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Metabolic Reactions of *Apodemus* (*S.*) *uralensis* (Muridae, Rodentia) to Radioactive Contamination of the Environment Depending on the Population Number Dynamics

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Abstract—In order to reveal the most important reactions of animals and humans to radioactive contamination of the environment, the dependence of the biochemical parameters of lipid, carbohydrate, and protein metabolism on the population number dynamics as a major environmental factor has been studied in the pygmy wood mouse (*Apodemus* (*S.*) *uralensis*) within the East Ural Radioactive Trace (EURT). As the population number within the EURT area increases, the level of oxidative metabolism and cell-tissue functional activity, combined with inhibition of protein and lipid biosynthesis, has been found to become more pronounced compared to the reference (background) territory. This characterizes the condition of chronic stress with some signs of exhaustion of energy resources in the body. A differentiated account of the population number allows us to correct the results of radiation effects and their interpretation, emphasizing the need to study major environmental factors in the evaluation of technogenic (first of all, radioactive) effects on human and animal populations.

Keywords: EURT area, pygmy wood mouse, lipid, carbohydrate, and protein metabolism, population number dynamics

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INTRODUCTION

The morphophysiological and functional-metabolic states of animals in the natural environment demonstrate the consequences of radiation accidents and, at the same time, turn out to be parts of multivariate analysis of the combined influence exercised by natural and anthropogenic factors on the body and on the population as a whole. The population number dynamics as the main ecological factor of population homeostasis is the result of external and internal influences: weather conditions, food supply, predators, etc., and density-dependent autoregulatory mechanisms (Shilov, 1967; Zhigal'skii, 2002; Rogovin and Moshkin, 2007). The role played by the high population number as a stress factor influencing the metabolic characteristics of the body and, thus, energy-producing processes determining the functioning level of the cell-tissue systems and the body as a whole has been revealed (Christian, 1963; Shilov, 1984; Chernyavskii et al., 2003).

The purpose of this paper is to study the dependences of metabolic reactions in the body of small-sized mammals within the East Ural Radioactive Trace (EURT) on the average annual values of their population number.

MATERIALS AND METHODS

Rodent specimens were caught in 2002–2006 according to the standard methods (Karaseva and Telitsyna, 1996) at two stationary plots. The first plot is located in the head part of the EURT, where the density of soil contamination with ^{90}Sr varies from 6740 to 16690 kBq/m^2, while the second one in the adjacent territory varies with a density of 43.7 kBq/m^2; i.e., it was taken as the reference plot (Pozolotina et al., 2008). The level of soil contamination at the reference plot was more than one order lower than the concentrations of radionuclides, which were accepted as critical for safe living in the EURT area, where the γ-background does not exceed the average values in the Urals (Nikipelov et al., 1989).

The samplings of pygmy wood mouse (*Apodemus* (*S.*) *uralensis* Pall., 1811) came from 34 specimens within the EURT area and 30 specimens in the reference area. All specimens were calibrated by the functional-age status. They were underyearlings of the second ontogenetic type that do not reproduce in the year of birth, which was estimated by the state of the generative system and dentition (Kolcheva, 1992; Olenev, 2002).

In 2002–2006, according to the investigations by E.B. Grigorkina, G.V. Olenev, and M.V. Modorov (Grigorkina et al., 2008), the average annual relative abundance of *A. uralensis* varied from 6.7 to 21.1 spec./100 t.-d. at the reference plot and from 7.6 to 28.1 spec./100 t.-d. within the EURT area. The maximum abundance was registered in 2005 and 2006, whereas the minimum one occurred in 2004 (Table).

The metabolic reactions were studied by 12 biochemical characteristics using spectrometric and colorimetric methods:

—carbohydrate metabolism by the content of glycogen in the liver (Danchenko and Chirkin, 2010), glucose concentration in the blood plasma, and phosphate isomerase activity of erythrocytes in the peripheral blood (Korovkin, 1965);

—lipid exchange based on the concentration of total lipids (Fletcher, 1968) and malondialdehyde (MDA) as secondary product of their peroxidation in the liver, adrenals, myocardium, and plasma of the peripheral blood (Stal'naya and Garishvili, 1977);

—protein metabolism based on the content of total protein in the blood plasma and spleen (Bradford, 1976).

The methods of biochemical investigation are given by L.N. Rasina and N.A. Orekhova (2009).

The data were statistically processed using the STATISTICA (v. 8.0) and STATGRAPHICS (v. 8.0) program packages. The dependence of the biochemical characteristics on the average annual abundance was studied by regression analysis (Draper and Smith, 2007). Multivariate comparison of the samplings was analyzed with the help of discriminant analysis (Kim et al., 1998).

