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Article

Mercury in the body of mammals of the Republic of Karelia (Russia)

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Abstract. The study analyzed mercury (Hg) concentrations in mammals with different ecological and trophic specializations living in the Republic of Karelia. The subjects of this study comprised 18 species from the orders Carnivora, Artiodactyla, Eulipotyphla, and Rodentia. The total Hg content in the liver, kidney, and skeletal muscle of the animals was determined by direct pyrolytic decomposition with atomic absorption detection. The identified features of Hg levels in the studied animals were consistent with well-known patterns of metal distribution both between organs in individual species and within the level of consumers in food chains. In the majority of animal species examined, the kidneys were found to contain the highest concentrations of Hg, with the liver exhibiting a lower but still significant level of accumulation. Notwithstanding the subject's lifestyle (terrestrial or semi-aquatic), second-order consumers (carnivorous species) were distinguished by elevated Hg levels in the body in comparison to first-order consumers (species that primarily consume plant-based foods). The concentrations of Hg in the bodies of animals in Karelia did not generally reach lethal levels and did not exceed the established norms for the same or taxonomically closely related species from other regions of Russia and countries around the world. The findings of the study suggest that the level of Hg in the bodies of mammals inhabiting terrestrial and semi-aquatic ecosystems in Karelia is relatively low.

Keywords: methylmercury, European North of Russia, trophic groups, predators, omnivores, herbivores, toxicity, terrestrial and semi-aquatic ecosystems, liver, kidney, skeletal muscles

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Научная статья

Ртуть в организме млекопитающих Республики Карелия (Россия)

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Аннотация. В ходе работы проанализированы концентрации ртути (Hg) у млекопитающих с разной эколого-трофической специализацией, обитающих в Республике Карелия. Объектами служили 18 видов из отрядов Carnivora, Artiodactyla, Eulipotyphla и Rodentia. Содержание общей Hg в печени, почке и скелетной мышце животных определяли методом прямого пиролитического разложения с атомно-абсорбционной детекцией. Выявленные особенности уровня Hg у исследованных животных согласовывались с хорошо известными закономерностями распределения металла как между органами у отдельных видов, так и в пределах уровня консументов в пищевых цепях. Почти у всех видов животных содержание Hg было максимальным в почке, реже в печени. Вне зависимости от образа жизни (наземного или полуводного) консументы второго порядка (плотоядные виды) характеризовались более высоким содержанием Hg в организме по сравнению с консументами первого порядка (питающимися преимущественно растительной пищей). Концентрации Hg в организме животных Карелии в основном не достигали летальных значений и не превышали норм, зафиксированных для тех же или таксономически близких видов из других регионов России и стран мира. Результаты исследования свидетельствуют об относительно низком уровне Hg в организме млекопитающих наземных и полуводных экосистем Карелии.

Ключевые слова: метилртуть, Европейский север России, эколого-трофические группы, хищные, всеядные, растительноядные, токсичность, наземные и полуводные экосистемы, печень, почка, скелетные мышцы

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Introduction

Given its high toxicity, capacity for long-range transportation, and tendency to bioaccumulate and biomagnify, mercury (Hg) poses a significant threat to humans and animals across all ecosystems (Kalisińska, 2019; WHO, 2017[1]). The metal enters the environment as a result of natural processes (e.g., volcanic activity, weathering of rocks, forest fires) as well as human activities (e.g., burning of coal and waste, refining and production of metals, chlorine, and alkalis, and the use of certain herbicides and pesticides). Thereafter, mercury is transported and redistributed among the environment's primary components (air, soil, and water) until it is removed from the system by deposition in coastal and deep-sea ocean and lake sediments and underground soils (Gworek et al., 2020). In biological systems, Hg exists in various forms, including elemental (Hg^0), inorganic compounds (Hg^+ and Hg^{2+}), and organic compounds ($R\text{-}Hg^+$ or R-Hg-R, where R represents an organic ligand).

Mercury is absorbed into the bodies of animals and humans through various routes, including ingestion, respiration, and dermal contact, with subsequent accumulation in the kidneys, liver, and central nervous system (Dahmardeh Behrooz et al., 2022; Kalisińska, 2019; WHO, 2017[1]). In humans, birds, and mammals, elevated levels of methylated mercury (CH_3Hg, MeHg) have been demonstrated to result in impaired motor functions, as well as impaired nervous, hormonal, and excretory systems. Furthermore, these levels have been associated with reduced reproductive capacity and death (Scheuhammer et al., 2015; Wolfe et al., 2007). The toxic effects of metals (including Hg) during chronic exposure include membrane structure disruption, enzyme inactivation, and DNA damage, which are largely similar to oxidative stress induced by reactive oxygen species (Ding et al., 2022; Isaksson, 2010).

