Total mercury in small mammals from forest ecosystems (nearby Cherepovets, Vologda region)

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Abstract. The aim of the research is to determine the total mercury (THg) in small mammals in forest ecosystems at a distance of 3 – 8 km from the boundaries of the industrial site of PJSC Severstal near Cherepovets, Vologda region. THg in the pelage and organs of the Ural field mouse (Apodemus uralensis, Pallas, 1811) varies from less than 0.001 to 0.56 mg/kg of dry weight (DW), the average maximum THg value was in the spleen (0.18 ± 0.07 mg/kg) and minimum in the muscles (0.02 ± 0.01 mg/kg). The content of THg in the pelage and organs of the common shrew (Sorex araneus, Linnaeus, 1758) varies from 0 to 4.57 mg /kg DW, the average maximum value of THg was in pelage (0.76 ± 0.15 mg / kg) and the average minimum in the liver (0.11 ± 0.01 mg /kg). The estimated mean THg level in the common shrew in the wet years 2021-2022 is lower than in the dry years 2009 and 2010. The reason for this is not clear. The results indicate the need for further investigation of changes in the total mercury content in the terrestrial ecosystem.

1 Introduction

Mercury is a unique chemical object with a high migration capacity in the biosphere [1, 2], where natural mercury compounds are in a dispersed state. Mercury is widely used in many industries. Anthropogenic impact leads to increased migration of mercury compounds due to technogenic mercury [3-7]. The existence of mercury in various compounds causes its volatility and high toxicity for all living organisms [8-12]. The danger of mercury became apparent after the mass poisoning of people who used fish with a high content of mercury compounds in the 1950s and 1970s. As a result, international and federal documents were adopted on the need to study the mercury problem [3, 11].

Currently, there are ideas about two main types of mercury circulation: global, which mainly involves atomic mercury vapors, and local, which is associated with mercury entering the atmosphere as a result of anthropogenic activity [12]. One of the main ways mercury enters the environment is the burning of various types of coals. Due to the fact that metallurgical plants use coal in production, in 2009-2010 mercury was assessed in the

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organs and tissues of background species of small mammals near the industrial zone of PJSC Severstal [13].

Terrestrial small mammals (such as shrews, moles, voles, mice) can be successfully used in biomonitoring and ecotoxicological studies, including studies related to mercury pollution [14-20]. Currently, most studies are devoted to the accumulation of mercury in the aquatic environment and there are few studies on the bioaccumulation of mercury in terrestrial ecosystems [21, 22].

Man's impact on nature is growing and the amount of mercury involved in a cycle of matter increases [23, 24], therefore the study of consumption, distribution and accumulation of mercury in different ecosystems does not lose its relevance [25]. In this regard, the purpose of our study was to determine the level of total mercury in small mammals in forest ecosystems near Cherepovets, Vologda region and compare with the results of a study from this area in 2009-2010 [13]. This work is also part of the work aimed at finding out the background level of mercury in living components of different districts of the Vologda Oblast.

2 Materials and methods

The materials for the work are background small mammals in the research area – 45 individuals of the common shrew (*Sorex araneus*, Linnaeus, 1758) and 20 individuals of the Ural field mouse (*Apodemus uralensis*, Pallas, 1811). The animals were captured in forest ecosystems located south of the border of the city of Cherepovets in during the year from September 2020 to August 2021. During the study period, the number of rodents was low, because the high level of precipitation during the breeding season of small mammals and the low level of snow cover in winter led to a high natural death of rodents and insectivores. The research area is located south of the industrial zone of PJSC Severstal, the wind of the southern direction prevails here, wind from the industrial zone towards the stationary observation has a northern and north-western direction and account for 18.5% of the wind rose.

Fig. 1. Map of the research area: red circles – collection sites of small mammals, A – industrial zone, B – residential zone, maroon line – border between industrial and residential zones, blue line – administrative border of Cherepovets

From small mammals, samples of pelage, tissues and organs (brain, liver, kidneys, spleen, chyme, muscles) were taken approximately 0.5 mm^3 or 5-10 g and placed in Eppendorf tubes, frozen and stored at a temperature of about -16 °C. A total of 270 organ samples and 65 pelage samples were collected. Before the mercury content analysis, samples of pelage and organs of small mammals were dried in open test tubes at a temperature of 40 °C for 48 hours in a drying cabinet (SNOL 20/300).

