# Geographical Distribution Of Dioxins, Cadmium And Mercury Concentrations In Reindeer Liver, Kidneys And Meat In The Russian Far North

**Dmitry A. Makarov** (phorez@yandex.ru)
All-Russian State Center for Quality and Standardization of Veterinary Drugs and Feed: Vserossijskogo gosudarstvennogo Centra kacestva i standartizacii lekarstvennyh sredstv dla zivotnyh i kormov https://orcid.org/0000-0003-3834-0695

**Vladimir V. Ovcharenko**
All-Russian State Center for Quality and Standardization of Veterinary Drugs and Feed: Vserossijskogo gosudarstvennogo Centra kacestva i standartizacii lekarstvennyh sredstv dla zivotnyh i kormov

**Elena A. Nebera**
All-Russian State Center for Quality and Standardization of Veterinary Drugs and Feed: Vserossijskogo gosudarstvennogo Centra kacestva i standartizacii lekarstvennyh sredstv dla zivotnyh i kormov

**Alexander I. Kozhushkevich**
All-Russian State Center for Quality and Standardization of Veterinary Drugs and Feed: Vserossijskogo gosudarstvennogo Centra kacestva i standartizacii lekarstvennyh sredstv dla zivotnyh i kormov

**Andrey A. Shelepchikov**
All-Russian State Center for Quality and Standardization of Veterinary Drugs and Feed: Vserossijskogo gosudarstvennogo Centra kacestva i standartizacii lekarstvennyh sredstv dla zivotnyh i kormov

**Xenia A. Turbabina**
All-Russian State Center for Quality and Standardization of Veterinary Drugs and Feed: Vserossijskogo gosudarstvennogo Centra kacestva i standartizacii lekarstvennyh sredstv dla zivotnyh i kormov

**Anastasia M. Kalantaenko**
All-Russian State Center for Quality and Standardization of Veterinary Drugs and Feed: Vserossijskogo gosudarstvennogo Centra kacestva i standartizacii lekarstvennyh sredstv dla zivotnyh i kormov

**Nikita S. Bardyugov**
All-Russian State Center for Quality and Standardization of Veterinary Drugs and Feed: Vserossijskogo gosudarstvennogo Centra kacestva i standartizacii lekarstvennyh sredstv dla zivotnyh i kormov

**Maria A. Gergel**
All-Russian State Center for Quality and Standardization of Veterinary Drugs and Feed: Vserossijskogo gosudarstvennogo Centra kacestva i standartizacii lekarstvennyh sredstv dla zivotnyh i kormov

---

**Research Article**

**Keywords:** Reindeer, liver, kidneys, dioxins, mercury, cadmium, Russia, monitoring

**Posted Date:** June 15th, 2021

**DOI:** https://doi.org/10.21203/rs.3.rs-573227/v1



---

## Abstract

Reindeer herding is a vitally important agricultural sector in the Russian Far North. It is believed, that Nothern ecosystems are prone to accumulation of persistent pollutants for the reasons of trophical chains, features and climate. Reindeers graze on vast areas, having seasonal migrations on distances up to hundreds kilometers in one side in North-South direction, that increases likehood to cross a locally polluted area. Here we present results of a large-scale countrywide study of reindeer liver, kidneys and meat pollution by dioxins, cadmium and mercury. Samples were taken in 2015-2020 years from 41 locations in 8 reindeer-herding regions of Russia. Dioxins were determined in 383 samples of liver and 13 of meat, cadmium and mercury – in 505 samples of liver, 315 of kidneys and 22 of meat. Dioxin pollution has shown a clear geographical trend: liver concentrations gradually decrease from the Western to the Eastern parts on the country, with the highest concentration of 76.5 pg/g of fat WHO-TEQ. The following factors are likely to explain the discovered trend: localization of chemical enterprises and density of reindeer population. The highest concentrations of metals were found in kidneys (7.3 mg/kg of cadmium and 1.1 mg/kg of mercury). The contribution of local sources to cadmium and mercury pollution was found to be less, than expected. We also speculate, that reindeer liver may serve as a good additional indicator of environmental pollution by the investigated contaminants.


## Introduction

Reindeer herding is vitally important part of Russian agricultural sector, especially for the regions located in the Far North. Total reindeer livestock population of the country is about 1.5 millions of animals [Ministry 2013].

It is believed than Nothern ecosystems are prone to the accumulation of persistent pollutants for the reasons of trophical chains features and climate. Higher rates of dioxins accumulation in the liver of reindeers and sheep was shown comparing to other food-producing animals (cows, pigs, poultry)[EFSA 2011]. The main source of dioxins for reindeers are feed and soil [EFSA 2011; Schröter-Kermani 2011].

The reasons of higher dioxins contamination in reindeer are believed to be: biochemical features (e.g. lower activity of detoxification enzymes, in particular CYP1A); frequent changing of grazing areas, raising the probability to move on the locally polluted area; ingestion of soil particles while grazing [EFSA 2011]. For calves, mother's milk was also shown to be a source of dioxins pollution [Holma-Suutari et al. 2014]. High dioxin content is specific only for liver, their concentrations in other organs and tissues like muscle, kidneys, fat, spleen, blood etc. are relatively low [Holma-Suutari et al. 2016].

During all the year, lichens and plant, especially reindeer moss are the main feed for the animals. During winter period lichens account to more than 50% of feed. Accumulation of heavy metals in lichens linked with atmospheric contamination and active lichen supplementation during the winter period are believed to be the key factors determining the heavy metals content in reindeer [Hassan et al. 2012]. Among toxic elements (cadmium, mercury, lead and arsenic), reindeer liver and kidneys accumulate predominantly cadmium and mercury in high concentrations [Welfinger et al. 2011].

Deposition of persistent pollutants, including dioxins and heavy metals on the territory of the Russian Far North is mainly determined by transboundary atmospheric and hydrospheric carry-over from other regions of Russia and countries. For example, sources of mercury emission, located on the territory of Kola Peninsula account for only 13% of mercury deposition content, while sources located in other Russian regions account for 22%, and sources in Europe, China, USA, Central Asia and others – for the rest. However local sources, e.g. industrial objects are believed to make important contribution in dioxins and heavy metals deposition [AMAP 2004].

Within State Monitoring program we have analyzed reindeer meat, liver and kidney analyses for several persistent pollutants, including dioxins and dioxin-like polychlorinated biphenyls (dl-PCBs), organochlorine pesticides, indicator PCBs, polyaromatic hydrocarbons and heavy metals: arsenic, lead, cadmium and mercury. Dioxins, dl-PCBs in liver, and cadmium and mercury in liver and kidneys of reindeers were found in concentration generally much higher than in other's food producing animals (cows, pigs, poultry) tissues (National monitoring of undesirable substances in food and feed, data not shown). Providing that the 4 abovementioned contaminants exhibit well-known harmful effects on health, we have made the risk assessment [Makarov et al. 2018]. It was shown that cadmium poses the highest health risk comparing to sum of dioxins, dl-PCB and mercury. Consumption of reindeer offal in several regions may lead to cadmium intake exceeding the tolerable intake level more than threefold. In the meantime, consumption of reindeer meat poses no health risk related to any of the investigated contaminants [Makarov et al. 2018].

The main aim of our study on reindeer offal and meat monitoring for dioxins, cadmium and mercury, was the detailed investigation of geographical distribution of the contaminants and assessment of reindeer offal as a suitable indicator of environmental pollution. Dl-PCBs were not included in the program as these compounds are not yet regulated by Russian Food Legislation.

# Materials And Methods

Reindeer (*Rangifer tarandus*) tissue samples were collected by regional authorities in 2014–2020 years within the National Program of Undesired Substances Monitoring in Food and Feed. In total, 842 samples of liver, kidneys and meat were taken from semi-domestic reindeer in 8 reindeer-herding regions: Kola Peninsula (other name is Murmansk Oblast), Nenets Autonomous Okrug (AO), Komi Republic, Yamalo-Nenets Autonomous Okrug (AO), Taymir Peninsula (part of Krasnoyarsk Krai), Republic of Sakha (Yakutia), Chukotka and Kamchatka (see Fig. 1). The animals were raised on natural food resources (lichens, plants etc.) without any feed additives or supplements. The age of the animals of both sexes varied from 0.5 to 5 + years, generally being more than one year. Detailed data on age and sex was available only for one region - Yamalo-Nenets Autonomous Okrug. Liver, kidneys and meat samples, weighting 100-300g, from individual animals were taken at slaughterhouses in the winter period (from the end of November to the beginning of April) and stored at -10°C prior to analysis.

Dioxins (sum of PCDDs and PCDFs) were determined by gas-chromatography/high resolution mass-spectrometry (GC-HR MS) according to GOST (Customs union official standard) 34449 – 2018 «Food products and feed materials. Determination of dioxins by GC-HR MS». Briefly, thawed samples (50-100g) were homogenized and internal standards (solutions of isotope-labelled dioxins, «Wellington labs», Canada) were added. Homogenized samples were thoroughly mixed with the Prep DE sorbent («Dionex», USA). Dioxins were extracted by hexane:dichloromethane 1:1 v/v mix under pressure using ASE 350 extractor («Dionex», USA). The extract was defatted (by $H_2SO_4$/silicagel), cleaned up on columns with 10% activated charcoal on zeolite and evaporated. Resuspended extract was analysed using GC/HRMS instrument Autospec Premier («Waters Corp.») in selected ion monitoring mode at resolution not lower than 10.000. Capillary column VF-Xms (60 m ½ 0,25 µm, Agilent, USA). Dioxins concentrations (sum of PCDDs and PCDFs) were expressed as pg WHO-TEQ(2005)/g of fat. Fat content in liver and meat was determined by gravimetry (GOST 23042-86 «Meat and meat products. Determination of fat content»).The percent of fat in reindeer liver samples varied from 3.9 to 7.5%, for most part of the samples being in the range of 5–7%.The fat content in meat was around 5%.

Cadmium and mercury concentrations were determined by mass-spectrometry with inductively-coupled plasma according to GOST 31414 – 2017 «Food products and feed. Determination in arsenic, cadmium, mercury and lead by ICP-MS». Measurements were performed using an inductively coupled plasma mass spectrometer Agilent 7900MS model ICP-MS system (Agilent, USA) equipped with an autosampler, a Babington nebulizer, nickel cones, and a peristaltic sample delivery pump. Analysis of each sample was done in duplicate. High purity argon gas was used to form the plasma in the ICP-MS. The pulse to analog factor was determined on the day of analysis. Agilent ICP-MS tuning solution of 10 µg/L (Ce, Co, Li, Tl, and Y) was used to tune the instrument. Data acquisition was done in spectrum analysis and full quantitative mode. The following isotopes of trace elements were considered: $^{111}Cd$ and $^{200}Hg$. A microwave system Ethos up (Milestone, Italy) equipped with a microwave acid digestion bomb made from Teflon was used for microwave digestion. All solutions were prepared using ultra-high purity water (18.2 MΩ cm − 1, Ultrapure Water System (Sartorius arium mini plus). All the reagents used were of analytical reagent grade. High purity ICP-MS multi element standard solution obtained from Merck (Darmstadt, Germany) was used for the preparation of calibration curves in the quantitative analysis of the elements. This solution is a mixture of 10 mg/L of elements. Internal standards (Indium and Bismuth) were used for control of mass shift and signal suppression.

Selected round of internationally recognized Proficiency Testing Schemes of cadmium, mercury and dioxins determination are shown in Table 1. Z-index ≤ 2 means that the round was successfully passed.