Aquatic ecosystems play a pivotal role in the global biogeochemical cycle of mercury, and the processes of methylation and biomagnification of this metal within them have been the focus of extensive research (Lavoie et al., 2013). The transformation of inorganic Hg by anaerobic microorganisms in bottom sediments leads to the formation of MeHg, which is subsequently accumulated at different levels of the food chain (Zillioux et al., 1993). A growing body of research has indicated a general tendency of increasing Hg concentrations, with a shift from producers to primary and secondary consumers (Bezel et al., 1994; Giebichenstein et al., 2025; Kalisińska, 2019; Poleshchuk et al., 2025). Consequently,

[1] WHO, 2017. Ten chemicals of major health concern. Web page. URL: http://www.who.int/ipcs/assessment/public_health/chemicals_phc/en/index.html (accessed: 18.12.2025).

mercury levels are highest in the bodies of predatory fish, fish-eating birds, and marine and semi-aquatic mammals (Kalisińska, 2019; Lavoie et al., 2013). The biomagnification of MeHg has also been observed in terrestrial ecosystems, although this phenomenon has been the subject of significantly less research (Chételat et al., 2020). In terrestrial ecosystems, wild animals are likely to experience chronic exposure to low doses of Hg present in food, water, and ambient air (Kalisińska, 2019), which may affect the functioning of physiologically important neurochemical systems, growth, and reproduction (Scheuhammer et al., 2015; Wolfe et al., 2007).

The Republic of Karelia (RK) is one of the constituent entities of the Russian Federation, located in the Northwestern Federal District. A study of Hg accumulation in the main natural and urbanized environments of Karelia (Gorbunov et al., 2019) revealed that levels of this metal in soil, aquatic vegetation, and bottom sediments in the studied areas do not exceed Russian standards and are close to background levels. According to the State Report on the State of the Environment of the Republic of Karelia, no impacts of anthropogenic Hg on the natural environment of Karelia have been recorded in recent years[2]. However, the RK is a region with a very high lake density. Surface waters in Karelia are characterized by increased acidification and humification, which contribute to increased mobility and bioavailability of Hg in food chains (Gorbunov et al., 2019; Litvinenko et al., 2011). In light of the aforementioned considerations, it is imperative to undertake comprehensive research endeavors focusing on Hg accumulation in diverse ecological systems.

The aim of this study was to assess Hg concentrations in 18 mammal species with different ecological and trophic specializations inhabiting the RK. The sample included a diverse group of animals, classified as carnivorous, omnivorous, and herbivorous, inhabiting terrestrial and semi-aquatic environments.

Materials and methods

The subjects in this study were representatives of the Carnivora (*Canis lupus* L., 1758; *Lutra lutra* L., 1758; *Lynx lynx* L., 1758; *Martes martes* L., 1758; *Mustela nivalis* L., 1766; *Neogale vison* Schreber, 1777; *Nyctereutes procyonoides* Grey, 1834; *Ursus arctos* L., 1758), Artiodactyla (*Alces alces* L., 1758, *Cervus elaphus* L., 1758; *Sus scrofa* L., 1758), Eulipotyphla (*Neomys fodiens* Pennant, 1771; *Talpa europeae* L., 1758) and Rodentia (*Arvicola amphibious* L., 1758; *Castor fiber* L., 1758; *Agricola (Microtus) agrestis* L., 1761; *Ondatra zibethicus* L., 1766; *Sicista betulina* Pallas, 1779). The list of species is based on A.A. Lisovsky et al. (2019).

Between 2009 and 2024, biological samples (liver, kidney, skeletal muscle) were collected from animals obtained through other research projects or that had died from other causes, such as traffic accidents (as in the case of *L. lutra, L. lynx*, *M. nivalis*, *N. vison*, *N. procyonoides*).

The total Hg content in the liver, kidney, and skeletal muscle of the animals was determined by pyrolysis using a PA-915M atomic absorption spectrometer equipped with a PYRO accessory (Lumex, St. Petersburg) (Nazarenko et al., 1986). The accuracy of the analytical measurement methods was verified using certified biological reference materials DORM-4 and DOLT-5 (Institute of Environmental Chemistry, Ottawa, Canada). Mercury concentrations were expressed in μg/g of wet tissue weight (w.w.).

The data were analyzed using standard statistical methods in MS Excel 2019 and STATGRAPHICS Centurion XIX (USA). Since the data distributions deviated from the normal distribution, the results were presented as medians and lower and upper quartiles (Me [Q1; Q3]); in addition, the minimum and maximum values were reported. The age and sex of the animals were not taken into account during statistical analysis, as these characteristics were not known in all cases. To assess differences between trophic groups, the Kruskal–Wallis *H*-test (nonparametric analysis of variance) was used. To identify correlations and assess their strength and direction, we used correlation analysis (Spearman's rank correlation test). Differences were considered statistically significant at $p < 0.05$.

