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The role of the Korean wood mouse (Apodemus peninsulae Thomas, 1907) in mercury transport in ecosystems in the south-east of Sikhote-Alin

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Abstract. The role of the Korean wood mouse in mercury transport was studied by total mercury in 2018 and 2022. In 2018, the total mercury content of the Korean wood mouse was generally lower than in 2022. What is the reason for such differences in mercury levels between years is not clear. Total mercury in this rodent ranged from 0.000 mg/kg dry weight (DW, brain, pelage, muscles, liver, kidney) up to 0.576 mg/kg DW (liver). Median distribution decreased as following: kids (0.053 mg/kg DW) → lien (0.048) → chyme (0.047) → pelage (0.045) → gut (0.044) → liver (0.042) → muscles (0.025) → brain (0.015). The Korean wood mouse is the main prey of the leopard cat. The high level of mercury in the leopard cat's fur (1,736 ± 0,351 mg/kg) is associated with mice. The Korean wood mouse, as a food object of more than 200 vertebrates, accumulates mercury in its body and transfers to the following trophic levels in an amount much larger than true herbivores, for example, water deer. This indicates its significant role in the transport of mercury in the terrestrial ecosystem.

1 Introduction

The high toxicity of mercury to various living organisms and the anthropogenic increase in the amount of mercury involved in the circulation of matter require the scientific community to pay attention and study it everywhere [1]. And if the mercury content in the lithosphere as a whole is approximately estimated from 0.007 g/t [2] to 0.5 g/t [3] – 0.77 g/t [4], then the mercury content in the biosphere and its components and the natural processes of mercury transport in different environments are insufficiently studied [5, 6]. For example, a recent study of various forms of mercury in the inanimate and living components of the ocean and land [7, 8] showed that sea fog is a source of mercury for terrestrial ecosystems in California [9]. The assessment of the total mercury (THg) content in the Amur tiger fur in the Sikhote-Alin mountain system and in the Southwestern Primorye [10, 11] confirmed the pattern established by Weiss-Penzias and co-authors [9]: the mercury level in the zone of influence of the sea is higher than in the inner zone [10, 11]. At the same time, the south of the Russian Far East is of interest for the study of mercury due to the fact that gold, coal and mercury-containing minerals are actively mined

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in this region and in its neighborhood. In this region, pilot studies of the total mercury content in organs, tissues and fur of bears [12], wild cats [10, 11], shrews [13] and deer [14] were conducted on small samples.

Due to the fact that there is a need to know the background levels of mercury in living components of systems, the background species of forest ecosystems in the south of the Russian Far East, the Korean forest mouse, was selected at this stage of the study. These rodents are eaten by birds, mammals, reptiles, and fish [15, 16]. Therefore, the aim of the work was to find out the role of the Korean forest mouse in the transport of mercury to different trophic levels in the ecosystem, for this purpose, the concentration of total mercury in the organs, tissues and pelage of this rodent was studied.

2 Materials and methods

The level of total mercury in organs, tissues and pelage was studied in the Korean wood mouse (n = 75) collected in 2018-2022 on the territory of Southern Primorye (Fig. 1). The determination of THg was carried out in the ecological and analytical laboratory of Cherepovets State University using the mercury analyzer RA-915M (Lumex). Measurements are made in dry weight. The accuracy of the analyzer was tested using DORM-4 reference samples with a known mercury concentration (mg/kg). Statistical analysis was carried out using the programs Stat Soft Statistica 12.0 and Microsoft Excel 2016. The normality of data distribution of THg concentration in the samples was tested by the Kolmogorov–Smirnov test with Lilliefors correction. Since the distribution of all the data was not normal, nonparametric Mann–Whitney U-test and Kruskal Wallis H-test were applied. The level of significance was set at $p < 0.05$. Nonparametric Spearman's correlation (Rs, $p < 0.05$) was applied to analyze the pairwise relationship of mercury concentration in the studied tissues, as well as to assess the relationships between the mercury concentration and population parameters.

Fig. 1. Research area: sample collection site (according to [17]).