**Table 1. Selected rounds of Proficiency testing schemes succeeded by VGNKI (cadmium and mercury).**

|Z-index| ≤ 2 means that the round was passed successfully.

| Year | Provider | Round | Matrix | Analyte | Certified value | Laboratory value, | Z-index |
|---|---|---|---|---|---|---|---|
| 2018 | European Union Reference Laboratory<br>for Halogenated POPs in Feed and Food | EURL-PT-DPB_1802-BE | Beef | Dioxins (PCDD/F) | 0.601 pg WHO-TEQ/g of fat | | 1.0. |
| 2018 | FAPAS | 07315 | Liver (Bovine) | Cadmium | 772 µg/kg | 706 µg/kg | -0.5 |
| | | | | Mercury | 887 µg/kg | 951 µg/kg | 0.4 |
| | CEFAO | 29 | Meat (Turkey) | Cadmium | 63.9 µg/kg | 47 µg/kg | -1.2 |
| | | | | Mercury | 13.8 µg/kg | 13 µg/kg | -0.3 |
| 2017 | FAPAS | 07279 | Meat (Crab) | Cadmium | 7550 µg/kg | 7400 µg/kg | -0.2 |
| | | | | Mercury | 106 µg/kg | 100 µg/kg | -0.2 |
| 2016 | FAPAS | 07265 | Liver (Bovine) | Cadmium | 881 µg/kg | 908 µg/kg | 0.2 |
| | | | | Mercury | 811 µg/kg | 846 µg/kg | 0.3 |
| 2015 | FAPAS | 07243 | Liver (Bovine) | Cadmium | 800 µg/kg | 841 µg/kg | 0.3 |
| | | | | Mercury | 707 µg/kg | 653 µg/kg | -0,5 |

Statistical analysis was made using Microsoft excel 2010 Analysis pack. Maps were made using eSpatial map software.

## Results And Discussion

# Dioxins

Dioxins mean concentrations in reindeer liver and meat depending on sampling place location are presented in Table 2. Mean concentrations depending on region, including values of standard deviation and concentrations ranges in 95% Confidence Intervals are shown in Table 3.

**Table 2. Dioxins concentrations in reindeer liver and meat depending on sampling place location**

| Region | Sampling place | Latitude, DMS | Longitude, DMS | Mean LB, ng WHO-TEQ/kg of fat | Mean UB, ng WHO-TEQ/kg of fat | Range, ng WHO-TEQ/kg of fat | N of samples |
|---|---|---|---|---|---|---|---|
| **Liver samples** | | | | | | | |
| Kola Peninsula (Murmansk oblast) | Lovozero, Lovozero district | 68.00466 | 35.014147 | 40.7 | 40.7 | 11.6-118.5 | 34 |
| | Krasnoschelie, Lovozero district | 67.349847 | 37.053197 | 28.3 | 28.3 | 6.8-49.2 | 91 |
| Nenets autonomous okrug | Mgla, Zapolyarni district | 66.498855 | 44.449269 | 76.5 | 76.5 | 76.48 | 1 |
| | Nes', Zapoliarni district | 66.600876 | 44.678905 | 31.7 | 31.7 | 12.9-59.0 | 23 |
| | Oma, Zapolyarni district | 66.641769 | 46.492496 | 31.4 | 31.4 | 21.0-36.4 | 8 |
| | Verhniaia Pesha, Zapolyarni district | 66.609449 | 47.953301 | 26.9 | 26.9 | 20.6-32.8 | 5 |
| | Indiga, Zapolyarni district | 67.655217 | 49.037136 | 30.1 | 30.1 | 17.2-54.3 | 16 |
| | Khongurey, Zapoliarni district | 67.557642 | 51.955412 | 17.6 | 17.6 | 10.5-21.4 | 4 |
| | Naryan-Mar | 67.63805 | 53.006926 | 25.2 | 25.2 | 15.9-56.1 | 10 |
| | Iskateley, Zapoliarni district | 67.677629 | 53.127704 | 20.7 | 20.7 | 8.9-32.8 | 13 |
| | Charyaginski, Zapolyarni district | 67.214359 | 56.774622 | 47.2 | 47.2 | 24.7-84.0 | 17 |
| Komi Republic | Verhnekolvinsk, Uninsk City district | 66.668506 | 56.988744 | 32.2 | 32.2 | 23.3-45.1 | 3 |
| Nenets autonomous okrug | Khorey-Ver, Zapoliarni district | 67.42082 | 56.988744 | 32.1 | 32.1 | 10.7-61.8 | 23 |
| | Kharuta, Zapoliarni district | 66.840223 | 59.526054 | 23.9 | 23.9 | 26.3-52.5 | 11 |
| Komi Republic | Inta, Inta City district | 66.03682 | 60.115367 | 30.4 | 30.4 | 25.4-37.9 | 3 |
| | Petrun', Inta City district | 66.472032 | 60.742615 | 36.9 | 36.9 | 26.4-49.8 | 3 |
| | Abez', Inta City district | 66.520928 | 61.756166 | 23.6 | 23.6 | 4.5-34.6 | 3 |
| | Vorkuta | 67.4935 | 64.050113 | 18.4 | 18.4 | 17.0-22.2 | 4 |
| Yamalo-Nenets Autonomous Okrug | Muzhi, Shurishkarskiy district | 65.400443 | 64.70556 | 13.3 | 13.3 | 11.4-16.0 | 3 |
| | Gorki, Shuryshkarskiy district | 65.055353 | 65.273825 | 20.6 | 20.6 | 20.6 | 1 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Aksarka, Priuralskiy district | 66.558885 | 67.806086 | 10.9 | 10.9 | 5.2-26.6 | 17 |
| | Beloyarsk, Priuralskiy district | 66.868108 | 68.143053 | 11.1 | 11.1 | 8.2-13.5 | 3 |
| | Panaevsk, Yamalskiy district | 66.744918 | 70.086244 | 13.5 | 13.5 | 10.1-15.9 | 5 |
| | Yar-Sale, Yamalskiy district | 66.861201 | 70.839311 | 13.3 | 13.3 | 7.0-25.2 | 19 |
| | Se-Yakha, Yamalskiy district | 70.167798 | 72.511058 | 15.4 | 15.4 | 13.8-16.8 | 4 |
| | Nyda, Nadymskiy district | 66.629301 | 72.923663 | 15.8 | 15.8 | 14.8-16.6 | 3 |
| | Antipayuta, Tazovskiy district | 69.101507 | 76.865075 | 14.2 | 14.2 | 11.5-16.9 | 6 |
| | Tarko-Sale, Purovskiy disctrict | 64.911819 | 77.761055 | 13.0 | 13.0 | 10.7-14.5 | 5 |
| | Samburg, Purovskiy district | 67.003022 | 78.223471 | 15.3 | 15.3 | 8.8-18 | 5 |
| | Tazovskiy, Tazovskiy district | 67.469359 | 78.701905 | 12.1 | 12.1 | 6.9-17.4 | 2 |
| | Krasnoselkup, Krasnoselkupskiy district | 65.707158 | 82.466035 | 14.0 | 14.0 | 10.3-17.6 | 2 |
| Taymir Peninsula (Krasnoyarsk Krai) | Dudinka, Taymir Dolgano-Nenets Autonomous okrug | 69.404172 | 86.190953 | 1.2 | 4.4 | 1.2-1.3 | 5 |
| | Volochanka, Taymir Dolgano-Nenets Autonomous okrug | 70.976083 | 94.541377 | 4.4 | 3.5 | 2.7-5.3 | 10 |
| Kamchatka krai | Esso, Bystrinskiy district | 55.928058 | 158.707517 | 3.5 | 3.5 | 2.3-5.2 | 4 |
| | Khailino, Olutorskiy district | 60.958573 | 166.84867 | 0.0 | 1.0 | 0 | 2 |
| | Slautnoe, Penzhiskiy district | 63.170231 | 167.973181 | 0.0 | 1.0 | 0.00 | 2 |
| | Apuka, Olutorskiy district | 60.442644 | 169.605636 | 0.6 | 1.1 | 0-1.2 | 2 |
| | Achayvayam, Olutorskiy district | 61.007986 | 170.507868 | 1.7 | 2.2 | 0-3.5 | 2 |
| Chukotka Autonomous Okrug | Komsomolskiy, Pevek City district | 69.132383 | 172.745939 | 0.0 | 1.0 | | 1 |
| | Anadyr | 64.735814 | 177.518904 | 1.4 | 1.4 | 1.0-1.7 | 8 |
| **Meat samples** | | | | | | | |
| Kola Peninsula (Murmansk oblast) | Lovozero, Lovozero district | 68.00466 | 35.014147 | 1.1 | 1.3 | 0-1.6 | 6 |
| | Krasnoschelie, Lovozero district | 67.349847 | 37.053197 | 1.2 | 1.6 | 0.-2.5 | 3 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Nenets autonomous okrug | Iskateley, Zapoliarni district | 67.677629 | 53.127704 | 0.0 | 1.0 | 0.00 | 10 |
| Komi Republic | Verhnekolvinsk, Uninsk City district | 66.668506 | 56.988744 | 0 | 1.0 | | 3 |
| Nenets autonomous okrug | Kharuta, Zapoliarni district | 66.840223 | 59.526054 | 0.0 | 1.0 | | 1 |
| Komi Republic | Yustydor, Inta City district | 66.054149 | 60.087914 | 2.0 | 2.0 | 2.0 | 1 |
| | Abez', Inta City district | 66.520928 | 61.756166 | 0.00 | 1.00 | | 1 |
| | Vorkuta | 67.4935 | 64.050113 | 0.3 | 1.1 | 0-1.3 | 10 |
| Yamalo-Nenets Autonomous Okrug | Aksarka, Priuralskiy district | 66.558885 | 67.806086 | 0.0 | 1.0 | | 4 |
| | Yar-Sale, Yamalskiy district | 66.861201 | 70.839311 | 0.0 | 1.0 | 0-0.4 | 7 |
| Republic of Sakha (Yakutia) | Udachniy, Mirniy municipal district | 66.406966 | 112.306389 | 0.0 | 1.0 | | 1 |
| | Iengra, Nerungri district | 56.223391 | 124.848397 | 0.0 | 1.0 | | 1 |
| Chukotka Autonomous Okrug | Egvekinot, Egvekinot City district | 66.32159 | 179.11981 | 0.0 | 1.0 | | 3 |

**Table 3. Mean concentrations of dioxins in liver depending on the region.**

| Region | Number of samples | Dioxins, mean concentration, pg WHO-TEQ/g of fat | Standard deviation | Concentration range in 95% confidence interval, pg WHO-TEQ/g of fat |
|---|---|---|---|---|
| Kola Peninsula (Murmansk oblast) | 125 | 31.7 | 14.3 | 26.6-31.2 |
| Nenets autonomous okrug | 131 | 31.0 | 13.9 | 25.9-30.5 |
| Komi Republic | 16 | 27.7 | 11.4 | 18.4-33.3 |
| Yamalo-Nenets Autonomous Okrug | 75 | 13.1 | 4.6 | 11.3-13.3 |
| Taymir Peninsula (Krasnoyarsk Krai) | 15 | 3.3 | 1.7 | 2.0-4.0 |
| Kamchatka and Chukotka | 21 | 1.4 | 1.4 | 0.8-2.0 |

The overall number of meat samples from 13 locations was 51. Dioxins concentrations found in meat were relatively low, for most part of samples being under the Limit of Quantification of 1 pg WHO-TEQ/g. The highest concentration was found in one individual sample originating from Murmansk oblast (2.5 pg/g of fat WHO-TEQ). There are no regulatory limits for dioxins in reindeer meat in Russian and Eurasian Economical Union Legislation. Providing the low concentration, no conclusions could be made on geographical trends of reindeer meat pollution by dioxins.

The overall number of liver samples from 40 locations was 383, ranging from 1 to 91 samples for each sampling location. Dioxins concentrations varied from those below the Limit of Quantification (1 pg WHO-TEQ/g) up to 76.5 pg WHO-TEQ/g of fat, found in one individual sample from Nenets Autonomous Okrug.

In 31 locations mean Upper-Bound estimate (UB) dioxins concentration in liver exceeded the National and Eurasian Economical Union maximum levels for dioxins from the Customs Union Technical Regulation TR TS 021/2011–6 pg WHO-TEQ/g of fat, and only in 9 locations (all locations from Krasnoyarsk Krai, Chukotka and Kamchatka) the mean UB concentrations were lower than the maximum level.