Results

In the majority of the animal species examined, the Hg concentrations were found to be highest in the kidneys and, less frequently, in the liver. The exceptions were *N. vison*, in which metal concentrations were virtually the same across all tissues examined, and *C. fiber* and *C. elaphus*, in which Hg levels were highest in the muscles compared to the liver and kidneys ($p < 0.05$) (Table 1).

[2] State report on the state of the environment in the Republic of Karelia in 2024, 2025.

Correlation analysis revealed significant correlations between mercury levels in the internal organs of certain animal species ($p < 0.05$) (Table 2). In the *S. scrofa* and *S. betulina*, strong correlations were observed between mercury concentrations in the liver and kidneys; in *T. europeae* – between values in the kidneys and muscle; whereas in *O. zibethicus* correlations of moderate strength were observed in all cases studied.

An analysis of the relationships between Hg concentrations in internal organs and the ecological and trophic specialization of animals showed (Fig. 1) that, among terrestrial species, metal levels decreased in the row carnivores – omnivores – herbivores; among semi-aquatic species, carnivores also exhibited higher values of this indicator compared to omnivores and herbivores. The Hg levels were found to be higher in terrestrial omnivorous species compared to semi-aquatic omnivorous ones. Higher Hg levels were detected in the kidneys of terrestrial herbivores compared to semi-aquatic herbivores and semi-aquatic omnivorous species.

Discussion

The study assessed the patterns of mercury accumulation in 18 mammal species in the RK with different trophic specializations (herbivores, carnivores, and omnivores, including terrestrial and semi-aquatic species). Our findings align with those of other researchers (Bezel et al., 1994; Chételat et al., 2020; Kalisińska, 2019) and are attributable to multiple factors influencing Hg accumulation in mammals. Levels of Hg in wild animals are directly influenced by the combined effects of environmental and physiological processes. On the one hand, environmental factors are associated with dietary Hg intake, while on the other hand, physiological processes regulate the absorption, transformation, and excretion of this toxicant.

Tissue-specific distribution of mercury in the bodies of mammals in the RK

Mercury accumulates in many animal organs, particularly in protein-rich tissues (Shore et al., 2011). This can be attributed to the strong binding affinity of inorganic and organic forms of Hg for SH groups in amino acids, as well as for the primary intracellular non-protein thiol – glutathione (GSH) (de Lima Lemes, 2010). Different tissue types demonstrate various aspects of Hg's effects on animals, so it is important to consider the tissue's inertness/physiological activity, as well as its role in the metabolization of the toxin (storage, transformation, excretion) (Chételat et al., 2020). In metabolically inert tissues (feathers, hair, vibrissae, claws, scales, etc.), MeHg forms a complex with keratin during growth, providing information on Hg bioaccumulation over discrete time periods (Vo et al., 2011). Metal concentrations in metabolically active tissues (muscle, liver, kidney, brain, and blood) allow for the assessment of relatively recent Hg exposure to the body, as well as the association of these concentrations with potential health risks (Scheuhammer and Sandheinrich, 2008).

In mammals, Hg levels are typically highest in the liver and kidneys, followed by the muscles, and finally the brain (Dahmardeh Behrooz et al., 2022; Kalisińska, 2019; WHO, 2017[3]). In our study, metal concentrations were found to decrease in the order of kidney–liver–muscle across nearly all animal species. The exceptions were species such as *N. vison*, in which metal concentrations were high and remained at nearly the same level in all tissues examined, as well as *C. fiber* and *C. elaphus*, in which Hg levels were highest in the muscles.

The liver and kidneys are responsible for synthesizing metallothioneins, important proteins that bind the toxin. In addition, the liver undergoes MeHg demethylation processes, whereas the kidneys have a high affinity for inorganic Hg, which can accumulate in the organ and be subsequently excreted (the half-life is approximately 40 days) (Gover, 1991). When low doses of Hg are administered, continuous renal excretion can prevent its accumulation; however, at high doses of the metal, accumulation prevails over excretion (Eagles-Smith and Ackerman, 2009; Evans et al., 2016).

While the overall concentration of Hg in muscle tissue is generally lower than in other tissues, muscles account for more than 40% of a mammal's body weight. This makes muscles the largest proportional contributor to the total metal content in the body. Muscle tissue is a key indicator of methylmercury exposure, as most of the Hg found in muscle tissue is present as MeHg (Squadrone et al., 2015). Furthermore,

[3] WHO, 2017. Ten chemicals of major health concern. Web page. URL: http://www.who.int/ipcs/assessment/public_health/chemicals_phc/en/index.html (accessed: 18.12.2025).