RESULTS AND DISCUSSION

The homeostasis of the population is based on ecological and physiological mechanisms of the adaptive syndrome (Shilov, 1984; Christian, 1963). During the abundance peak when specimens begin to compete more fiercely over the environmental resources, the state of stress develops. It not only causes metabolism intensification, but also modifies the behavior and inhibits both growth and the reproductive system (Chernyavskii et al., 2003; Zav'yalov et al., 2007). These changes limit overpopulation, thereby favoring adaptation under the conditions of poor food supply (Rogovin and Moshkin, 2007).

At the same time, the classic concept of stress as described by H. Selye (1946) states that it can be only one expression in the overall system of nonspecific adaptive reactions in the body. It was demonstrated by many authors (Gorizontov and Protasov, 1968; Panin, 1983; Khaidarliu, 1989; Garkavi et al., 1990) that metabolic changes depend on the degree of influence exercised by ecological factors.

Average annual values of *A. uralensis* abundance

Year of trapping	Abundance, spec./100 t.-d.	
	reference area	EURT
2002	15.2	14.4
2004	6.7	7.6
2005	21.1	26.3
2006	18.4	28.1

Differences were established in functional–metabolic reactions of *A. uralensis* to changes in the abundance of populations within the reference and EURT areas. In the reference area, mobilization of energy reserves increases as the population abundance gets higher in accordance with the higher concentration of total lipids and glucose in the blood plasma, as well as the decrease in the content of glycogen and the increase in the level of lipids in the liver (Fig. 1). Intensification of the oxidative metabolism in tissues, which is determined by their more active functioning as a result of glucose phosphate isomerase activation of erythrocytes, increased the concentration of MDA in the liver, myocardium, and adrenals. These metabolic mechanisms are meant to increase the level of homeostasis (Barnett et al., 1960; Dubuc et al., 1983; Hershos and Vogel, 1989; Goda et al., 1991) and reflect the reaction to an increase in the population abundance. As the population abundance grows, the concentration of total protein in the blood plasma and spleen (see Fig. 1) grows, which characterizes the state of moderate physical tension (Panin, 1983; Garkavi et al., 1990).

On the territory of EURT, metabolic reactions to an increase in the population abundance, in contrast to those within the reference area, are characterized by a decrease in the concentration of glucose within the blood plasma, an increase in the content of glycogen in the liver, and a decrease in the level of total protein in the spleen (see Fig. 1). The revealed dependence is caused by the long-term stimulation of adrenocorticoid activity initiating more intensive glucose utilization in the tissues at the expense of the protein component of tissues, especially the spleen, which is a symptom of chronic stress (Panin, 1983; Mayer and Rosen, 1977; Scheurink et al., 1989; Aguas et al., 1999; Kirillov and Smorodchenko, 1999). Along with that, higher MDA concentration in the liver, myocardium, and adrenals is accompanied by lower level of total lipids in the tissues, in contrast to the reference level, and indicates a shift in lipid metabolism towards the catabolic component, which is especially pronounced in the adrenals. The results demonstrate a long-term hyperfunction of cells and tissues under a lack of energy resources for recovery processes in the body (Meyerson, 1981). Functional and metabolic shifts in the body of animals inhabiting the EURT area, which are