A clear trend in geographical distribution in dioxins concentration in liver is shown with the highest concentration in the western part of the country and than gradually decreasing as one proceeds to the east. Heatmap of dioxins concentrations is presented in Fig. 2. Diagram of dioxins concentrations in liver depending of latitude is shown in Fig. 3. Coefficients of correlation between dioxins concentrations in liver and latitude are presented in Supplementary Table 1.

Providing that dioxin concentrations are generally higher in calves than in adult hinds, [4] and that we had no detailed information on age and sex of the animals for most part of the samples, the absence of data stratification by age group could be a source of bias.

Several factors, that may contribute to discovered trend in geographical distribution of reindeer liver dioxin contamination, are discussed below.

Generally, chemical industry is one of well-known sources of dioxin pollution [EFSA 2018]. In Russia, several hot-spots of dioxins pollution originating from organochlorine compounds production plants were investigated e.g. Chapayevsk, Samara oblast [Akhmedkhanov et al. 2002], Dzerzhinsk, Nizhniy Novgorod oblast [Petrlik et al. 2005] and Ufa, Bashkortostan [Amirova et al. 2015]. All of the abovementioned hotspots and most part of other chemical object, that may be a source of dioxin emission, are located in the western part of the country, while to the east from the Ural mountains there are quite few of them. The overwhelming majority of Russian chemical industry objects started functioning during the Soviet era and dioxins emmited and accumulated in the environment during this period and later are still likely to be among the most significant contributors to the Russian Far North pollution [AMAP 2004].

Soviet Union chemical and oil-refining industry is shown on the map in Fig. 4. Providing that dioxins emitted from chemical plants migrate first-of all to the closer regions [AMAP 2004], the conclusion may be made that dioxin concentration in reindeer liver has signs of correlation with the density of chemical industry objects. Among the Asian countries sharing the borders with Russia, China and Japan have the most developed chemical industry. Heavy chemically industrialized provinces of China e.g. Shandong, Jiangsu, Hubei, Henan and Inner Mongolia are located in more than 3000 km from the nearest sampling place in Kamchatka [Chen et al. 2020]. Japan is located much closer, the northern Japanese isle Hokkaido is approx. in 1500 km from the sampling place in Kamchatka. However, in Nenets Autonomous okrug, high concentrations of dioxins were found, and the closest chemical industry objects are located in approx. 1000 km from the plants. This indicates that nearest chemical industry is not the single factor making the critical contribution to the pollution.

It should be noted that not only chemical industry objects are a notable sources of dioxins, but other types of industry, waste incinerators and dumps, automobiles etc. as well [AMAP 2004]. However, the density of chemical industry objects in Figure corresponds well with the density of population and anthropogenic activity. The most part of cities are located in the Western part of Russia or along it's South border, while there are quite few cities in the Nothern part of the country to the east of Ural mountains.

In 2013, the global air-borne dioxin deposition model was made by Booth et al. [Booth et al. 2013], and our results partly match with this model. According to the model, dioxin deposition is intensive in European part of the Russian Far North (in Kola Peninsula, Nenets Autonomous okrug and Komi Republic), much lower in middle part of Russian Far North (Yamalo-Nenets Autonomous okrug and Taymir Peninsula), and that distribution matches well our results. However, in eastern part of the country (Chukotka and Kamchatka) we have found the same low concentrations as in the middle part and, while according to the abovementioned model, dioxin deposition in Chukotka and Kamchatka should be higher than in the middle part (Yamalo-Nenets Autonomous okrug and Taymir Peninsula). Only parts of the regions, whence the samples were taken, were subject to comparison with Booth model of dioxins deposition.

Other important factor, that may contribute to dioxin pollution geographical trend, is the density of reindeers at pastures. The more animals graze on one area, the higher is the probability that due to lack to reindeer moss and other lichens and plants, more particles of soil will be ingested by the animals. Soil is a well-known reservoir of dioxins [EFSA 2011]. Western part of Russian far North, including Kola Peninsula, Nenets AO, Komi Republic and Yamalo-Nenets AO are marked by much higher density of reindeers comparing to the eastern regions: Taymir Peninsula, Yakutia, Kamchatka and Chukotka [Ministry 2013], see Fig. 5.

# Cadmium and Mercury

Cadmium and mercury were determined in 505 samples of liver, 315 samples of kidneys and 22 samples of meat from 41 location. Cadmium and mercury concentrations depending on the sample place in reindeer liver, kidneys and meat are presented in the Tables 4 and 5, respectively. Mean concentrations depending on the region, including values of standard deviation and 95% Confidence Intervals are shown in Table 6.

**Table 4. Cadmium concentrations in liver and kidneys depending on sample place location**

| Region | Sampling place | Latitude, DMS | Longitude, DMS | Cadmium, mean LB, mg/kg | Cadmium, mean UB, mg/kg | Range, mg/kg | Number of samples |
|---|---|---|---|---|---|---|---|
| **Kidneys** | | | | | | | |
| Kola Peninsula (Murmansk oblast) | Lovozero, Lovozero district | 68.00466 | 35.014147 | 2.3 | 2.3 | 1.1-4.9 | 25 |
| | Krasnoschelie, Lovozero district | 67.349847 | 37.053197 | 5.1 | 5.1 | 1-19 | 65 |
| Nenets autonomous okrug | Nes', Zapoliarni district | 66.600876 | 44.678905 | 2.0 | 2.0 | 0.011-6.5 | 25 |
| | Oma, Zapolyarni district | 66.641769 | 46.492496 | 0.73 | 0.73 | 0.46 | 4 |
| | Verhniaia Pesha, Zapolyarni district | 66.609449 | 47.953301 | 0.57 | 0.57 | 0.56-0.58 | 2 |
| | Indiga, Zapolyarni district | 67.655217 | 49.037136 | 1.2 | 1.2 | 0.82-2 | 4 |
| | Khongurey, Zapoliarni district | 67.557642 | 51.955412 | 0.8 | 0.8 | 0.52-1.6 | 7 |
| | Naryan-Mar | 67.63805 | 53.006926 | 3.2 | 3.2 | 3.1-3.2 | 2 |
| | Iskateley, Zapoliarni district | 67.677629 | 53.127704 | 0.76 | 0.76 | 0.48-0.91 | 3 |
| | Khorey-Ver, Zapoliarni district | 67.42082 | 56.988744 | 0.97 | 0.97 | 0.61-1.2 | 4 |
| Komi Republic | Verhnekolvinsk, Uninsk City district | 66.668506 | 56.988744 | 1.8 | 1.8 | 0.44-6.7 | 10 |
| Nenets autonomous okrug | Kharuta, Zapoliarni district | 66.840223 | 59.526054 | 6.7 | 6.7 | 1.4-12 | 2 |
| Komi Republic | Inta, Inta City district | 66.03682 | 60.115367 | 5.5 | 5.5 | 4.6-6.5 | 3 |
| | Petrun', Inta City district | 66.472032 | 60.742615 | 2.8 | 2.8 | 1-9.3 | 12 |
| | Abez', Inta City district | 66.520928 | 61.756166 | 3.0 | 3.0 | 0.7-9.2 | 10 |
| | Vorkuta | 67.4935 | 64.050113 | 6.0 | 6.0 | 1.2-21 | 7 |
| Yamalo-Nenets Autonomous Okrug | Muzhi, Shurishkarskiy district | 65.400443 | 64.70556 | 7.3 | 7.3 | 5.9-9.2 | 4 |
| | Gorki, Shuryshkarskiy district | 65.055353 | 65.273825 | 3.5 | 3.5 | 1.2-6 | 4 |
| | Aksarka, Priuralskiy district | 66.558885 | 67.806086 | 3.4 | 3.4 | 0.42-7.8 | 16 |
| | Beloyarsk, Priuralskiy district | 66.868108 | 68.143053 | 2.9 | 2.9 | 1-7.6 | 8 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Panaevsk, Yamalskiy district | 66.744918 | 70.086244 | 5.0 | 5.0 | 0.52-13 | 12 |
| | Yar-Sale, Yamalskiy district | 66.861201 | 70.839311 | 4.0 | 4.0 | 1-6.5 | 12 |
| | Se-Yakha, Yamalskiy district | 70.167798 | 72.511058 | 4.0 | 4.0 | 1.1-8.9 | 10 |
| | Nyda, Nadymskiy district | 66.629301 | 72.923663 | 3.85 | 3.85 | 0.9-12 | 8 |
| | Antipayuta, Tazovskiy district | 69.101507 | 76.865075 | 1.3 | 1.3 | 0.42-3.5 | 8 |
| | Tarko-Sale, Purovskiy disctrict | 64.911819 | 77.761055 | 4.0 | 4.0 | 0.89-8 | 5 |
| | Samburg, Purovskiy district | 67.003022 | 78.223471 | 6.8 | 6.8 | 0.43-12 | 5 |
| | Tazovskiy, Tazovskiy district | 67.469359 | 78.701905 | 2.0 | 2.0 | 0.36-4.6 | 4 |
| | Krasnoselkup, Krasnoselkupskiy district | 65.707158 | 82.466035 | 2.8 | 2.8 | 0.95-6.6 | 4 |
| Taymir Peninsula (Krasnoyarsk Krai) | Dudinka, Taymir Dolgano-Nenets Autonomous okrug | 69.404172 | 86.190953 | 0.74 | 0.74 | 0.056-1.6 | 10 |
| Kamchatka krai | Esso, Bystrinskiy district | 55.928058 | 158.707517 | 1.0 | 1.0 | 0.63-1.2 | 4 |
| | Khailino, Olutorskiy district | 60.958573 | 166.84867 | 5.3 | 5.3 | 4.1-6.4 | 2 |
| | Slautnoe, Penzhiskiy district | 63.170231 | 167.973181 | 2.9 | 2.9 | 2.2-3.5 | 2 |
| | Achayvayam, Olutorskiy district | 61.007986 | 170.507868 | 2.4 | 2.4 | 2.1-2.6 | 2 |
| Chukotka Autonomous Okrug | Anadyr | 64.735814 | 177.518904 | 5.5 | 5.5 | 3.4-8.3 | 10 |
| **Liver** | | | | | | | |
| Murmansk oblast | Lovozero, Lovozero district | 68.00466 | 35.014147 | 0.76 | 0.76 | 0.26-1.5 | 49 |
| | Krasnoschelie, Lovozero district | 67.349847 | 37.053197 | 1.13 | 1.13 | 0.062-2.4 | 105 |
| Nenets autonomous okrug | Mgla, Zapolyarni district | 66.498855 | 44.449269 | 0.2 | 0.2 | 0.2 | 1 |
| | Nes', Zapoliarni district | 66.600876 | 44.678905 | 0.41 | 0.41 | 0.17-0.78 | 29 |
| | Oma, Zapolyarni district | 66.641769 | 46.492496 | 0.55 | 0.55 | 0.15-1.1 | 8 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Verhniaia Pesha, Zapolyarni district | 66.609449 | 47.953301 | 0.31 | 0.31 | 0.19-0.44 | 5 |
| | Indiga, Zapolyarni district | 67.655217 | 49.037136 | 0.17 | 0.17 | 0.071-0.34 | 16 |
| | Khongurey, Zapoliarni district | 67.557642 | 51.955412 | 0.24 | 0.24 | 0.16-0.33 | 4 |
| | Naryan-Mar | 67.63805 | 53.006926 | 0.21 | 0.21 | 0.099-0.44 | 12 |
| | Iskateley, Zapoliarni district | 67.677629 | 53.127704 | 0.28 | 0.28 | 0.15-0.37 | 13 |
| | Charyaginski, Zapolyarni district | 67.214359 | 56.774622 | 0.23 | 0.23 | 0.081-0.7 | 17 |
| | Khorey-Ver, Zapoliarni district | 67.42082 | 56.988744 | 0.31 | 0.31 | 0.14-0.7 | 29 |
| Komi Republic | Verhnekolvinsk, Uninsk City district | 66.668506 | 56.988744 | 0.53 | 0.53 | 0.16-1.2 | 10 |
| Nenets autonomous okrug | Kharuta, Zapoliarni district | 66.840223 | 59.526054 | 0.46 | 0.46 | 0.1-2 | 15 |
| Komi Republic | Inta, Inta City district | 66.03682 | 60.115367 | 0.33 | 0.33 | 0.2-0.42 | 3 |
| | Petrun', Inta City district | 66.472032 | 60.742615 | 0.51 | 0.51 | 0.24-1.2 | 12 |
| | Abez', Inta City district | 66.520928 | 61.756166 | 0.43 | 0.43 | 0.2-0.73 | 10 |
| | Vorkuta | 67.4935 | 64.050113 | 0.76 | 0.76 | 0.44-1.2 | 7 |
| Yamalo-Nenets Autonomous Okrug | Muzhi, Shurishkarskiy district | 65.400443 | 64.70556 | 1.23 | 1.23 | 0.85-1.9 | 4 |
| | Gorki, Shuryshkarskiy district | 65.055353 | 65.273825 | 0.83 | 0.83 | 0.45-1.3 | 4 |
| | Aksarka, Priuralskiy district | 66.558885 | 67.806086 | 0.61 | 0.61 | 0.24-1.4 | 24 |
| | Beloyarsk, Priuralskiy district | 66.868108 | 68.143053 | 0.48 | 0.48 | 0.26-0.76 | 8 |
| | Panaevsk, Yamalskiy district | 66.744918 | 70.086244 | 0.82 | 0.82 | 0.19-2 | 12 |
| | Yar-Sale, Yamalskiy district | 66.861201 | 70.839311 | 0.71 | 0.71 | 0.33-1.7 | 23 |
| | Se-Yakha, Yamalskiy district | 70.167798 | 72.511058 | 0.74 | 0.74 | 0.22-1.7 | 10 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Nyda, Nadymskiy district | 66.629301 | 72.923663 | 0.69 | 0.69 | 0.29-1.7 | 8 |
| | Antipayuta, Tazovskiy district | 69.101507 | 76.865075 | 0.41 | 0.41 | 0.14-0.86 | 8 |
| | Tarko-Sale, Purovskiy disctrict | 64.911819 | 77.761055 | 0.49 | 0.49 | 0.16-0.73 | 5 |
| | Samburg, Purovskiy district | 67.003022 | 78.223471 | 0.55 | 0.55 | 0.28-1.2 | 5 |
| | Tazovskiy, Tazovskiy district | 67.469359 | 78.701905 | 0.34 | 0.34 | 0.19-0.49 | 4 |
| | Krasnoselkup, Krasnoselkupskiy district | 65.707158 | 82.466035 | 0.46 | 0.46 | 0.27-0.62 | 4 |
| Taymir Peninsula (Krasnoyarsk Krai) | Dudinka, Taymir Dolgano-Nenets Autonomous okrug | 69.404172 | 86.190953 | 0.51 | 0.51 | 0.22-1.2 | 8 |
| | Volochanka, Taymir Dolgano-Nenets Autonomous okrug | 70.976083 | 94.541377 | 0.41 | 0.41 | 0.12-1 | 10 |
| | Tura, Evenki district | 64.272252 | 100.206396 | 1.3 | 1.3 | | 1 |
| Kamchatka krai | Esso, Bystrinskiy district | 55.928058 | 158.707517 | 0.64 | 0.64 | 0.42-0.82 | 4 |
| | Khailino, Olutorskiy district | 60.958573 | 166.84867 | 0.33 | 0.33 | 0.31-0.35 | 2 |
| | Slautnoe, Penzhiskiy district | 63.170231 | 167.973181 | 0.55 | 0.55 | 0.33-0.76 | 2 |
| | Achayvayam, Olutorskiy district | 61.007986 | 170.507868 | 0.49 | 0.49 | | 2 |
| | Vaegi, Anadyrskiy district | 64.165339 | 171.040631 | 0.52 | 0.52 | | 1 |
| | Khatyrka, Anadyr district | 62.061584 | 175.288773 | 0.17 | 0.17 | | 1 |
| Chukotka Autonomous Okrug | Anadyr | 64.735814 | 177.518904 | 0.81 | 0.81 | 0.49-1.4 | 10 |
| **Meat** | | | | | | | |
| Kola Peninsula (Murmansk oblast) | Lovozero, Lovozero district | 68.00466 | 35.014147 | 0.0031 | 0.0060 | 0-0.0087 | 7 |
| | Krasnoschelie, Lovozero district | 67.349847 | 37.053197 | 0.0074 | 0.0099 | 0-0.023 | 8 |
| Nenets autonomous okrug | Nelmin nos, Zapolyarni district | 67.979742 | 52.956746 | 0.00 | 0.00 | | 2 |
| | Iskateley, Zapoliarni district | 67.677629 | 53.127704 | 0.00 | 0.00 | | 4 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Charyaginski, Zapolyarni district | 67.214359 | 56.774622 | 0.00 | 0.00 | 1 |