Table 1. The mercury concentration (μg/g w.w.) in mammals of different trophic groups (Me [Q1; Q3]; min–max). Legend: Terr-Herb – terrestrial herbivores, SemiAq-Herb – semi-aquatic herbivores, Terr-Omn – terrestrial omnivores, SemiAq-Omn – semi-aquatic omnivores, Terr-Carn – terrestrial carnivores, SemiAq-Carn – semi-aquatic carnivores

Trophic groups	Species	n	Tissues		
			liver	kidney	muscle
Terr-Herb	*Alces alces* Moose	41	0.001 [0.001;0.004]; 0–0.013	0.038 [0.028; 0.065]; 0.012–0.167	0.0008 [0.0003; 0.001]; 0–0.004
	Cervus elaphus Red deer	6	0 [0;0]; 0–0.001	0.0002 [0; 0.0003]; 0–0.0007	0.0003 [0; 0.0003]; 0–0.0007
	Agricola agrestis Field vole	2	0.014 [0.007;0.022]; 0.007–0.022	0.084 [0.009; 0.159]; 0.009–0.159	0.006 [0.002; 0.009]; 0.002–0.009
SemiAq-Herb	*Castor fiber* Eurasian beaver	1	0.005	0.002	0.008
	Ondatra zibethicus Ondatra	23	0.004 [0.001; 0.008]; 0.0002–0.027	0.007 [0.005; 0.012]; 0.001–0.093	0.002 [0.001; 0.003]; 0.0002–0.019
Terr–Omn	*Martes martes* Pine marten	5	0.322 [0.319;0.647]; 0.309–0.695	0.766 [0.649; 0.884]; 0.547–1.529	0.478 [0.305; 0.569]; 0.242–0.919
	Ursus arctos Brown bear	3	0.089 [0.046; 0.153]; 0.046–0.153	0.200 [0.083; 0.264]; 0.083–0.264	0.005 [0; 0.010]; 0–0.030
	Sus scrofa Wild boar	71	0.011 [0.005; 0.021]; 0–0.160	0.048 [0.038; 0.099]; 0–0.273	0.002 [0.0003; 0.008]; 0–0.032
	Sicista betulina Northern birch mouse	8	0.004 [0.003; 0.006]; 0.001–0.012	0.010 [0.004; 0.020]; 0.003–0.021	0.005 [0.004; 0.008]; 0.001–0.048
SemiAq-Omn	*Nyctereutes procyonoides* Raccoon dog	1	0.261	0.294	0.094
	Arvicola amphibious Water vole	12	0.002 [0.001; 0.004]; 0.0002–0.005	0.003 [0.002; 0.006]; 0.001–0.026	0.0009 [0.0005; 0.0021]; 0.0002–0.0044
Terr-Carn	*Canis lupus* Wolf	2	0.146 [0.046; 0.245]; 0.046–0.245	0.153 [0.094; 0.213]; 0.094–0.213	0.014 [0.011; 0.016]; 0.011–0.016
	Lynx lynx Eurasian lynx	1	0.085	0.086	0.068
	Mustela nivalis Weasel	1	0.102	0.136	0.061
	Talpa europeae European mole	6	0.059 [0.055; 0.080]; 0.042–0.175	0.140 [0.097; 0.163]; 0.086–0.478	0.030 [0.026; 0.046]; 0.020–0.170
SemiAq-Carn	*Lutra lutra* River otter	1	3.730	1.425	1.5
	Neogale vison American mink	3	4.064 [0.728; 22.75]; 0.728–22.75	4.167 [0.876; 16.35]; 0.876–16.35	4.749 [0.437; 8.515]; 0.437–8.515
	Neomys fodiens Water shrew	18	0.189 [0.145; 0.474]; 0.094–6.2	0.328 [0.260; 0.446]; 0.158–0.513	0.182 [0.113; 0.531]; 0.068–3.845

Table 2. Spearman's rank correlation coefficients (r) reflecting the strength of relationships between Hg levels in the tissues of animals. Legend: * – p < 0.05, ** – p < 0.01, dash – analysis not performed, × – p > 0.05..

Species	Tissues		
	liver – kidney	liver – muscle	kidney – muscle
S. scrofa	0.81**	×	×
T. europeae	×	×	0.94*
O. zibethicus	0.66*	0.60*	0.62*
S. betulina	0.89*	–	–