The content of total mercury (THg – the total mercury index, including all forms of mercury that were in the sample) in dried samples was determined on a mercury analyser PA-915+ by the atomic absorption method [26]. A sample weight from 10 to 73 mg was used for incineration in the analyzer. Each sample was tested for mercury twice. The accuracy of analytical measurement methods was controlled using certified biological material DORM-2 and DOLN-2 (Institute of Environmental Chemistry, Ottawa, Canada) [27].

Statistical analyzes were performed using Stat Soft Statistica 12.0 and Microsoft Excel 2016 software. Arithmetic means (AM), error of mean (SE), median, standard deviations (SD), and minimum / maximum (ranges) were calculated. Distribution of empirical data on THg concentrations in the pelage of the studied animals diverged from the expected normal distribution, as shown by the Kolmogorov-Smirnov test with Lilliefors correction. Therefore, in comparisons of mean values of THg concentration, nonparametric Kraskell-Wallis tests were used. Statistical significance was determined at $p < 0.05$.

The work is done using equipment Regional shared services center of Cherepovets State University.

3 Results

The content of THg in the pelage and organs of the Ural field mouse varies from less than 0.001 to 0.56 mg/kg of dry weight. In the pelage and organs of the Ural field mouse, the average value was maximal in the spleen (0.18 ± 0.07 mg/kg dry weight) and minimal in the muscles (0.02 ± 0.01 mg/kg dry weight), and in general it is characterized by the accumulation of mercury in the rank row: muscles (0.023 mg/kg) < kidneys (0.057 mg/kg) < pelage (0.067 mg/kg) < liver (0.068 mg/kg) < chyme (0.074 mg/kg) < brain (0.085 mg/kg) < spleen (0.179 mg/kg).

The content of THg in the pelage and organs of the common shrew in forest ecosystems varies from 0 to 4.57 mg/kg of dry weight. In the pelage, organs and tissues of this shrew, the average value was maximum in pelage (0.76 ± 0.15 mg/kg dry weight) and minimal in the liver (0.11 ± 0.01 mg / kg dry weight). The mercury content in the pelage of adult common shrew (n=4) was higher than in young (n=16): 0.47 ± 0.18 mg/kg and 0.19 ± 0.04 mg/kg (differences are not statistically significant (p=0.89)). This background type of the research area is characterized by the accumulation of mercury in a row: liver (0.11) < brain < (0.12) < spleen (0.13) < muscles (0.15) < chyme (0.15) < kidneys (0.22) < pelage (0.76 mg/kg dry weight).

Interspecific differences in the level of mercury accumulation in the studied small mammals were noted (Fig. 2). The average content of total mercury in almost all organs, except the spleen, is higher in the studied organs of the common shrew (limits: 0 – 4.57 mg/kg dry weight) compared with the organs of the Ural field mouse (limits: 0 – 0.56 mg/kg of dry weight). Statistically significant differences were noted in pelage, kidneys and muscles (p=0,0004; 0,0004; 0,00002, respectively, at $p < 0.05$) (Fig. 3).

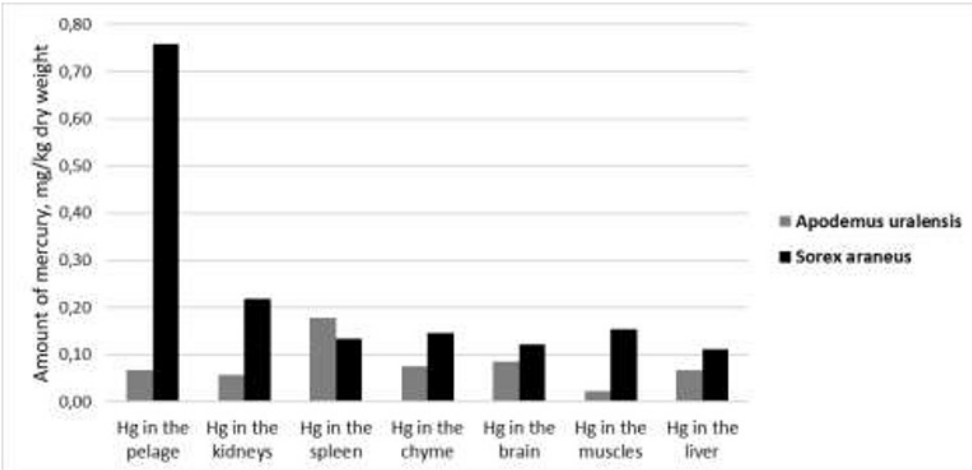

Fig. 2. The average content of total mercury in the organs and tissues of the Ural field mouse (*Apodemus uralensis*, Pallas, 1811) (n = 20) and the common shrew (*Sorex araneus*, Linnaeus, 1758) (n = 45).