**Table 5. Mercury concentrations in liver and kidneys depending on sample place location**

| Region | Sampling place | Latitude, DMS | Longitude, DMS | Mercury, mean LB, mg/kg | Mercury, mean UB, mg/kg | Range, mg/kg | N of samples |
|---|---|---|---|---|---|---|---|
| **Kidneys** | | | | | | | |
| Kola Peninsula (Murmansk oblast) | Lovozero, Lovozero district | 68.00466 | 35.014147 | 0.34 | 0.34 | 0.23-0.52 | 25 |
| | Krasnoschelie, Lovozero district | 67.349847 | 37.053197 | 0.73 | 0.73 | 0.34-1.8 | 65 |
| Nenets autonomous okrug | Nes', Zapoliarni district | 66.600876 | 44.678905 | 0.65 | 0.65 | 0-1 | 25 |
| | Oma, Zapolyarni district | 66.641769 | 46.492496 | 1.1 | 1.1 | 1-1.2 | 4 |
| | Verhniaia Pesha, Zapolyarni district | 66.609449 | 47.953301 | 0.44 | 0.44 | 0.4-0.48 | 2 |
| | Indiga, Zapolyarni district | 67.655217 | 49.037136 | 0.73 | 0.73 | 0.53-1.1 | 4 |
| | Khongurey, Zapoliarni district | 67.557642 | 51.955412 | 0.63 | 0.63 | 0.51-0.71 | 7 |
| | Naryan-Mar | 67.63805 | 53.006926 | 0.9 | 0.9 | 0.86-0.93 | 2 |
| | Iskateley, Zapoliarni district | 67.677629 | 53.127704 | 0.4 | 0.4 | 0.3-0.49 | 3 |
| Komi Republic | Verhnekolvinsk, Uninsk City district | 66.668506 | 56.988744 | 0.48 | 0.48 | 0.29-0.8 | 10 |
| Nenets autonomous okrug | Khorey-Ver, Zapoliarni district | 67.42082 | 56.988744 | 0.6 | 0.6 | 0.44-0.78 | 4 |
| | Kharuta, Zapoliarni district | 66.840223 | 59.526054 | 0.75 | 0.75 | 0.61-0.88 | 2 |
| Komi Republic | Inta, Inta City district | 66.03682 | 60.115367 | 0.59 | 0.59 | 0.45-0.67 | 3 |
| | Petrun', Inta City district | 66.472032 | 60.742615 | 0.32 | 0.32 | 0.19-0.51 | 12 |
| | Abez', Inta City district | 66.520928 | 61.756166 | 0.45 | 0.45 | 0.28-0.6 | 10 |
| | Vorkuta | 67.4935 | 64.050113 | 0.46 | 0.46 | 0.25-0.78 | 7 |
| Yamalo-Nenets Autonomous Okrug | Muzhi, Shurishkarskiy district | 65.400443 | 64.70556 | 0.71 | 0.71 | 0.61-0.77 | 4 |
| | Gorki, Shuryshkarskiy district | 65.055353 | 65.273825 | 0.46 | 0.46 | 0.37-0.53 | 4 |
| | Aksarka, Priuralskiy district | 66.558885 | 67.806086 | 0.56 | 0.56 | 0.22-0.79 | 16 |
| | Beloyarsk, Priuralskiy district | 66.868108 | 68.143053 | 0.53 | 0.53 | 0.36-0.78 | 8 |
| | Panaevsk, | 66.744918 | 70.086244 | 0.4 | 0.4 | 0.21- | 12 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Yamalskiy district | | | | | 0.7 | |
| | Yar-Sale, Yamalskiy district | 66.861201 | 70.839311 | 0.6 | 0.6 | 0.43-0.92 | 12 |
| | Se-Yakha, Yamalskiy district | 70.167798 | 72.511058 | 0.5 | 0.5 | 0.38-0.71 | 10 |
| | Nyda, Nadymskiy district | 66.629301 | 72.923663 | 0.6 | 0.6 | 0.43-0.82 | 8 |
| | Antipayuta, Tazovskiy district | 69.101507 | 76.865075 | 0.34 | 0.34 | 0.2-0.54 | 8 |
| | Tarko-Sale, Purovskiy disctrict | 64.911819 | 77.761055 | 0.84 | 0.84 | 0.47-1.2 | 5 |
| | Samburg, Purovskiy district | 67.003022 | 78.223471 | 0.38 | 0.38 | 0.24-0.58 | 5 |
| | Tazovskiy, Tazovskiy district | 67.469359 | 78.701905 | 0.37 | 0.37 | 0.17-0.51 | 4 |
| | Krasnoselkup, Krasnoselkupskiy district | 65.707158 | 82.466035 | 0.42 | 0.42 | 0.3-0.54 | 4 |
| Taymir Peninsula (Krasnoyarsk Krai) | Dudinka, Taymir Dolgano-Nenets Autonomous okrug | 69.404172 | 86.190953 | 0.054 | 0.054 | 0.02-0.1 | 10 |
| Kamchatka krai | Esso, Bystrinskiy district | 55.928058 | 158.707517 | 0.25 | 0.25 | 0.22-0.27 | 4 |
| | Khailino, Olutorskiy district | 60.958573 | 166.84867 | 0.66 | 0.66 | 0.46-0.85 | 2 |
| | Slautnoe, Penzhiskiy district | 63.170231 | 167.973181 | 0.53 | 0.53 | 0.39-0.67 | 2 |
| | Achayvayam, Olutorskiy district | 61.007986 | 170.507868 | 0.38 | 0.38 | 0.36-0.39 | 2 |
| Chukotka Autonomous Okrug | Anadyr | 64.735814 | 177.518904 | 1.1 | 1.1 | 0.93-1.5 | 10 |
| **Liver** | | | | | | | |
| Kola Peninsula (Murmansk oblast) | Lovozero, Lovozero district | 68.00466 | 35.014147 | 0.12 | 0.12 | 0.052-0.23 | 49 |
| | Krasnoschelie, Lovozero district | 67.349847 | 37.053197 | 0.26 | 0.26 | 0.022-0.52 | 105 |
| Nenets autonomous okrug | Mgla, Zapolyarni district | 66.498855 | 44.449269 | 0.20 | 0.20 | | 1 |
| | Nes', Zapoliarni district | 66.600876 | 44.678905 | 0.18 | 0.18 | 0.094-0.34 | 29 |
| | Oma, Zapolyarni district | 66.641769 | 46.492496 | 0.27 | 0.27 | 0.13-0.47 | 8 |
| | Verhniaia Pesha, Zapolyarni district | 66.609449 | 47.953301 | 0.25 | 0.25 | 0.21-0.28 | 5 |
| | Indiga, Zapolyarni district | 67.655217 | 49.037136 | 0.22 | 0.22 | 0.15-0.32 | 16 |
| | Khongurey, | 67.557642 | 51.955412 | 0.21 | 0.21 | 0.014- | 4 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Zapoliarni district | | | | | 0.3 | |
| | Naryan-Mar | 67.63805 | 53.006926 | 0.21 | 0.21 | 0.076-0.33 | 12 |
| | Iskateley, Zapoliarni district | 67.677629 | 53.127704 | 0.18 | 0.18 | 0.11-0.29 | 13 |
| | Charyaginski, Zapolyarni district | 67.214359 | 56.774622 | 0.16 | 0.16 | 0.074 | 17 |
| Komi Republic | Verhnekolvinsk, Uninsk City district | 66.668506 | 56.988744 | 0.15 | 0.15 | 0.089-0.2 | 10 |
| Nenets autonomous okrug | Khorey-Ver, Zapoliarni district | 67.42082 | 56.988744 | 0.20 | 0.20 | 0.1-0.36 | 29 |
| | Kharuta, Zapoliarni district | 66.840223 | 59.526054 | 0.15 | 0.15 | 0.056-0.25 | 15 |
| Komi Republic | Inta, Inta City district | 66.03682 | 60.115367 | 0.18 | 0.18 | 0.12-0.22 | 3 |
| | Petrun', Inta City district | 66.472032 | 60.742615 | 0.11 | 0.11 | 0.078-0.14 | 12 |
| | Abez', Inta City district | 66.520928 | 61.756166 | 0.13 | 0.13 | 0.069-0.25 | 10 |
| | Vorkuta | 67.4935 | 64.050113 | 0.11 | 0.11 | 0.065-0.2 | 7 |
| Yamalo-Nenets Autonomous Okrug | Muzhi, Shurishkarskiy district | 65.400443 | 64.70556 | 0.15 | 0.15 | 0.14-0.16 | 4 |
| | Gorki, Shuryshkarskiy district | 65.055353 | 65.273825 | 0.23 | 0.23 | 0.12-0.41 | 4 |
| | Aksarka, Priuralskiy district | 66.558885 | 67.806086 | 0.19 | 0.19 | 0.094-0.55 | 24 |
| | Beloyarsk, Priuralskiy district | 66.868108 | 68.143053 | 0.14 | 0.14 | 0.088-0.18 | 8 |
| | Panaevsk, Yamalskiy district | 66.744918 | 70.086244 | 0.12 | 0.12 | 0.08-0.17 | 12 |
| | Yar-Sale, Yamalskiy district | 66.861201 | 70.839311 | 0.19 | 0.19 | 0.12-0.4 | 23 |
| | Se-Yakha, Yamalskiy district | 70.167798 | 72.511058 | 0.10 | 0.10 | 0.055-0.17 | 10 |
| | Nyda, Nadymskiy district | 66.629301 | 72.923663 | 0.19 | 0.19 | 0.14-0.24 | 8 |
| | Antipayuta, Tazovskiy district | 69.101507 | 76.865075 | 0.11 | 0.11 | 0.073-0.17 | 8 |
| | Tarko-Sale, Purovskiy disctrict | 64.911819 | 77.761055 | 0.39 | 0.39 | 0.22-0.52 | 5 |
| | Samburg, Purovskiy district | 67.003022 | 78.223471 | 0.17 | 0.17 | 0.13-0.24 | 5 |
| | Tazovskiy, Tazovskiy district | 67.469359 | 78.701905 | 0.15 | 0.15 | 0.091-0.18 | 4 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Krasnoselkup, Krasnoselkupskiy district | 65.707158 | 82.466035 | 0.14 | 0.14 | 0.11-0.19 | 4 |
| Krasnoyarsk Krai | Dudinka, Taymir Dolgano-Nenets Autonomous okrug | 69.404172 | 86.190953 | 0.051 | 0.057 | 0-0.2 | 8 |
| | Volochanka, Taymir Dolgano-Nenets Autonomous okrug | 70.976083 | 94.541377 | 0.053 | 0.053 | 0.02-0.082 | 10 |
| | Tura, Evenki district | 64.272252 | 100.206396 | 1.0 | 1.0 | | 1 |
| Kamchatka krai | Esso, Bystrinskiy district | 55.928058 | 158.707517 | 0.067 | 0.067 | 0.054-0.072 | 4 |
| | Khailino, Olutorskiy district | 60.958573 | 166.84867 | 0.12 | 0.12 | 0.093-0.15 | 2 |
| | Slautnoe, Penzhiskiy district | 63.170231 | 167.973181 | 0.13 | 0.13 | 0.13-0.13 | 2 |
| | Achayvayam, Olutorskiy district | 61.007986 | 170.507868 | 0.088 | 0.088 | 0.056-0.12 | 2 |
| | Vaegi, Anadyrskiy district | 64.165339 | 171.040631 | 0.25 | 0.25 | | 1 |
| | Khatyrka, Anadyr district | 62.061584 | 175.288773 | 0.25 | 0.25 | | 1 |
| Chukotka Autonomous Okrug | Anadyr | 64.735814 | 177.518904 | 0.089 | 0.089 | 0.059-0.12 | 10 |
| **Meat** | | | | | | | |
| Kola Peninsula (Murmansk oblast) | Lovozero, Lovozero district | 68.00466 | 35.014147 | 0.0051 | 0.011 | 0-0.013 | 7 |
| | Krasnoschelie, Lovozero district | 67.349847 | 37.053197 | 0.0071 | 0.011 | 0-0.013 | 8 |
| Nenets autonomous okrug | Nelmin nos, Zapolyarni district | 67.979742 | 52.956746 | 0.0 | 0.0 | 0-0.011 | 2 |
| | Iskateley, Zapoliarni district | 67.677629 | 53.127704 | 0.0 | 0.0 | | 4 |
| | Charyaginski, Zapolyarni district | 67.214359 | 56.774622 | 0.0 | 0.0 | | 1 |