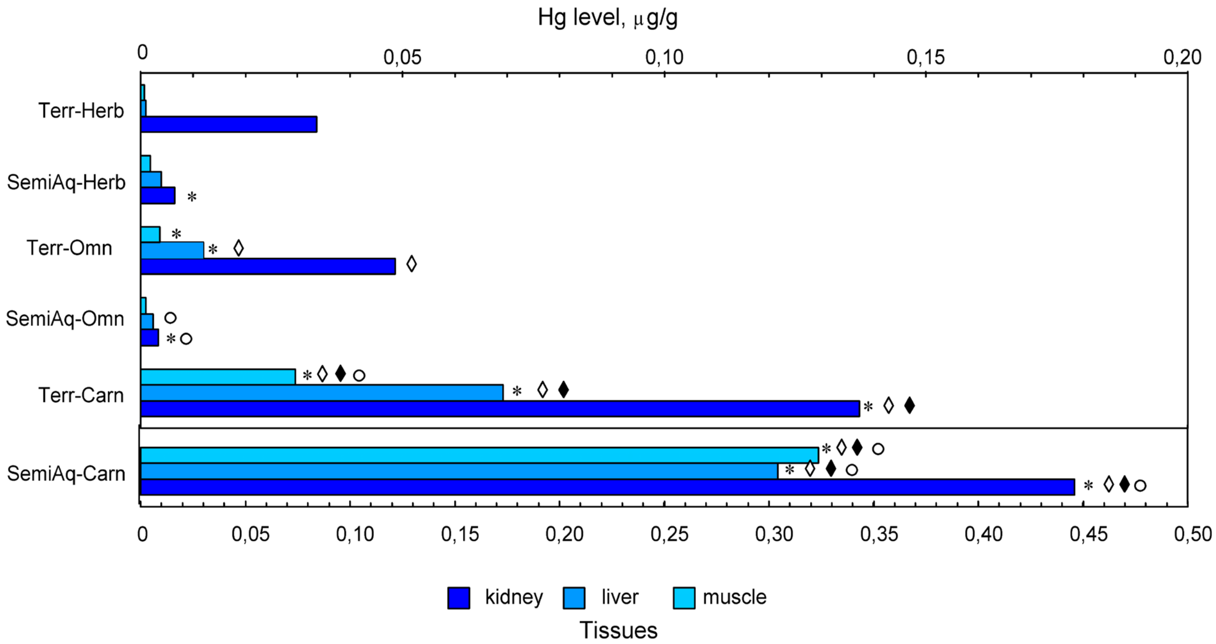

Fig. 1. Median Hg concentrations in animals from different trophic groups.
Note: The lower scale applies to the SemiAq-Carn group, while the upper scale applies to the other animal groups.
Legend: Terr-Herb – terrestrial herbivores, SemiAq-Herb – semi-aquatic herbivores, Terr-Omn – terrestrial omnivores, SemiAq-Omn – semi-aquatic omnivores, Terr-Carn – terrestrial carnivores, SemiAq-Carn – semi-aquatic carnivores.
Differences are statistically significant (*p*<0.05) compared to: * – Terr-Herb, ◊ – SemiAq-Herb, ○ – Terr-Omn, ♦ – SemiAq-Omn.

MeHg concentrations in the muscles (and sometimes in the liver) of game animals harvested for human consumption may represent an important source of human exposure to MeHg.

Studies on the correlations between mercury concentrations in the internal organs of mammals have yielded conflicting results. Some reported statistically significant correlations (Dahmardeh Behrooz et al., 2022; Kalisińska, 2019), while others found none (Halbrook et al., 1994). We also conducted a correlation analysis (except in cases where this was not possible due to small sample sizes) and found correlations between Hg levels in internal organs in some animal species.

An assessment of the impact of trophic specialization on Hg concentrations in Karelian mammals

As food represents the primary route of mercury exposure in wild animals (Chételat et al., 2020; WHO, 2017[4]), an important role in interpreting toxin levels in a given species is played by its position in the food web, habitat, food availability and quality, as well as spatial use in combination with life cycle characteristics (changes in diet during ontogenesis or migration) (Chételat et al., 2020).

It is generally recognized that the most significant factor influencing Hg accumulation in animals is the organism's trophic level within the ecosystem or the length of the food chain (Cabana and Rasmussen, 1994). It is important to note that an increase in the number of links in this chain corresponds to a greater likelihood of increased MeHg concentrations. This is precisely why carnivorous animals often have higher mercury levels compared to herbivores, as demonstrated in our study and confirmed by previous research (Bedouet et al., 2025; Bezel et al., 1994; Kalisińska, 2019).

The accumulation of Hg in animals is also influenced by their habitat. In the water environment, the inorganic form of the metal is methylated by anaerobic microorganisms in the sediment layers at the base of the water column. MeHg is then sequentially accumulated at different levels in the food chain (Lavoie et al., 2013). Therefore, organisms in aquatic and, as in our case, semi-aquatic ecosystems generally accumulate more Hg than animals in terrestrial ecosystems. Semiaquatic predators, particularly piscivorous species, are at a significantly higher risk of Hg accumulation in their bodies compared to typical terrestrial carnivores feeding on terrestrial prey (Kalisińska, 2019), as evidenced by our study of mammals in the RK.