3 Results and discussion

The total mercury concentration in the tissues of the Korean wood mouse ranged from 0.000 mg/kg dry weight (DW, brain, pelage, muscles, liver, kidneys) up to 0.576 mg/kg

DW (liver). The average THg mercury concentration in the tissues of the Korean wood mouse decreased as following: kidneys (0.099 mg/kg DW) → pelage (0.084) → liver (0.063) → lien (0.054) → chyme (0.054) → intestine (0.052) → muscles (0.051) → brain (0.026). The median THg values were slightly different from the mean and decreased as following: kidneys (0.053 mg/kg DW) → lien (0.048) → chyme (0.047) → pelage (0.045) → intestine (0.044) → liver (0.042) → muscles (0.025) → brain (0.015) (Fig. 2). Median THg values in kidneys, pelage and muscles were two times lower than the average values (Fig. 2), these data more accurately characterize the population of the Korean forest mouse and its role in the transfer of mercury to higher trophic levels, because these data show mercury levels for half of the Korean wood mouse population.

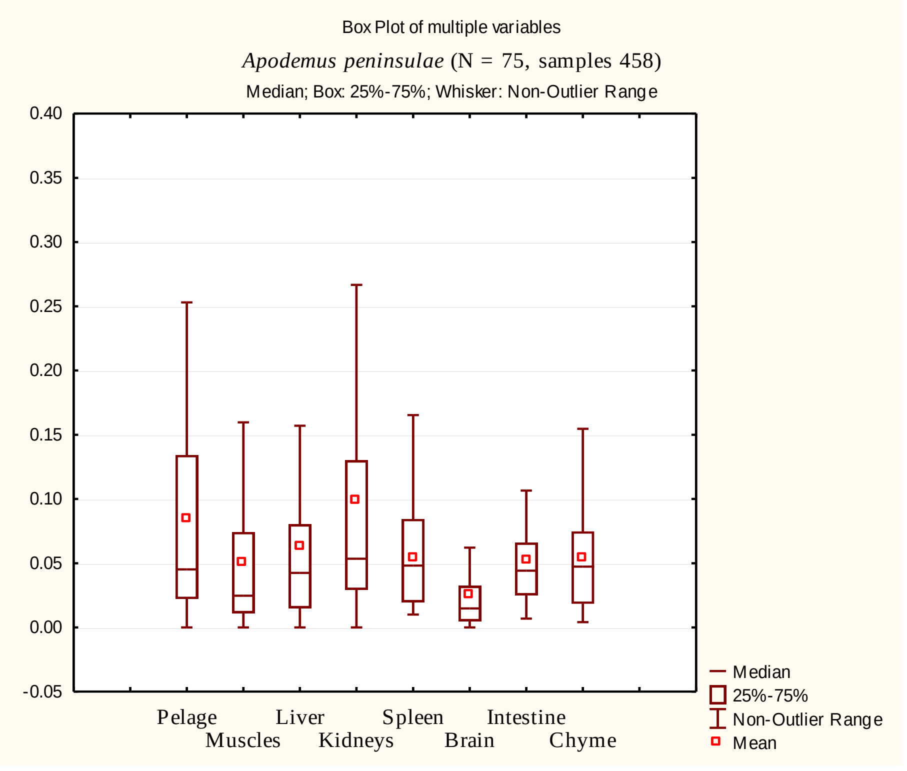
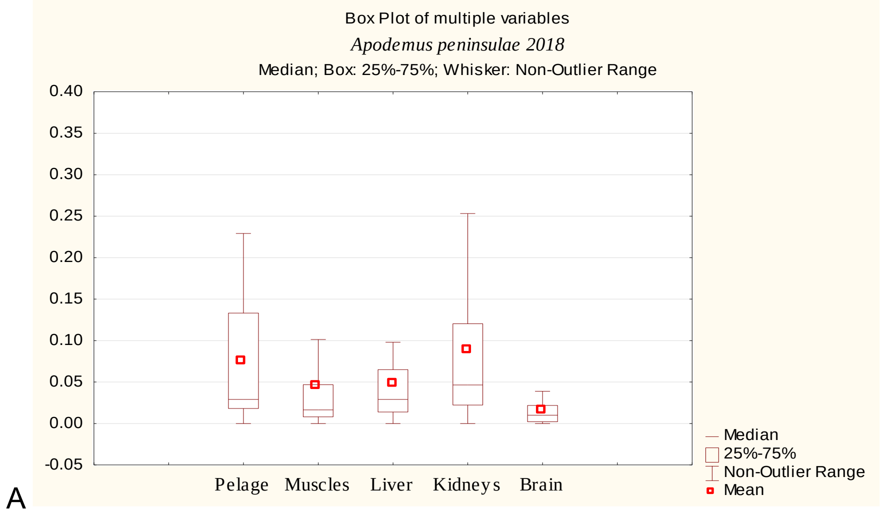