**Table 6. Mean cadmium and mercury concentrations in liver and kidneys depending on the region.**

| Region | Number of samples | Mean, pg WHO-TEQ/g of fat | Standard deviation | Concentration range in 95% confidence interval, pg WHO-TEQ/g of fat |
|---|---|---|---|---|
| Dioxins in liver, Lowerbound estimate | | | | |
| Kola Peninsula (Murmansk oblast) | 125 | 31.7 | 14.3 | 26.6-31.2 |
| Nenets autonomous okrug | 131 | 31.0 | 13.9 | 25.9-30.5 |
| Komi Republic | 16 | 27.7 | 11.4 | 18.4-33.3 |
| Yamalo-Nenets Autonomous Okrug | 75 | 13.1 | 4.6 | 11.3-13.3 |
| Taymir Peninsula (Krasnoyarsk Krai) | 15 | 3.3 | 1.7 | 2.0-4.0 |
| Kamchatka and Chukotka | 21 | 1.4 | 1.4 | — |
| Dioxins in liver, lowerbound | | | | |
| Cadmium in liver, Lowerbound estimate | | | | |
| Murmansk oblast (Kola Peninsula) | 154 | 1.0 | 0.51 | 0.8 - 1 |
| Nenets autonomous okrug | 149 | 0.32 | 0.23 | 0.2-0.3 |
| Komi Republic | 42 | 0.52 | 0.28 | 0.4-0.5 |
| Yamalo-Nenets Autonomous Okrug | 119 | 0.65 | 0.39 | 0.5-0.6 |
| Taymir Peninsula (Krasnoyarsk Krai) | 19 | 0.5 | 0.38 | 0.3-0.5 |
| Kamchatka and Chukotka | 22 | 0.64 | 0.28 | 0.5-0.7 |
| Cadmium in kidneys, Lowerbound estimate | | | | |
| Murmansk oblast (Kola Peninsula) | 90 | 4.4 | 3.3 | 3.1-4 |
| Nenets autonomous okrug | 53 | 1.7 | 2.0 | 0.8-1.5 |
| Komi Republic | 42 | 3.4 | 3.8 | 1.7-2.9 |
| Yamalo-Nenets Autonomous Okrug | 100 | 3.8 | 3.1 | 2.3-3.2 |
| Taymir Peninsula (Krasnoyarsk Krai) | 10 | 0.74 | 0.49 | 0.3-1.1 |
| Kamchatka and Chukotka | 20 | 4 | 2.27 | 2.3-4.6 |
| Mercury in liver, Lowerbound estimate | | | | |
| Murmansk oblast (Kola Peninsula) | 154 | 0.21 | 0.11 | 0.2-0.2 |
| Nenets autonomous | 149 | 0.19 | 0.07 | 0.2-0.2 |

| | | | | |
|---|---|---|---|---|
| okrug | | | | |
| Komi Republic | 42 | 0.13 | 0.04 | 0.1-0.1 |
| Yamalo-Nenets Autonomous Okrug | 119 | 0.17 | 0.09 | 0.1-0.2 |
| Taymir Peninsula (Krasnoyarsk Krai) | 19 | 0.06 | 0.07 | — |
| Kamchatka and Chukotka | 22 | 0.11 | 0.05 | 0.1-0.1 |
| Mercury in kidneys, Lowerbound estimate | | | | |
| Murmansk oblast (Kola Peninsula) | 90 | 0.62 | 0.3 | 0.5-0.6 |
| Nenets autonomous okrug | 53 | 0.67 | 0.22 | — |
| Komi Republic | 42 | 0.43 | 0.15 | 0.4-0.5 |
| Yamalo-Nenets Autonomous Okrug | 100 | 0.52 | 0.18 | 0.5-0.5 |
| Taymir Peninsula (Krasnoyarsk Krai) | 10 | 0.05 | 0.02 | 0-0.1 |
| Kamchatka and Chukotka | 20 | 0.75 | 0.4 | 0.5-0.9 |

Cadmium concentrations were found to be generally much higher than mercury concentrations. The concentrations of metals in kidneys were much higher than in liver. In meat only low concentration of cadmium and mercury were found, mostly below the limit of detection. The highest concentrations of cadmium in liver (more than 1 mg/kg) were found in 3 sampling places from Murmansk oblast, Yamalo-Nenets Autonomous okrug and Taymir Peninsula. Highest cadmium concentrations in kidneys (more than 6 mg/kg) were found in Komi republic, Nenets and Yamalo-Nenets AO. Highest mercury concentration in liver (1 mg/kg) was found in one sample from Taymir Peninsula. Highest mercury concentrations (more than 1 mg/kg) in kidneys were found in Nenets AO and Chukotka.

Cadmium and mercury concentrations in kidneys and liver exceeded the National Maximum Levels from the Customs Union Technical Regulation TR TS 021/2011 (0.3 mg/kg – cadmium in offal, 0.1 mg/kg – mercury in offal) for almost all sampling places. No violations of Maximum Level (0.05 mg/kg – cadmium, 0.03 mg/kg - mercury) were found for meat.

Heatmap of cadmium and mercury concentrations in kidneys are presented in pictures 6 and 7, respectively. Unlike dioxins, no signs of concentration dependence on latitude may be seen from our data. Coefficients of correlation between heavy metals concentrations and latitude are presented in Supplementary Table 1.

Limited data on age and sex of animals did not allow to plot data by these parameters. However, these data was provided for samples from Yamalo-Nenets AO. Data on cadmium and mercury concentrations depending on sex are presented in Supplemental Table 2. For mercury and cadmium, the difference in concentrations between two sexes did not exceed 10% for both liver and kidneys. Data on metals concentrations, depending on age of the animals, is presented in Supplemental table 3. Coefficients of correlation between heavy metals concentrations and age groups are presented in Supplementary Table 1. The following age groups were considered: up to 0-0.5 years, 0.5–1.5 years, 1.5-3 years, 3-4.5 years, 4.5 + years. Statistically significant correlation was found only for cadmium in kidneys, and it was strong negative correlation (R is -0.9115, the P-value is 0.031444). This does not correspond with literature indicating that cadmium accumulates in kidneys with age and the correlation is positive [Hooser 2018; Gamberg et al. 2020], while mercury renal concentrations are highly dependent on sex [Gamberg et al. 2020]. Taking into account the confusion in data, geographical localization may be a better predictor of cadmium and mercury concentration in reindeer liver and kidneys, than age and sex of the animals.