The highest concentrations of Hg were recorded in semi-aquatic members of the Mustelidae family: *N. vison* and *L. lutra*. The diet of *N. vison* consists mainly of semi-aquatic and aquatic animals (voles, frogs, crayfish, small fish, and aquatic insects), whereas *L. lutra* is a typical piscivorous species. The Hg levels we observed in these animal species mostly exceeded the toxicant values recorded in previous studies on animals from other regions of Russia and countries around the world (Dibbern et al., 2021; Komov et al., 2012; Lake et al., 2007; Lodenius et al., 2014; Wren et al., 1986), but were not toxic to mustelids (WVDL, 2015[5]).

Some wildlife species may remain within their habitats and exist in short food chains, yet still accumulate significant concentrations of Hg (Chételat et al., 2020). This is facilitated when their prey moves from one habitat to another, which is particularly common in near- and semi-aquatic ecosystems. In these ecosystems, aquatic insects emerging onto land act as carriers of MeHg, obtained from rivers or lakes, into the terrestrial environment (Becker et al., 2018). Consequently, insectivorous animals such as *N. fodiens* can accumulate substantial concentrations of Hg. A previous study revealed that higher levels of Hg were observed in some terrestrial birds feeding on predatory invertebrates (e.g., spiders) compared to fish-eating birds (Cristol et al., 2008). Analogous to marine coastal ecosystems (McGrew et al., 2014; Noël et al., 2014), it is probable that processes of transfer and accumulation of water-derived MeHg in the bodies of terrestrial animals also occur in areas near freshwater bodies. The available literature offers scant documentation of Hg accumulation in insectivores (Ivanova et al., 2023; Talmage and Walton, 1993). A comparison of the concentrations of the toxicant detected in *N. fodiens* with those in other members of the order Eulipotyphla reveals higher levels in *N. fodiens* than in *Sorex araneus* (Ivanova et al., 2023), but lower levels than in *Blarina brevicauda* (Talmage and Walton, 1993).

[4] WHO, 2017. Ten chemicals of major health concern. Web page. URL: http://www.who.int/ipcs/assessment/public_health/chemicals_phc/en/index.html (accessed: 18.12.2025).

[5] WVDL, 2015. Normal range values for WVDL Toxicology. Web page. URL: https://www.yumpu.com/en/document/read/52919318/normal-range-values-for-wvdl-toxicology (accessed: 18.12.2025).

Another member of the order Eulipotyphla that we studied is *T. europeae*, which leads a subterranean lifestyle and feeds primarily on earthworms and, to a lesser extent, on beetle larvae and millipedes – that is, organisms in close contact with the soil. We classified this species as a terrestrial carnivore. The mercury levels recorded in *T. europeae* were lower than those in animals of the same species from Finland and Chelyabinsk (Russia) (Pankakoski et al., 1993; Samburova et al., 2021).

The group of terrestrial carnivores, whose mercury levels were higher than those of semi-aquatic and aquatic animals, as well as terrestrial herbivores, included species such as *C. lupus*, *L. lynx,* and *M. nivalis*. These predators have distinct diets, including: for *C. lupus* – ungulates, marmots, hares, and badgers; for *L. lynx* – snowshoe hares, mouse-like rodents, and occasionally small ungulates; and for *M. nivalis* – small voles. The Hg concentrations observed in these animal species in the RK were comparable to the norms for canids, felids, and mustelids, respectively[6], as well as to metal concentrations in the same animal species from other regions of Russia and countries around the world (Bedouet et al., 2025; Bilandžić et al., 2012; Gamberg and Braune, 1999; Komov et al., 2012; McGrew et al., 2014; Ottemo, 2009; Subotić et al., 2017; Vass et al., 2025).

Omnivorous terrestrial animals (*M. martes*, *U. arctos*, *S. scrofa* and *S. betulina*) exhibited higher Hg levels compared to omnivorous semi-aquatic species (*N. procyonoides* and *A. amphibious*) and herbivorous organisms. The diversity of food sources for terrestrial omnivorous animals may contribute to significant accumulation of the toxin in their bodies. *M. martes*'s diet consists of a variety of foods, including rodents, insects, amphibians, berries, and carrion. The diet of *U. arctos* consists primarily of plant matter (succulent green plant parts, fruits, rhizomes), but insects, fish, and carrion may also be included during the autumn fattening period. The diet of *S. scrofa* is quite diverse: year-round, the wild boar consumes underground plant parts (rhizomes, roots, tubers, bulbs), and seasonally – fruits, nuts, berries, and seeds, as well as the above-ground vegetative parts of plants and animal food (worms, mollusks, insects and their larvae, small vertebrates, and carrion). *S. betulina* is an omnivorous species; it consumes animal matter (small invertebrates) as well as plant matter (flowers and seeds). *A. amphibious* inhabits riverbanks, feeding on succulent plant matter and animal food (insects, their larvae, fish, mollusks, crayfish). *N. procyonoides* inhabits a variety of environments, including wet meadows, adjacent marshy lowlands, river floodplains overgrown with reeds and willows, and riparian forests with dense undergrowth. Its diet consists primarily of insects, rodents, and plant matter.