Fig. 2. Total mercury (mg/kg dry weight) in the organs, tissues and pelage of the Korean wood mouse (*Apodemus peninsulae* Thomas, 1907).

The mercury concentration in all organs of the Korean wood mouse did not differ significantly. There were no differences in THg content between organs in adult and young males. In females, the THg concentration increased with age and differed significantly in pelage ($p = 0.006$), in muscles ($p = 0.006$), liver ($p = 0.000$), kidneys ($p = 0.000$) and brain ($p = 0.005$). In adult females, the THg concentration was higher than in adult males in the liver ($p = 0.005$), kidneys ($p = 0.032$), spleen ($p = 0.029$), intestine ($p = 0.012$) and chyme ($p = 0.002$). There were no differences in THg concentration in organs, pelage and tissues in young immature males and females.

In 2018, the THg content of the Korean wood mouse was generally lower than in 2022 (Fig. 3). Differences in the level of mercury between the years were also revealed for the common shrew [1, 18]. What is the reason for such differences in mercury levels between years is not clear. This may depend on the soil moisture [1, 5], but, apparently, also on some other parameters, so the THg of the common shrew in the wetter 2021 was lower than in humid seasons 2009 and 2010 [18]. Although differences were revealed, the numerical values of mercury for the Korean wood mouse obtained in protected areas were in the range of the same order. And these values were less than data on other organs in different mice (genus *Apodemus*) obtained in the zone of strong anthropogenic pollution near industrial plants [18-21]. Thus, the content of THg in the pelage of the Ural field mouse was 0.067 mg/kg in the zone around a metallurgical plant [18], this was more than that of the Korean wood mouse (0.045 mg/kg) in the study area. Data from protected areas support the proposal to preserve the nature reserves of the Russian Federation as reference territories [14].



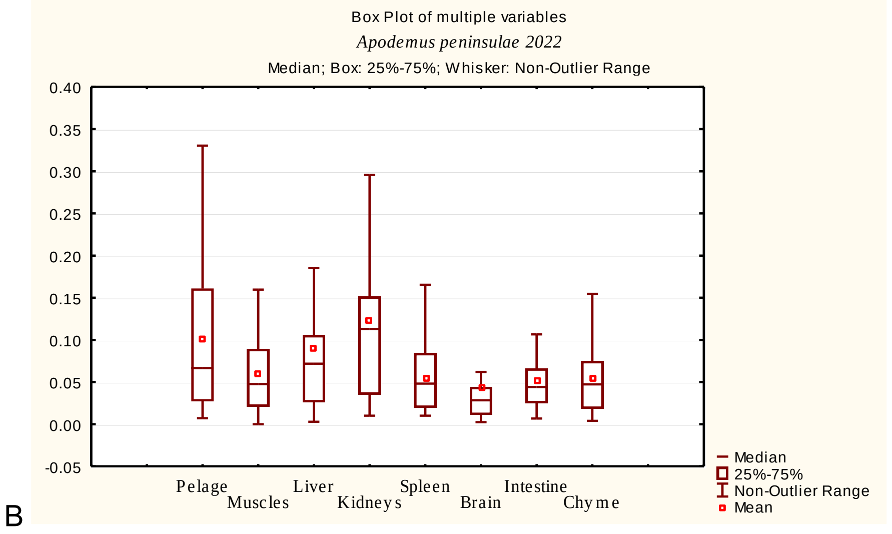


Fig. 3. Total mercury (mg/kg dry weight) in the organs, tissues and pelage of the Korean wood mouse (*Apodemus peninsulae* Thomas, 1907) in A – 2018 and B – 2022.