Data on individual samples from Yamalo- Nenets AO with indication of age and sex of the animals is presented in Supplemental Table 4.

Mean cadmium concentrations in kidneys for each age groups and each sampling place were compared to each other. The range of cadmium concentrations in kidneys for age groups was 2.81–4.71 mg/kg (1.7-fold difference between the lowest and the highest concentrations), while the range of concentration between sampling places in Yamalo-Nenets AO was much wider: 1.30–7.30 mg/kg (5.6-fold difference). Along with relatively low difference in cadmium concentrations between male and female tissues (< 10%), this indicates, that cadmium concentrations in our data are dependent more on geographical localization, than age and sex. However, absence of data stratification by age group due to lack of information could be a source a bias.

Mining enterprises, including non-ferrous metals production, are believed to be important sources of mercury and cadmium pollution of the environment [AMAP 2004; Zengwei et al. 2019]. The most active local sources of mercury emission in Russian Far North are located in two places in Kola Peninsula - Monchegosrk and Zapolyarni district and one place in Taymir Peninsula (Krasnoyarsk krai) - Norilsk. These sources are combined smelters of «Norilsk Nickel» company – one of the world's largest producers of non-ferrous metals: palladium, nickel, platinum, cobalt and copper and other ore-dressing and processing enterprises.

There were two sampling places in relatively close vicinity to the abovementioned enterprises – one in Lovozero: 60 km to Monchegorsk, the other in Dudinka: 60 km to Norilsk. As it may be seen from Tables 3 and 4, cadmium concentrations in these sampling places in liver and kidneys are not among the highest, and mercury concentrations are even among the lowest.

There were two sampling places in Kola Peninsula: Krasnoschelie and Lovozero. Krasnoschelie is located in approx. 100 km from Lovozero to the South East, being further from Monchegorsk than Lovozero. Average mercury concentrations in liver and kidneys from Krasnoschelie are approx twice as high as in Lovozero, and quite the same situation is with cadmium. These data indicate that local sources of pollution may not play a crucial role of cadmium and liver accumulation in reindeers, at least at the distance greater than 60 km.

The overall density of domesticated reindeer population leading to increased digestion of the soil particles may play less role for metals, than in case of dioxins. Dioxins, being lypophilic compounds, accumulate poorly in lichens and plants, while cadmium and mercury do it well [Hassan et al. 2012; WHO 2016; Bačkor et al. 2009], so additional swallowing of soil will have less effect of heavy metals accumulation in reindeer tissues, comparing to dioxins.

Lichen and plant contamination, originating from atmospheric deposition and soil pollution, coupled with individual and subpopulational biochemical variability, age, sex, month of sampling may be the factors, that are responsible for the differences in cadmium and mercury distribution between sampling places in the Russian Far North.

# Reindeer liver as global indicator of dioxins, cadmium and mercury pollution

Here we present data on geographical distribution of reindeer liver and kidneys pollution by dioxins, cadmium and mercury and discuss possible factors that could affect it.

For environmental monitoring purposes, reindeer liver may serve as good additional indicator of dioxins, cadmium and mercury pollution of Nothern regions of the planet, along with air, soil, plants etc., for the following reasons:

- All reindeers in Europe and Asia belong to the same species *Rangifer tarandus*, which is the only representative of the genus *Rangifer.* There are several subspecies, e.g. *Rangifer tarandus tarandus* and *Rangider tarandus sibiricus in Eurasia*, and *Rangifer tarandus caribou* in America. Differences between reindeer (Eurasia) and caribou (America), for example caribou is larger than reindeer. However, data indicate typical similarity in terms of biochemistry, resistance to harmful agents and feeding habits for both species [Johnson 2012; Tryland et al. 2018].

- Both reindeer and caribou are likely to exhibit the longest terrestrial migrations among mammalians on the planet. The animals graze on vast areas, having seasonal migrations on distances up to hundreds kilometers in one side in North-South direction [Hansen et al. 2010, Nicholson et al. 2016]. Dioxins and heavy metals are unevenly spatially distributed in soil. Reindeer and caribou graze on the whole path of their migration, and have a higher, than other animals, likehood to cross the contaminated local areas. So, their tissues may be representative for dioxins and metals environmental concentrations for the whole grazing area, and thus may serve for effective comparison of pollution between the regions with different latitudes [EFSA 2011; Kachova 2015].

- Most reindeers are semi-domestic animals, feeding with natural feeds e.g. lichens, mosses, plants, mushrooms etc. Supplementary feeding is used only in certain conditions [Horstkotte et al. 2020], so the impact of artificial feeds on reindeer dioxin and heavy metals contamination is minimal. At the other hand, taking samples from reindeer may be easily made at slaughterhouses and presents less difficulties, than sampling of wild animals.

## Conclusions

Here for the first time we present the results of a large-scale investigation of reindeer liver, kidneys and meat pollution by dioxins, cadmium and mercury in the Russian Far North. Dioxins geographical distribution show a clear trend with highest concentrations in the West with gradual decrease as one proceeds to the East. The most important factors, contributing to the trend discovered, are likely to be: the geographical localization of chemical industry enterprises (sources of dioxins pollution); and greater density of reindeer population in the Western part of the country, leading to increased ingestion of soil particles that accumulate dioxins. We have founds no trend in geographical distributions of cadmium and mercury. Our data indicates, that objects of mining industry, that are local sources of cadmium and mercury environmental pollution, may not play a crucial role of cadmium and liver accumulation in reindeers at the distances, greater than 60 km. We also speculate, that liver of reindeer and caribou may serve as a good additional indicator of environmental pollution by the investigated contaminants.

## Abbreviations

**AO** – Autonomous okrug (type of federal subject of Russia)

**dl-PCBs** – Dioxin-like polychlorinated biphenyls

**DMS** – Degrees, minutes, seconds

**GC-HR MS** – Gas Chromatography/High Resolution Mass-Spectrometry

**GOST** – Eurasian Economical Union Official Standard

**ICP-MS** – Mass spectrometry with inductively coupled plasma

**LB** – lower-bound estimate

**PCBs** – Polychlorinated biphenyls

**PCDDs** – Polychlorinated dibenzodioxins

**PCDFs** – Polychlorinated dibenzofurans

**TR TS** - Eurasian Economical Union Technical Regulation

**UB** – upper-bound estimate

**WHO-TEQ** – World Health Organization Toxic Equivalent

# Declarations

### Avalaibility of data and materials

The data with dioxins, cadmium and mercury concentrations in individual samples is available from the corresponding author upon a request.

### Competing interests

The authors declare that they have no competing interests


### Funding

The study was funded by the Federal Service for Veterinary and Phytosanitary Surveillance


### Authors' contributions

Dmitry A. Makarov – study design, data analysis, preparation of the manuscript

Vladimir V. Ovcharenko – dioxins analysis, preparation of the manuscript

Elena A. Nebera – heavy metals analysis, preparation of the manuscript

Alexander I. Kozhushkevich – dioxins analysis

Andrey A. Shelepchikov - dioxins analysis

Xenia A. Turbabina – sample preparation for dioxins analysis

Anastasia M. Kalantaenko – sample preparation for dioxins analysis

Nikita S. Bardyugov – sample preparation for heavy metals analysis

Maria A. Gergel – supervision of the work


### Acknowledgements

Not applicable


### Ethics approval and consent to participate

Not applicable

### Consent for publication

Not applicable

# References


1. Akhmedkhanov A, Revich B, Adibi J, Zeilert, Vladimir et al (2002) Characterization of dioxin exposure in residents of Chapaevsk. Russia Journal of exposure analysis environmental epidemiology 12:409–417 https://doi.org/10.1038/sj.jea.7500243

2. AMAP: Arctic Monitoring and Assessment Programme (2004) Persistent Toxic Substances, Food Security and Indigenous Peoples of the Russian North. Final Report. Arctic Monitoring and Assessment Programme (AMAP), Oslo, 2004. 192 p. AMAP Report 2004:2 Link: https://www.amap.no/documents/doc/persistent-toxic-substances-food-security-and-indigenous-peoples-of-the-russian-north.-final-report/795 Last accessed 25.05.2021
3. Amirova Z, Weber R (2015) Massive PCDD/F contamination at the Khimprom organochlorine plant in Ufa—a review and recommendations for future management. Environ Sci Pollut Res 22:14416–14430. https://doi.org/10.1007/s11356-015-5048-8
4. Bačkor M, Loppi S (2009) Interactions of lichens with heavy metals. Biol Plant 53:214–222. https://doi.org/10.1007/s10535-009-0042-y
5. Booth S, Hui J, Alojado Z et al (2013) Global deposition of airborne dioxin. Mar Pollut Bull 75(1–2):182–186 https://doi.org/10.1016/j.marpolbul.2013.07.041
6. Chen C, Reniers G (2020) Chemical industry in China: The current status, safety problems, and pathways for future sustainable development. Safety Science 128 https://doi.org/10.1016/j.ssci.2020.104741
7. EFSA Panel on Contaminants in the Food Chain, Knutsen HK, Alexander J, Barregard L, Bignami M et al (2018) Scientific Opinion on the risk for animal and human health related to the presence of dioxins and dioxin-like PCBs in feed and food. EFSA Journal 16(11):5333 https://doi.org/10.2903/ j.efsa.2018.5333
8. EFSA Panel on Contaminants in the Food Chain (2011) Scientific opinion on the risk to public health related to the presence of high levels of dioxins and dioxin-like PCBs in liver from sheep and deer. The EFSA Journal 9(7):2297. https://doi.org/10.2903/j.efsa.2011.2297
9. Gamberg M, Pratte I, Brammer J, Cuyler C et al (2020) Renal trace elements in barren-ground caribou subpopulations: Temporal trends and differing effects of sex, age and season. Sci Total Environ 724:138305 https:// doi: 10.1016/j.scitotenv.2020.138305
10. Hansen B, Aanes R, Saether B-E (2010) Partial seasonal migration in high-arctic Svalbard reindeer (Rangifer tarandus platyrhynchus). Can J Zool 88:1202–1209 https://doi.org/10.1139/Z10-086
11. Hassan AA, Rylander C, Brustad M et al (2012) Level of selected toxic elements in meat, liver, tallow and bone marrow of young semi-domesticated reindeer (Rangifer tarandus tarandus L.) from Northern Norway. Int J Circumpol Health 71:1–7 https://doi.org/10.3402/ijch.v71i0.18187
12. Holma-Suutari A, Ruokojärvi P, Komarov A, Makarov DA et al (2016) Biomonitoring of selected persistent organic pollutants (PCDD/Fs, PCBs and PBDEs) in Finnish and Russian terrestrial and aquatic animal species. Environ Sci Eur 28:5 https://doi.org/10.1186/s12302-016-0071-z
13. Holma-Suutari A, Ruokojärvi P, Laaksonen S et al (2014) Persistent organic pollutant levels in semi-domesticated reindeer (Rangifer tarandus tarandus L.), feed, lichen, blood, milk, placenta, foetus and calf. Sci Total Environ 476–477(1):125–135 https://doi.org/10.1016/j.scitotenv.2013.12.109
14. Hooser SB (2018) Veterinary Toxicology: Basic and Clinical Principles Chapter 24 - Cadmium, Editor(s): Ramesh C. Gupta, Veterinary Toxicology (Third Edition), Academic Press, 2018, Pages 417–421, ISBN 9780128114100 https://doi.org/10.1016/B978-0-12-811410-0.00024-6
15. Horstkotte T, Lépy É, Risvoll C et al (2020) Supplementary feeding in reindeer husbandry – Results from a workshop with reindeer herders and researchers from Norway, Sweden and Finland. Umeå University. https://10.13140/RG.2.2.12202.13762
16. Johnson D, Harms NJ, Larter NC, Elkin BT, Tabel H, Wei G (2010) Serum biochemistry, serology, and parasitology of boreal caribou (Rangifer tarandus caribou) in the Northwest Territories, Canada. J Wildl Dis 46(4):1096–1107 https://doi.org/10.7589/0090-3558-46.4.1096
17. Kachova V (2015) Behavior of heavy metals in soils – distribution and mechanism of interaction with soil constituents. Link:https://www.researchgate.net/publication/282942505_behavior_of_heavy_metals_in_soils_-_distribution_and_mechanism_of_interaction_with_soil_constituents Last accessed: 25.05.2021

