuous observations on the same rodent populations over 9 years, we can analyze the long-term dynamics of the ratio between the two types of ontogeny and discuss their features (fig. 3).

This ratio varied in the impact plot within a broad range covering virtually all possible values from 15 to 90% and in the control area – 30–80%.

Individuals of the first type of ontogeny - the mature children of overwintered animals, which form the second generation, dominate in the impact population. Their reproductive characteristics - actual fecundity was higher, whereas embryonic mortality and the proportion of females with embryonic losses were significantly lower compared with neighboring areas [8]. The same results – a significantly increase fertility, fecundity and maturation rate as compared to the control animals were revealed in *Microtus oeconomus* population from radioactively polluted plot in Komi Republic [9].

3.2.1 Sex ratio

As we above mentioned, 2010 year was unusual. There were no rodents of another species besides *S. uralensis*. In fig. 3 one cannot see differences between individuals of alternative types of ontogeny in the 2010 midsummer. However analysis of sex and demographic structures has shown that sex ratio of overwintered was skewed towards males. At the same time the overall sex ratio of matured young of the year (1 type) was weighted towards females ($p \leq 0.05$). The most part of young of the year males has

not matured and belonged to the second type of ontogeny. So the sex ratio of immature young of the year (2 type) was deviated significantly from 1:1 towards males at the 0.05 level.

Thus, detailed analysis of demography and sex structure on the base of the functional-ontogeny approach allowed for the first time to find the age cross in *S. uralensis* from the EURT zone – forming the pairs by crossing of different generation's individuals: overwintering males crossed with mature young females (1 type). One can consider the age cross as a mechanism of increasing of adaptive possibility of impact rodent's population.

3.2.2 Role of overwintered

The important role in reproduction of rodents in the EURT zone belongs to overwintered animals. Their proportion has been high and has reached 60–80%, compared to 40% in the control population. The results of long-term monitoring rodent populations show that the age composition of the overwintered group is highly variable (fig. 1). It is especially important under unfavorable environmental conditions. This provides the possibility of transgeneration transmission of genetic information, including radiation-induced effects from previous generations. There are enough data on genomic instability and transgenerational transmission of radiation-induced genetic instability between generations in human [10] and in mouse-like rodents chronically exposed to low-dose radiation from Chernobyl fallout (22 generations over 10 years) [11]. By the way, our data [12] also testify about intensive mutagenic process in *S. uralensis* and field mice (*Apodemus agrarius)* from the EURT zone and significant positive correlation of the frequency of aberrant cells in bone marrow and the specific activity of the ^{90}Sr in the bone tissue.

Thus, overwintered animals, whose members are equal physiologically, are highly heterogeneous, since include representatives of all generations born in the previous year (fig. 1), with their proportions being variable. This provides the possibility of genetic information transmission not only via successive change of generations, but also directly from the first generation born in a given year to the first generation born in the next year of birth (transgeneration transmission). Knowledge of these aspects appears important for the practice of ecogenetic studies on rodents, since overwintered animals, being similar in morphophysiological and many another aspects differ in origin and, in different years, may qualitatively differ in the ratio of allele frequencies. This is not only a result of successive generation change rations, but also a qualitative basis for assessing the adaptive potential of the population.

3.3 Accumulation of ^{90}Sr

The main question is how the specificity of two alternative types of ontogeny could be protecting a population in the radiocontaminated environment? Intensification of the mutation process is related to the elevated content of ^{90}Sr in the environment and its significant accumulation in the animals' bone tissue. According to our data [12], in spite of the significant variability of individual specific activities of ^{90}Sr and cytogenetic parameters, an excess over background values of radionuclide accumulation by eight or more times leads to a significant increase in chromosomal instability at the population level. However, the possibility of radioadaptation in a series of generations that developed due to ecophysiological features (subterranean borrowing way of life, quite low migratory activity) and isolation of settlement in the EURT zone (since 1957) was shown in mole-voles (*Ellobius talpinus*) [13, 14]. But mice and voles form a flowing population and slip off the prolonged influence of a damaging factor, this circumstance prevents the development of radioadaptation [3]. Multigenerational effects induced by chronic external and internal irradiation by ^{137}Cs (direct effects, transgeneration transmission of radiation-induced damages, radioadaptive effects) have been observed in natural bank vole (*Clethrionomys glareolus*) population inhabiting in the Chernobyl zone [15].

We revealed [16] higher (twice) intensity of ^{90}Sr accumulation in bone tissue of immature young of the year (2 type) as compared to mature young of the year (1 type), i.e. the rate of ^{90}Sr deposition

is determined by the functional status of animals. Accumulation of osteotropic radionuclides, hence, exposure to chronic irradiation influence refracts through functional structure of a population (through specificity of two alternative types of ontogenetic development). By the way it should be note that interpretation of obtained data (^{90}Sr accumulation) is difficult because of specific configuration of the EURT zone and migration processes in rodents. The future researches are necessary to estimate the share of migrants in both directions and to study correctly of ^{90}Sr specific activity and dose loads in specimens of different age and functional status depending on time of their stay in the polluted a zone.

4. CONCLUSION

Stability of a population, as a homeostatic system in the radiocontaminated environment, is reached due to intensification of metabolism and population reproduction i.e. increases of proportion of individuals of the first type of ontogeny. We suppose that the mechanism of switching to a certain type of ontogeny is mainly triggered by environmental factors of both natural and man-made nature, including ionizing radiation, which is known to act as a stressor. The most typical response to stressors in vertebrates is a steady modification of endocrine system and the release of glucocorticoids. The response is ultimately controlled by the hypothalamic-pituitary-adrenocortical (HPA) axis (stress axis) [17]. Physiological consequences of long-term activation of adrenocortical function as a response on environmental stress-stimul depends on stage of ontogenic development and display by suppression of sexual maturation, stimulation of dispersal, delayed reproduction and weak competitive ability in social interactions [18]. These effects traditionally considered as pathologies may be founded as adaptive in occasions when stimulation of reproductive effects is favor for the increase of population fitness.

Boonstra with co-authors [17] reported, that medow voles (*Microtus pennsilvanicus),* which exposed to a low dose of chronic gamma radiation from ^{137}Cs field radiator, display a hormetic response - stimulation of haemopoietic system. Levels of free and total corticosterone were significantly higher than those in the control or high-dose groups. Besides they revealed differences between the sexes and reproductive status of animals: free and total corticosterone levels were twice higher in breeding females than males, independent of radiation treatment. These differences are the result of male and female sex steroid hormones having differential effects on the HPA axis (adrenocorticotropine and glucocorticoids). Testosterone is known to be inhibitory, whereas estrogen is stimulatory, especially, in pregnant or lactating females [19].

Radiation stress stimulates of reproductive activity and modifies life histories of rodents which may provide to individual with some selective advantages in radioactively polluted environment. Despite on changing composition (because of migration) population is compelled to include more energy-intensive way of maintenance of its ability to live – the first pathway of ontogeny. It is important that these individuals have small life span and lower radionuclide's accumulation. There is positive correlation between the individual allozyme' heterozigosity and the intensity of basic metabolism, while the genetic control of other attributes (rates of development and maturation, life span, body size) refracts through this dependence [20]. Preconditions for acceleration of evolutionary transformations of populations are created, but this process is often restrained by both the local configuration of the polluted territories and migration of murine rodents. As a consequence, the population of mobile species decreases the probability that certain changes would have been fixed and inherited in a series of generations. Thus, chronic low-dose irradiation (radiation stress) can be considered as the mechanism of switching of life history of cyclomorphic mammals.

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