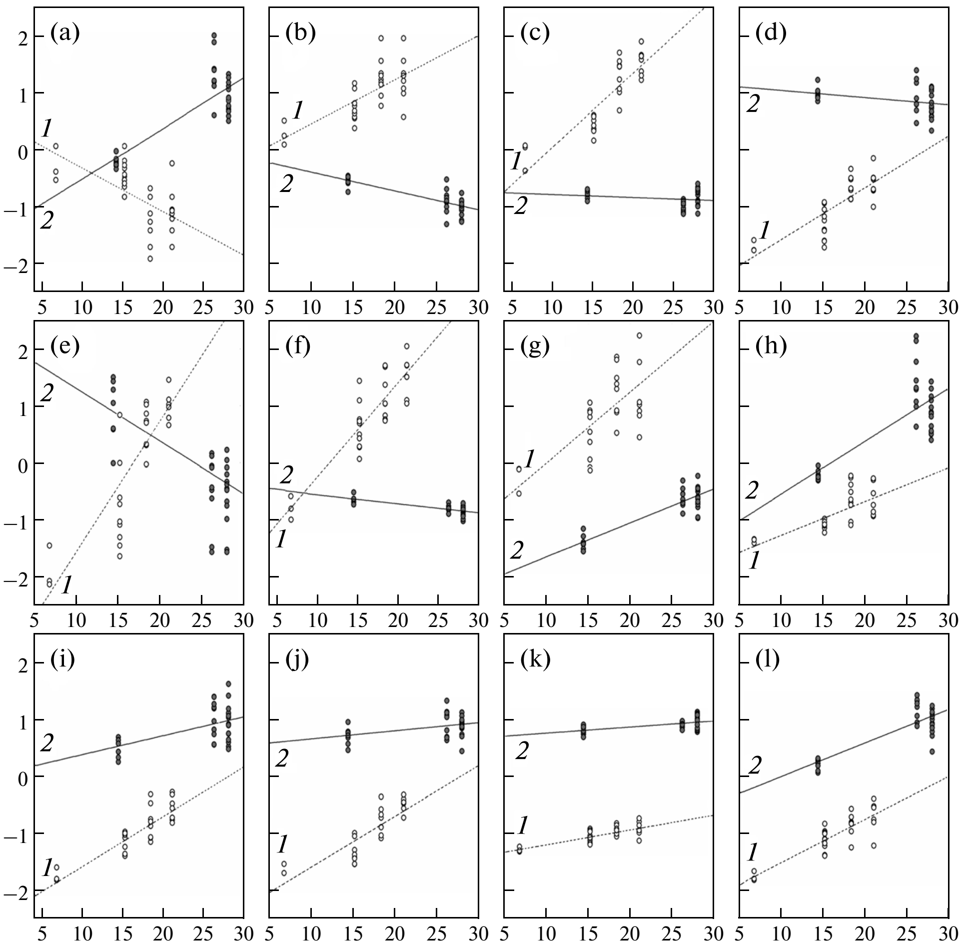

Fig. 1. Dependence of the biochemical parameters in *Apodemus* (*S.*) *uralensis* from the reference (*1*) and radioactively polluted (*2*) area on the average annual values of population number. X-axis: average annual values of the population number (spec./100 t.-d.). Y-axis: standard biochemical parameters: (a) glycogen content in the liver; (b) glucose concentration in the blood plasma; (c) total protein content in the spleen; (d) total lipid concentration in the liver; (e) total lipid concentration in the adrenals; (f) total lipid concentration in the myocardium; (g) total protein concentration in the blood plasma; (h) MDA concentration in the adrenals; (i) total lipid concentration in the blood plasma; (j) MDA concentration in the myocardium; (k) glucose phosphate isomerase activity of erythrocytes; (l) MDA concentration in the liver. Regression coefficients are statistically significant at $p \leq 0.05$.

associated with an increase in the abundance, are more pronounced compared to the reference ones and result from the influence of radiation and natural factors.

Comparison of the Mahalanobis squared distance (D^2) based on the complex of biochemical parameters at various levels of abundance between the samplings of specimens in the EURT and reference areas is characterized by a 1.5-times increase in the metabolic effects of chronic irradiation in the phase of high population abundance (Fig. 2).

CONCLUSIONS

The comparative analysis of the relation between the biochemical characteristics and the average annual values of the pygmy mouse population in the reference and EURT areas produced the following conclusions:

—as the population number in the reference, background, area increases, an increased level of oxidative metabolism and cell-tissue functional activity is observed along with an increase in the level of protein and lipid biosynthesis in the tissues, which indicates moderate physiological tension without symptoms of energy resource depletion;

—functional and metabolic changes in the body of animals within the EURT area are more pronounced as the population number becomes higher and result from the effect of radiation and natural factors;

—the dependence of these reactions on the population number is more pronounced, conjugated, in contrast to the reference territory, with the inhibition of biosynthesis of proteins, lipids, and characterizes severe chronic stress with the symptoms of long-term cell hyperfunction and depletion of energy resources;