Mercury levels in the omnivorous species studied (*U. arctos, S. scrofa* and *N. procyonoides*) were comparable to those reported for the same species from other regions of Russia and the world (Čelechovská et al., 2006; Florijancic et al., 2015; Kalisińska et al., 2009; Komov et al., 2016; Lazarus et al., 2014; Piskorová et al., 2003; Tomza-Marciniak et al., 2023). Hg concentrations in *M. martes* were comparable to the levels of the toxin detected in animals from the Vologda Region (Komov et al., 2012; Stepina et al., 2013), yet exceeded those observed in martens from Europe (Bilandžić et al., 2012; Kalisińska et al., 2009; Lodenius et al., 2014). The available literature lacks data on Hg levels in *S. betulina* and *A. amphibious*. However, compared to other small mammals (Durkalec et al., 2019; Gerstenberger et al., 2006), the animals we studied had lower levels of the toxin in their livers.

The group of herbivorous species (terrestrial: *A. alces*, *C. elaphus*, and *A. agrestis*; semi-aquatic: *C. fiber* and *O. zibethicus*) exhibited lower Hg concentrations compared to animals in other trophic groups. The diet of *A. alces* and *C. elaphus* consists primarily of herbaceous plants, shrub and tree branches, while that of *A. agrestis* consists of the green parts of plants, mosses and lichens, bark, and small twigs from shrubs and young trees. *O. zibethicus* feeds on riparian and aquatic plants, while *C. fiber* additionally consumes bark and thin branches of trees (aspen, willow, birch). Compared to studies from other countries that used the same or closely related species (Bull et al., 1977; Cokoski et al., 2024; Dobrowolska and Melosik, 2002; Giżejewska et al., 2014), the animals from Karelia exhibited similar or lower levels of Hg in their internal organs.

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[6] WVDL, 2015. Normal range values for WVDL Toxicology. Website. URL: https://www.yumpu.com/en/document/read/52919318/normal-range-values-for-wvdl-toxicology (accessed: 18.12.2025).

Assessment of the risk of mercury poisoning in mammals from Karelia

Wildlife health indicators are important components of a comprehensive approach to assessing and monitoring trends in environmental mercury pollution (Wolfe et al., 2007). There are notorious cases of mass chronic mercury poisoning of humans and animals in Japan (Minamata Disease: The History and Measures, 2002) and Iraq (Clarkson et al., 1981). In the 1950s, dramatic events occurred in Japan's Minamata Bay, leading to numerous fatal cases of mercury poisoning among humans, cats, and wild birds. More than 3000 victims with brain damage were diagnosed with so-called Minamata disease, and veterinary medicine introduced the term "dancing cats" to describe the neurological symptoms observed in cats. Both Minamata disease and "dancing cats" were the result of mercury poisoning, along with other pollutants that entered the bay from a nearby chemical plant. In the bay's sediments, bacteria converted inorganic Hg into MeHg, the levels of which gradually increased in the bodies of animals at each successive trophic level. Large amounts of MeHg in fish, crustaceans, and mussels entered the bodies of humans and animals through food, leading to illness and fatal poisoning (Grandjean et al., 2010).

The tragedy in Iraq in late 1971 was also caused by mass poisoning of the population with methylmercury (Clarkson et al., 1981). The source of the toxin was grain imported from Mexico, treated with fungicides and intended exclusively for sowing. Due to delivery delays and the inability to read the warning labels in a foreign language, rural residents used the seeds for food. The poisoning was accompanied by symptoms characteristic of Minamata disease (vision loss, impaired coordination, paresthesia) and resulted in the deaths of 650 people. Despite ongoing efforts to reduce mercury pollution worldwide, the problem of risks to ecosystem health and public health remains a pressing concern.

As a general rule, free-living terrestrial animals are chronically exposed to low concentrations of mercury present in food, water, and air. In aquatic environments, mercury is more deeply integrated into food chains. As a result, food of aquatic origin can pose a significant threat to human and wildlife health. Research on the toxicity of mercury has been conducted at the molecular, cellular, tissue, organism, species, and ecosystem levels (Wolfe et al., 2007). The consequences of chronic Hg exposure in wildlife are widespread and diverse, including neurotoxic effects (e.g., visual disturbances, ataxia), physiological effects (histopathology, growth retardation, etc.), behavioral effects (e.g., lethargy), and reduced reproductive success (Scheuhammer et al., 2015; Wolfe et al., 2007).