18. Makarov D, Komarov A, Ovcharenko V (2018) Dioxin and heavy metals contamination of reindeer offal from Russian Far North regions. Sel'skokhozyaistvennaya biologia [Agricultural biology]. 53, 2: 364–373 [ABSTRACT IN ENGLISH, FULL TEXT IN RUSSIAN] https://doi: 10.15389/agrobiology.2018.2.364rus
19. Ministry of Agriculture of the Russian Federation (2013) Order №11 of 14 January 2013 on approvement of sectoral program «Development of North reindeer herding in the Russian Federation in 2013–2015&#187 Link: http://docs.cntd.ru/document/902393115 Last accessed 25.02.2021
20. Nicholson KL, Arthur SM, Horne JS et al (2016) Modeling Caribou Movements: Seasonal Ranges and Migration Routes of the Central Arctic Herd. PLoS One 11(4):e0150333. https://doi.org/10.1371/journal.pone.0150333
21. Petrlik J, Speranskaya, Levashov D (2005) Contamination of chicken eggs from the Dzerzhinsk region, Russia by dioxins. PCBs and hexachlorobenzene https://10.13140/RG.2.2.27558.11845
22. Schröter-Kermani C, Rappolder M, Neugebauer F, Päpke O (2011) PCDD, PCDF, and dlPCB in terrestrial ecosystem: Are there correlations of levels or patterns in soil and roe deer liver? Organohalogen Compd 73:1325–1328
23. Tryland M, Kutz SJ (2018) Reindeer and Caribou: Health and Disease, 1st edn. CRC Press https://doi.org/10.1201/9780429489617
24. Welfinger G, Minholz J, Byrne S et al (2011) Organochlorine and Metal Contaminants in Traditional Foods from St. Lawrence Island, Alaska. Journal of toxicology and environmental health. Part A. 74. 1195 – 214. 10.1080/15287394.2011.590099 https://doi.org/10.1080/15287394.2011.590099
25. WHO World Health Organisation (2016) Dioxins and their effects on human health. Link: https://www.who.int/news-room/fact-sheets/detail/dioxins-and-their-effects-on-human-health Last accessed: 25.02.2021
26. Zengwei Y, Tao L, Xuewei L et al (2019) Tracing anthropogenic cadmium emissions: From sources to pollution. Sci Total Environ 676:87–96 https://doi.org/10.1016/j.scitotenv.2019.04.250

## Figures

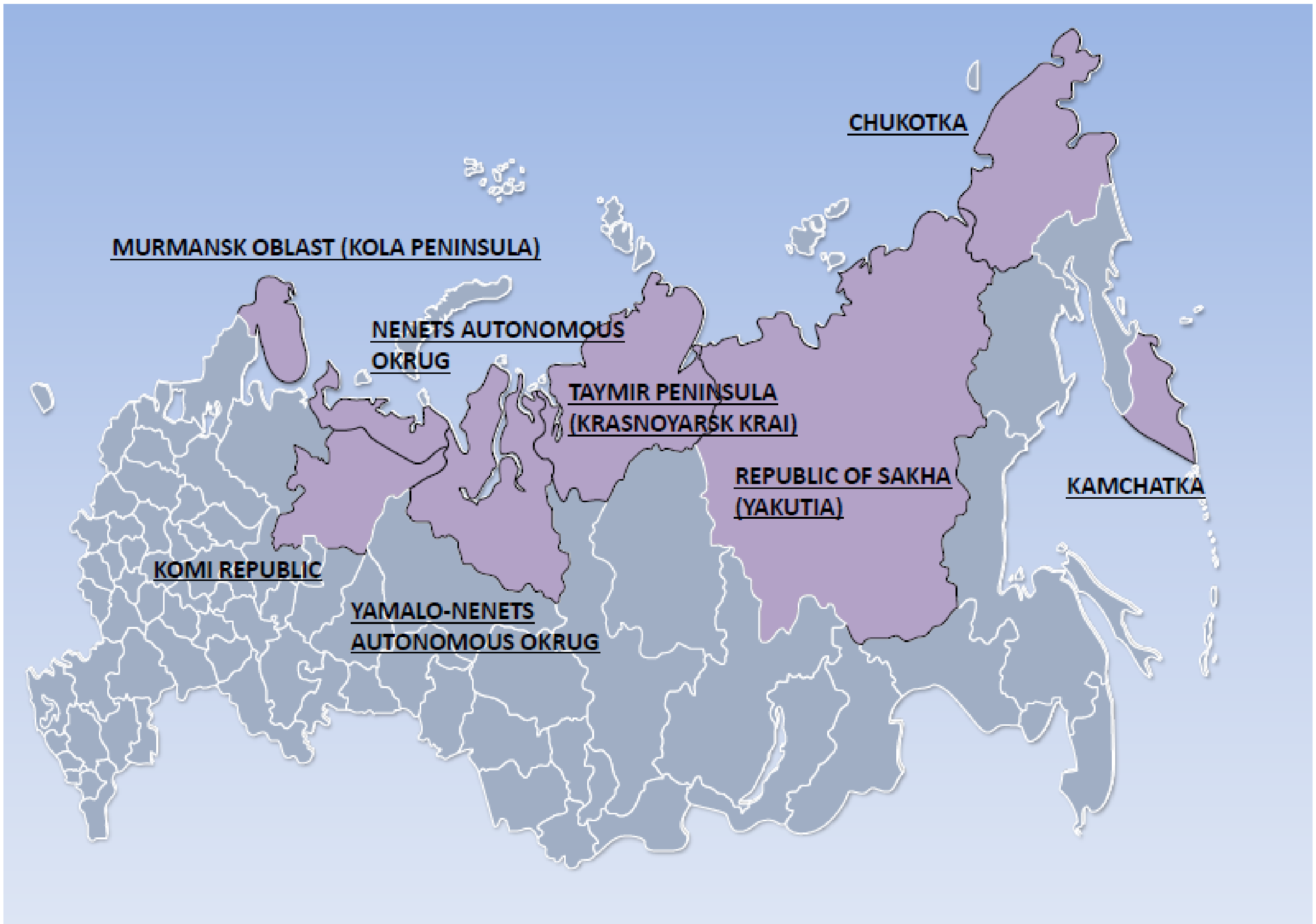



**Figure 1**

Regions of the Russian Far North whence reindeer samples were taken. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

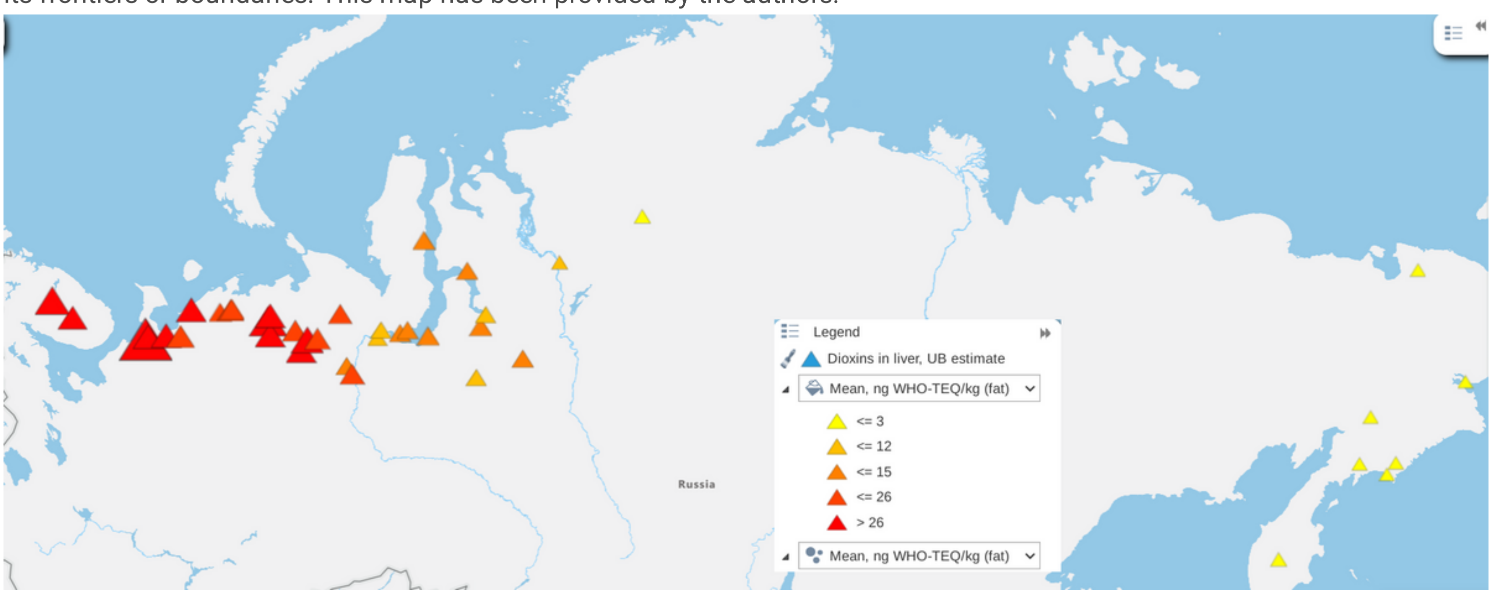
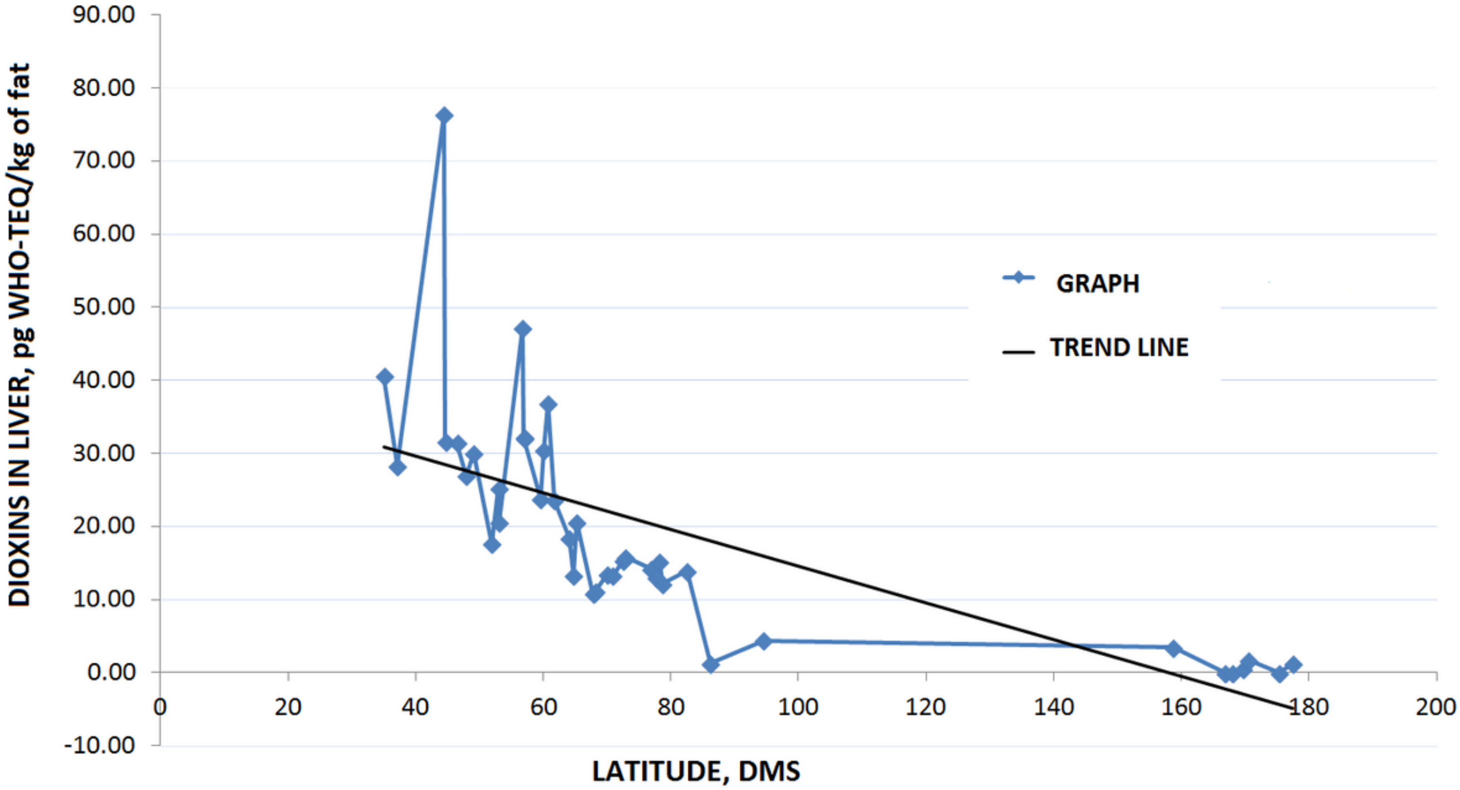



**Figure 2**

Heatmap of dioxins concentrations in reindeer liver from different sampling places. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.