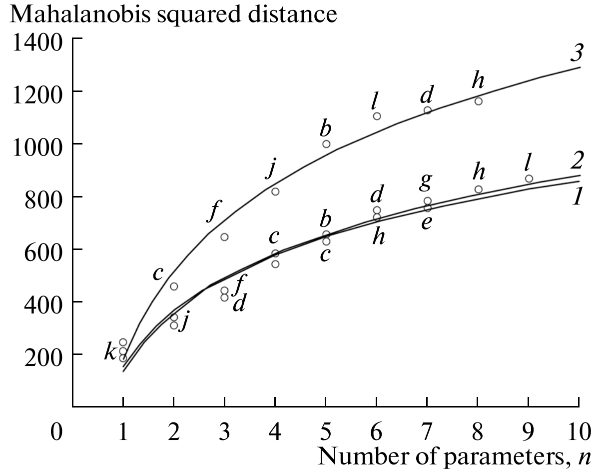

Fig. 2. Mahalanobis squared distance (D^2) calculated by the complex of biochemical characteristics for the samplings of specimens from the EURT and reference areas in the years of low (*1*), average (*2*), and high (*3*) abundance. Stepwise discriminant analysis was performed based on data extrapolated to the values of low (7.15 spec/100 t.-d.), average (14.8 spec./100 t.-d.), and high (23.5 spec./100 t.-d.) abundance. For designations, see Fig. 1.

—censuring of the population allows us to correct the results of radiation effects and their interpretation, emphasizing the need to study major ecological factors when estimating technogenic, first of all radiation, influences on populations of humans and animals.

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REFERENCES

Aguas, A.P., Esaguy, N., Grande, N., Castro, A.P., and Castelo Branco, N.A., Effect of low frequency noise exposure on BALB/c mice splenic lymphocytes, *Aviat. Space Environ. Med.,* 1999, vol. 70, no. 3, pp. 128–131.

Barnett, S.A., Eaton, J.C., and McCallum, N.M., Phisiological effects of "social stress" in wild rats: 2. Liver glycogen and blood glucose, *J. Phychosom. Res.*, 1960, vol. 4, pp. 251–260.

Bradford, M.M., A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principal of protein–dye binding, *Anal. Biochem.*, 1976, vol. 72, nos. 1–2, pp. 248–254.

Chernyavskii, F.B., Lazutkin, A.N., and Mosin, A.F., Variations of some physiological and biochemical indices in the population of red-backed vole (*Clethrionomys rutilus*), *Biol. Bull.,* 2003, vol. 30, no. 3, pp. 291–298.

Christian, J.J., Endocrine adaptive mechanisms and the physiologic regulation growth, *Physiol. Mammal.*, 1963, vol. 1, pp. 189–353.

Danchenko, E.O. and Chirkin, A.A., A new methodological approach to determination of tissue glycogen concentrations and some comments on interpretation of the results, *Sudebno-Med. Ekspert.*, 2010, no. 3, pp. 25–28.

Draper, N.R. and Smith, H., *Applied Regression Analysis*, 3rd ed., New York: Wiley, 1998. Translated under the title *Prikladnoi regressionnyi analiz. Mnozhestvennaya regressiya*, Moscow: Dialektika, 2007.

Dubuc, P.U., Risimaki, S., Cahn, P.J., and Willis, P.L., Glucose tolerance in aging obese (ob/ob) and lean mice, *Hormone Metabol. Res.*, 1983, vol. 15, pp. 120–123.

Fletcher, M.J., A colorimetric method for estimating serum triglycerides, *J. Clin. Chim. Acta*, 1968, vol. 22, no. 3, pp. 393–397.

Garkavi, L.Kh., Kvakina, E.B., and Ukolova, M.A., *Adaptatsionnye reaktsii i rezistentnost' organizma* (Adaptive Reactions and Organism Resistance), Rostov-on-Don: Rostov. Gos. Univ., 1990.

Goda, T., Takase, S., Yokogoshi, H., Mita, T., Isemura, M., and Hoshi, T., Changes in hepatic metabolism thorough simulated weightlessness: decrease of glycogen and increase of lipids following prolonged immobilisation in the rat, *Res. Exp. Med.*, 1991, vol. 191, no. 3, pp. 189–199.

Gorizontov, P.D. and Protasova, T.N., *Rol' AKTG i kortikosteroidov v patologii* (The Role of ACTH and Corticosteroids in Pathology), Moscow: Meditsina, 1968.

Grigorkina, E.B., Olenev, G.V., and Modorov, M.V., Analysis of rodent populations in technogenically transformed areas (with reference to *Apodemus (S.) uralensis* from the EURT zone *Russ. J. Ecol.*, 2008, vol. 39, no. 4, pp. 298–291.

Hershos, D. and Vogel, W.H., The effects of immobilisation stress on serum triglycerides, nonesterified fatty acids, and total cholesterol in male rats after dietary modifications, *Life Sci.*, 1989, vol. 45, pp. 157–165.

Karaseva, E.V. and Telitsyna, A.Yu., *Metody izucheniya gryzunov v polevykh usloviyakh* (Methods of Fields Studies on Rodents), Moscow: Nauka, 1996.