4 Discussion

The mercury content in the brain, muscles, liver and kidneys is most often studied, and the highest concentrations of mercury are found in the last two organs [22, 28, 29]. When the list of studied objects expands, it turns out that the maximum mercury values are set in pelage [30] and spleen [31]. T.S. Ershova and V.F. Zaitsev [31] showed that significant concentrations of THg were observed in organs characterized by active metabolic processes and active participation in processes aimed at maintaining homeostasis, such as the spleen. A higher concentration of mercury in pelage compared to internal organs may indicate a long-term accumulation of this toxicant [32]. In our study, the highest levels of THg in the spleen were noted in the Ural field mouse, and the maximum values of THg in the pelage in the common shrew. Apparently, such differences are related to the ecological and physiological specificity of rodents and insectivores.

The estimated mean THg level in the liver of the Ural field mouse (0.068 mg/kg) in the zone around a metallurgical plant and in the liver of *Ap. flavicollis* from Slovenia (0.06 – 0.33 mg/kg) [14], *Ap. sylvaticus* from northern Spain (0.018 mg/kg) [33] and the UK (0.001 and 0.076 mg/kg [34] suggests that the level we found approximately corresponds to anthropogenic ecosystems near power plants [14] and from various polluted and unpolluted areas in Galicia in northern Spain [33] and is one fifth of the mercury level near lead smelting in Slovenia [14].

The estimated mean THg level in the liver of the Ural field mouse is twice as high as in the liver of the bank vole (*Myodes glareolus*) from the same area in 2009-2010 [13]. Interspecific differences in mercury concentrations in the tissues and organs of small mammals are obviously related to the type of nutrition. Mercury enters the body of small mammals mainly with animal food (the basis of nutrition of the common shrew) and to a lesser extent – with plant food (the basis of nutrition of the Ural field mouse).

The average annual concentration Hg in the liver of a common shrew (0.11 mg/kg DW) is twofold higher than in the Ural field mouse. The average summer concentration THg in the liver (0.06 mg/kg DW) is less than average summer in 2009 and 2010 (0.2 and 0.18 mg/kg) [13]. And this is four tenfold lower than in three Sorex species in Sikhote-Alin [30] and industrial areas of Europe and North America [15, 13]. Sikhote-Alin located very close to the Pacific Ocean, so the sea fog may impact for the increase of the mercury concentration in terrestrial biota [35, 36].

Such low levels of mercury in the common shrews can be determined by both specific trophic features and polluted and unpolluted areas. For example, *Crocidura russula* living in near-water and wet places and eating semi-aquatic animals contained 0.83 mg/kg and 0.38 mg/kg females in the control and 1.49 mg/kg and 1.11 mg/kg in a contaminated area near a pyrite mine in Spain [15].

There is an idea that in seasons with different humidity, animals accumulate different amounts of mercury and more mercury accumulates in wet seasons. Thus, the total mercury concentrations in fish during the rainy season are about 15 fold higher than those in the dry season [37]. In our study, the estimated mean THg level in the common shrew in the wet years 2021-2022 is lower than in the dry years 2009 and 2010 [13]. The reason for this is not clear.

5 Conclusion

Thus, there is a low the mean THg level (mg/kg DW) in muscles (0.023), kidneys (0.057), liver (0.068), brain (0.085) of the Ural field mouse and in the liver (0.11), brain (0.12), muscles (0.15), kidneys (0.22) of a common shrew in forest ecosystems near the metallurgical plant zone in Cherepovets, Vologda region. The THg levels estimated are lower than from this area in 2009-2010. We are currently unable to determine the cause of such differences. Perhaps this is due to the use of modern filters to clean emissions at the plant in the last decade. The results indicate the need for further investigation of changes in the total mercury content in the terrestrial ecosystem and are needed to solve new problems in assessing background levels in living components of ecosystems in the Vologda Oblast.

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