The Wisconsin State Diagnostic Laboratory (USA)[7] has established reference values for total Hg in the internal organs of species belonging to the families Cervidae, Mustelidae, Suidae, Canidae, Ursidae, and Felidae. The concentrations of the toxicant detected in our study in the corresponding species of these taxa generally did not exceed the established standards and were not toxic.

Previous research has identified mortality-related Hg levels in mammals, but these have been found only in carnivores from the Mustelidae (*Mustela vison*, *Lutra canadensis*, and *L. lutra*) (Halbrook et al., 1994; Kim et al., 2023; O'Connor and Nielsen, 1981; Wobeser and Swift, 1976; Wren et al., 1987a, b) and the Felidae (*Felis catus* and *F. concolor coryi*) (Albanus et al., 1972; Eaton et al., 1980; Roelke et al., 1993). According to the findings of the aforementioned studies, the geometric mean lethal concentration of Hg is determined to be 42 μg/g (range 33–54) for the liver, 37.5 μg/g (range 26–69) for the kidneys, and 16 μg/g (range 11–21) for the brain (Shore et al., 2011). It is probable that levels of Hg exceeding 25–30 μg/g in both organs are associated with mortality in carnivorous mammals, and potentially in other mammalian groups as well (Shore et al., 2011).

There is limited data on tissue Hg levels that may be associated with reproductive dysfunction in mammals. In minks, the toxin concentration in the liver and kidneys was 30 and 36 μg/g, respectively (Wren et al., 1987b), which falls within the range of lethal Hg concentrations. It was also noted that Hg accumulation in female panthers (blood concentration > 0.5 μg/g) led to reduced survival rates among their cubs (Roelke et al., 1993).

In our study, the median Hg concentrations in all mammal species examined were below lethal levels. Only one *N. vison* individual exhibited mercury concentrations (22.75 and 16.35 μg/g in the liver and kidney, respectively) that could apparently be characterized as sublethal. This individual was killed by dogs in the vicinity of Petrozavodsk near a landfill, whereas other *N. vison* individuals were captured far from populated areas.

[7] WVDL, 2015. Normal range values for WVDL Toxicology. Web page. URL: https://www.yumpu.com/en/document/read/52919318/normal-range-values-for-wvdl-toxicology (accessed: 18.12.2025).

According to the State report on the state of the environment in the RK[8], there has been no recorded impact of anthropogenic Hg on the natural environment of Karelia in recent years. A study of mercury accumulation in the main natural and urbanized environments of the RK revealed that levels of this metal in soil and vegetation, water, and bottom sediments in the studied areas do not exceed Russian standards and are close to background levels (Gorbunov et al., 2019). The region's low population density and small number of industrial enterprises do not increase the environmental burden. However, the region's unique landscape and geographical location make it vulnerable to man-made disasters. Local impacts, especially in a cold climate, can cause erosion, waterlogging, and soil subsidence. The primary threat of toxicant contamination to ecosystems originates from the large cities of Petrozavodsk, Kondopoga, and Kostomuksha, where metallurgical, pulp-and-paper, and municipal enterprises are in operation. Outside the cities, power plants and processing plants pose a threat.

Conclusions

Our study confirmed that mercury concentrations in wild animals result from a combination of ecological processes affecting dietary Hg intake and physiological processes regulating the absorption, transformation, and excretion of this metal.

The identified patterns of Hg levels in mammals of Karelia are consistent with known patterns of toxin distribution among organs in individual species and within the trophic levels of food chains. In the majority of the species studied, Hg concentrations were highest in the kidneys and, less frequently, in the liver. However, *N. vison* was an exception, with metal concentrations being practically the same in all examined tissues. *C. fiber* and *C. elaphus* were also notable, with mercury being predominant in the muscles of these species.

A study of the relationship between Hg levels in the bodies of 18 mammalian species and the animals' trophic specializations revealed a clear pattern: the highest concentrations of the metal were found in carnivorous species, followed by omnivorous and herbivorous species. This trend has been observed in both terrestrial and semi-aquatic species. Terrestrial omnivorous animals exhibited higher mercury levels compared to semi-aquatic omnivorous and terrestrial herbivorous species.

In our study, the median Hg concentrations in all the mammal species we examined were below lethal levels, with the exception of a single *N. vison* individual, in which sublethal Hg concentrations were recorded. The toxin levels observed in the studied animals were generally comparable to the norms for Cervidae, Mustelidae, Suidae, Canidae, Ursidae, and Felidae, as well as with Hg concentrations in the same or closely related animal species from other regions of Russia and countries around the world. However, the region's unique landscape and geographical location make the ecosystem vulnerable to the toxic effects of Hg. Therefore, it is necessary to continue monitoring studies in this territory.

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[8] State report on the state of the environment in the Republic of Karelia in 2024, 2025.

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