Khaidarliu, S.Kh., *Neiromediatornye mekhanizmy adaptatsii* (Neurotransmitter Mechanisms of Adaptation), Chisinau: Shtiintsa, 1989.

Kim, J.-O., Mueller, Ch.W., and Klecka, W.R., *Faktornyi, diskriminantnyi i klasternyi analiz* (Factor, Discriminant, and Cluster Analysis), Moscow: Finansy i Statistika, 1998.

Kirillov, N.A. and Smorodchenko, A.T., Histochemical characteristics of lymphoid organs in rats subjected to stress, *Bull. Exp. Biol. Med.*, 1999, vol. 127, no. 2, pp. 171–173.

Kolcheva N.E. Dynamics of ecological structure of wood mouse populations in the Southern Urals, *Extended Abstract of Cand. Sci. (Biol.) Dissertation*, Yekaterinburg, 1992.

Korovkin, B.F., *Enzimy v diagnostike infarkta miokarda* (Enzymes in the Diagnosis of Myocardial Infarction), Leningrad: Meditsina, 1965.

Mayer, M. and Rosen, F., Interaction of glucocorticoids and androgens with skeletal muscle, *Metabol. Clin. Exp.*, 1977, vol. 26, no. 8, p. 937.

Meerson, F.Z., *Adaptatsiya, stress i profilaktika* (Adaptation, Stress, and Prophylaxis), Moscow: Nauka, 1981.

Nikipelov, B.V., Romanov, G.N., and Buldakov, L.A., Radiation accident in the South Urals in 1957 and the elimination of its consequences, in *Recovery Operation in the Event* *of Nuclear Accident or Radiological Emergency: Proc. Symp.*, Vienna: IAEA, 1989, pp. 373–403.

Olenev, G.V., Alternative types of ontogeny in cyclomorphic rodents and their role in population dynamics: an ecological analysis, *Russ. J. Ecol.*, 2002, vol. 33, no. 5, pp. 321–330.

Panin, L.E., *Biokhimicheskie mekhanizmy stressa* (Biochemical Mechanisms of Stress), Novosibirsk: Nauka, 1983.

Pozolotina, V.N., Molchanova, I.V., Karavaeva, E.V., Mikhailovskaya, L.N., and Antonova, E.V., *Sovremennoe sostoyanie nazemnykh ekosistem Vostochno-Ural'skogo radioaktivnogo sleda: urovni zagryazneniya, biologicheskie effekty* (Current State of Land Ecosystems in the Eastern Ural Radioactive Trace: Contamination Levels and Biological Effects), Yekaterinburg: Goshchitskii, 2008.

Rasina, L.N. and Orekhova, N.A., Metabolic homeostasis of small mammals in the Eastern Ural Radioactive Trace, *Radiats. Biol. Radioekol.*, 2009, vol. 49, no. 2, pp. 238–245.

Rogovin, K.A. and Moshkin, M.P., Self-regulation of population size in mammals and stress: Strokes to the picture painted long ago, *Zh. Obshch. Biol.*, 2007, vol. 68, no. 4, pp. 244–267.

Scheurink, A.J.W., Steffens, A.B., Bouritus, H., Dreteler, G.H., Bruntink, R., Remie, R., and Zaagsma, J., Adrenal and sympathetic catecholamines in exercising rats, *Am. J. Physiol.,* 1989, vol. 25, pp. 155–170.

Selye, H., The general adaptation syndrome and the diseases of adaptation, *J. Clin. Endocrinol. Metab.,* 1946, no. 6, pp. 117–231.

Shilov, I.A., On mechanisms of animal population homeostasis, *Usp. Sovrem. Biol.*, 1967, vol. 64, no. 2, pp. 333–351.

Shilov, I.A., Stress as an ecological phenomenon, *Zool. Zh.*, 1984, vol. 63, no. 6, pp. 805–811.

Stal'naya, I.D. and Garishvili, T.G., A method for determining malonic dialdehyde with thiobarbituric acid, in *Sovremennye metody v biokhimii* (Modern Methods in Biochemistry), Orekhovich, V.N., Ed., Moscow: Meditsina, 1977, pp. 66–68.

Zav'yalov, E.L., Gerlinskaya, L.A., Ovchinnikova, L.E., and Evsikov, V.I., Stress and territorial organization in the European water vole (*Arvicola terrestris*), *Zool. Zh.*, 2007, vol. 86, no. 2, pp. 242–251.

Zhigalski, O.A., Analysis of small mammal population dynamics, *Zool. Zh.*, 2002, vol. 81, no. 9, pp. 1078–1106.

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