## Figure 3

Diagram of dioxins concentrations in reindeer liver depending on the latitude of the sampling place.


## Figure 4

Location of the chemical and oil refining industry objects of the Soviet Union (1980s). Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

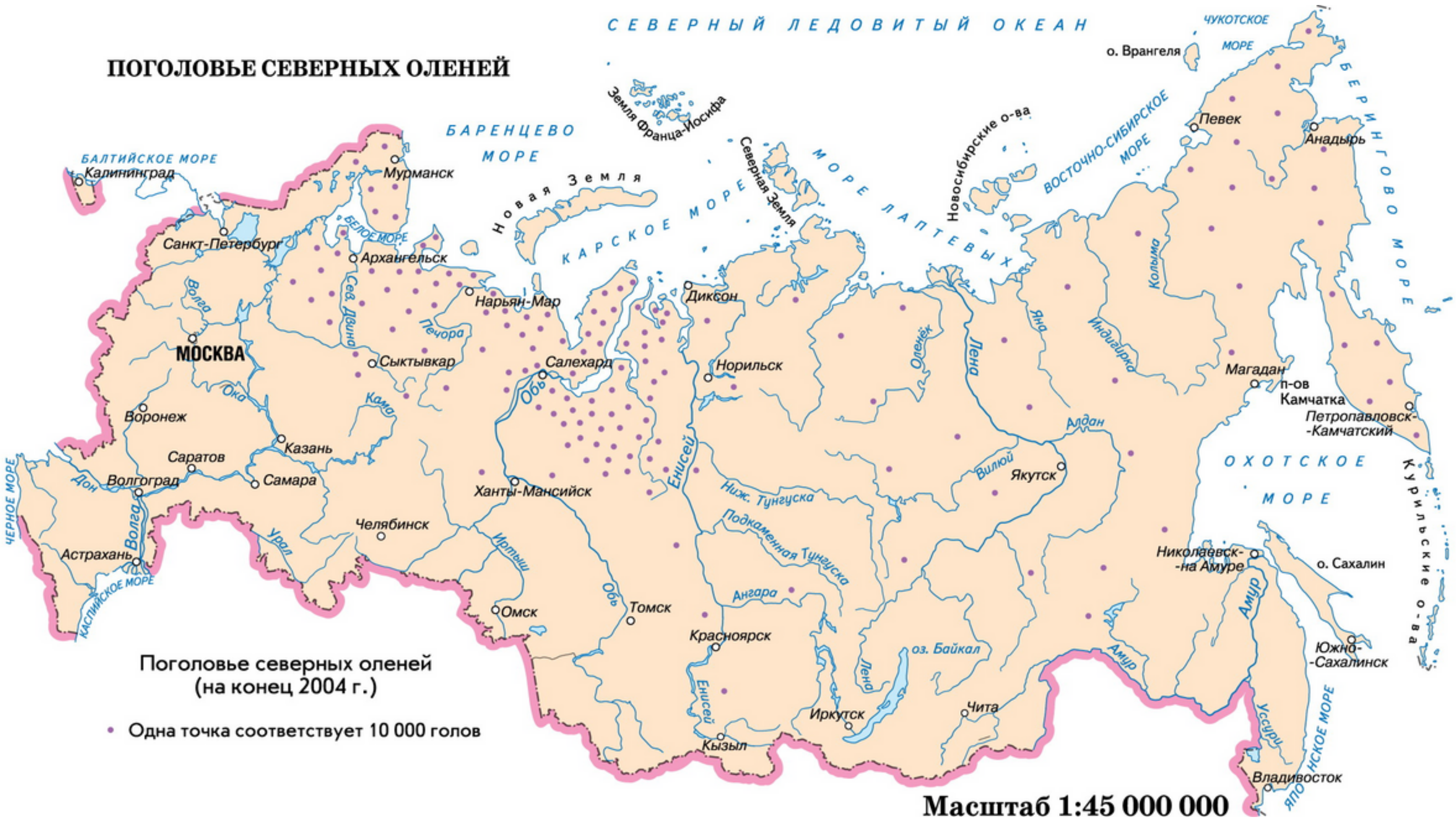



**Figure 5**

Density of reindeer population on the territory of the Russian Federation (2000s). One purple point corresponds to 10.000 of animals. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

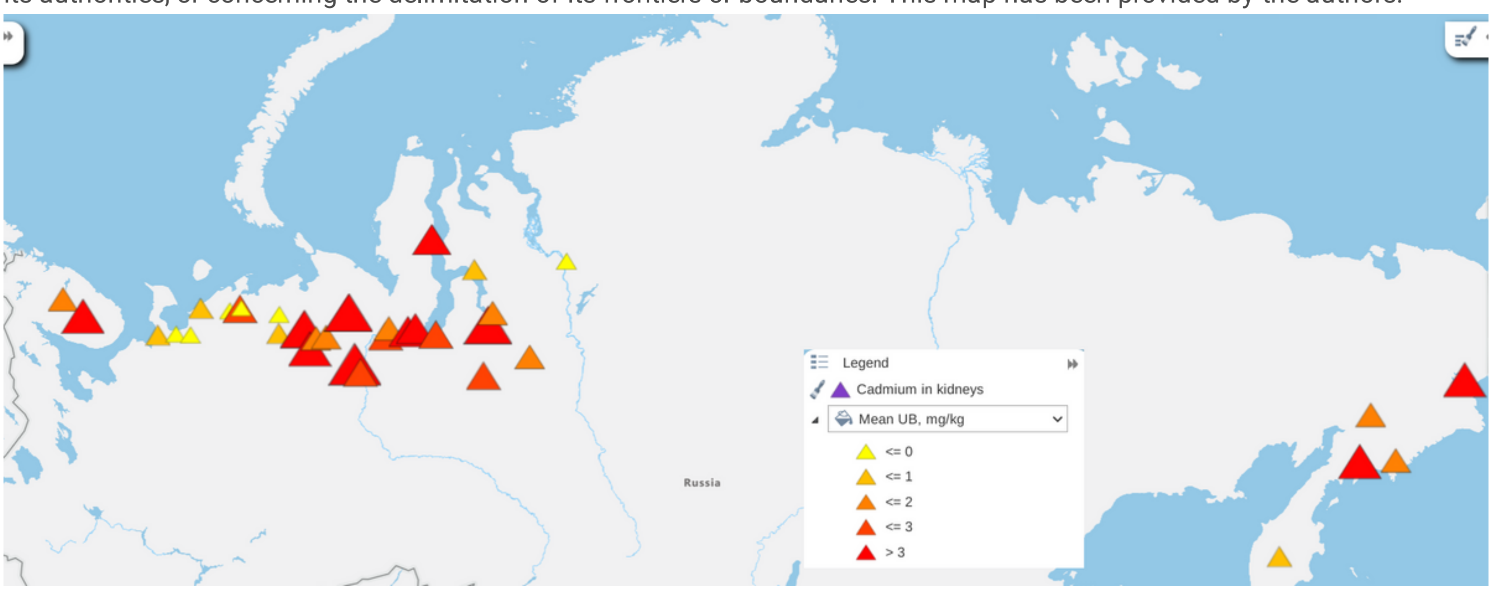



**Figure 6**

Heatmap of concentrations in reindeer kidneys from different sampling places. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

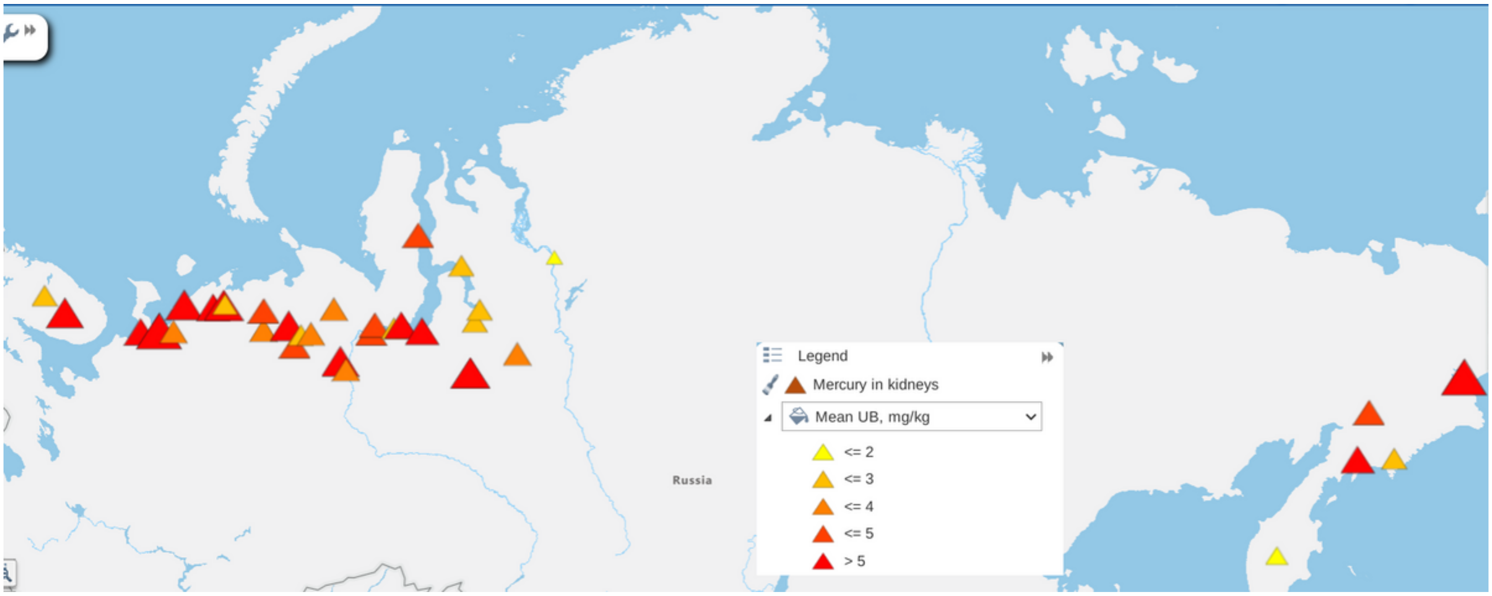



**Figure 7**

Heatmap of concentrations in reindeer kidneys from different sampling places. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

## Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementalTables.docx