Comparison of THg in mice and shrews from the same area [13] showed that the rank range was the same as that of the Korean forest mouse: the average THg mercury concentration in the tissues of the studied shrews decreased as following: kidneys (0.91

mg/kg DW) → pelage (0.87) → liver (0.56) → muscles (0.54) → brain (0.36). The average values in different organs, muscles and pelage differed 10–12 and median values 12–22 times: in the kidneys of the Korean wood mouse it was less than in shrews by about 15 times, in the liver – 13 times, in pelage – 12 times, in the brain – 22 times (Table 1). Mercury content is usually studied in four objects: liver, kidneys, muscles and brain, the maximum mercury values are noted in the kidneys and liver [20, 22, 23]. With the expansion of the list of organs and tissues, the maximum levels of mercury can be observed in the pelage of shrews (genus *Sorex*) [13] and the spleen of the Ural field mouse [18]. The Korean wood mouse has slightly less the mercury content in the spleen than in the kidneys.

Table 1. Total mercury content in all organs of the Korean wood mouse and Shrews (genus Sorex) of the Sikhote-Alin mountain system.

Objects	The median of total mercury (mg/kg)	
	Apodemus peninsulae Thomas, 1907	Shrews (genus *Sorex*)
Pelage	0.045	0.58
Muscles	0.025	0.40
Liver	0.042	0.40
Kidneys	0.053	0.78
Brain	0.015	0.35

To assess the role of mice in the transport of mercury in the ecosystem, we used available data on other animals that are at higher trophic levels and can sometimes or often eat mice and data on other animals having a trophic level similar to mice (Table 2). The fur of herbivore, a water deer (*Hydropotes inermis argyropus* Heude, 1884) contains mercury 15 times less than that of the Korean forest mouse. This difference may be due to the fact that mice often eat insects [15, 16]. The fur of carnivores, *Panthera tigris altaica* Temminck, 1844 and shrews (genus *Sorex*) contains mercury more near 4-8 times than that of the Korean forest mouse, the omnivore fur – the Ussuri black bear (*Ursus thibetanus* G. Cuvier, 1823) exceeds the mercury content in the fur of mice only by 3 times. The fur the leopard cat (*Prionailurus bengalensis euptilura* Elliot, 1871) exceeds the mercury content in the fur of mice by 15 times. This predator eats mainly mice and less often hares, birds, insects, shrews, other predators and hydrobiontes [24, 25]. Can mice mainly lead to such high levels of mercury in the leopard cat's fur? We cannot answer unequivocally. But if the lynx feeds on true herbivores – hares [26], and we assume a 26-fold increase in mercury from true herbivorous deer to lynx (Table 2), then we can expect that the high level of mercury in the leopard cat's fur is associated with mice.

Table 2. Total mercury content in mammalian fur in the south of Primorsky Krai (*a rare and protected animal [27]).

Species	N samples	Limits, mg/kg	Mean ± SE , mg/kg	Reference
Ap. penninsulae Thomas, 1907	75	0.004 - 0.502	0.118 ± 0.020	
Shrews *Sorex*	58	0.14 – 3.79	0.90 ± 0.16	[13]
**Hydropotes inermis argyropus* Heude, 1884	7	0.001 –0.026	0.008 ± 0.003	[14]
Lynx lynx Linnaeus, 1758	3	0.070 – 0.468	0.206	[11]
**Panthera tigris altaica* Temminck, 1844	6	0.115 – 0.918	0.434 ± 0.067	[11]
**Prionailurus bengalensis euptilurus* Elliot, 1871	14	0.108 – 6.180	1.736 ± 0.351	[25]
**Ursus thibetanus* G. Cuvier, 1823	22	0.055 – 1.233	0.336 ± 0.056	[12]

4 Conclusion

Thus, the Korean forest mouse, as a food object of more than 200 vertebrates [15, 16], accumulates mercury in its body and transfers to the following trophic levels in an amount much larger than true herbivores, for example, water deer. This indicates its significant role in the transport of mercury in the terrestrial ecosystem. And if we take into account that the south of the Russian Far East is a unique region where there are many species – Mesozoic relics and rare species, and the Korean forest mouse is eaten by five species of mammals, 29 species of birds, three species of snakes and eight species of fish listed in the Red Book of Primorsky Krai [27], then its role in the ecosystem seems significant also for this reason.

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