Acta Lapponica Fenniae 24

The clean nature of the North

Edited by
Rainer Peltola and Pertti Sarala

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To the reader

The Research Society of Lapland has promoted Lappish scientific and especially interdisciplinary discussion and research for more than 50 years. Its activities include organising topical lecture series and seminars, scientific publishing, and the society's own meetings.

Acta Lapponica Fenniae is the society's scientific publication series, published 1-2 times yearly. This 24th volume of Acta addresses the problem with the condition of the environment in Lapland from the perspective of various scientific disciplines, both domestically and in comparison with Europe. It attempts to shed light on natural resources and land use opportunities in Lapland, as well as possible threats, through articles by experts from various fields. In preparing the articles, as much use as possible has been made of popular sources that are readily available to the general public. A busy reader is likely to benefit most from acquaintance with the pictures and abstracts.

We hope that the book will provide useful basic information and will encourage the exploitation of knowledge in teaching, in developing the marketing and business life of Lapland, and in nurturing its environment.

This publication is a result of cooperation between The Research Society of Lapland and the LAPPI LUO working programme of Natural Reseurces Institute Finland. We warmly thank the writers, pre-examiners, and commentators.

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Lapland’s pure nature is a treasure

Esko Lotvonen
Regional Mayor

In a globalising world, the condition of the environment has taken a prominent place both in everyday life and as a source of attraction in developing industrial and commercial activity. In recent years, research has shown that tighter requirements on emissions in industry, housing, and traffic have improved soil and water conditions, as well as air quality. A good example is air transport, where emissions are declining by 30-40%. Technological advances allow for significant reductions in emissions.

Articles in this publication clearly show the improvement in Lapland over recent decades. The threats that were commonly discussed in the 1980s have thankfully not materialized; instead, the direction of change strongly favours the natural environment.

Lapland is a special province in many ways, both in Finland and internationally. Nature and natural resources are major development factors in the province. Tourism in Lapland is based largely on its unique outdoors. Lapland is spacious. Tourists expect their destination to provide a good environment and cleanliness. Lapland is now ready to respond to the challenge. Developments in living environments and livelihoods must ensure the continuation of this situation into the future. A unique outdoors comes with responsibility for maintaining its quality.

The world is constantly changing. Lapland is also changing and adapting to changes. An unusual number of interests are associated with land use in the Lapland region. We must therefore understand the broad and sometimes quite critical or even disruptive debate on these matters. However, a sense of proportion is needed and an inclination to find workable compromises without being driven to solutions that are irreversible from an environmental viewpoint.

Lapland is rich in natural resources, which are of national and global interest as well as influencing the local economy. Thus, it is clear that natural resources should be used according to the principles of sustainability. These principles include ecological, but also economic, social, and cultural dimensions. Lapland already successfully combines e.g. nature conservation, forestry, reindeer husbandry, tourism, mining, and Sámi cultural needs. The large province offers space and a place for everyone, while taking into account those special areas where compromise is not possible.

Research has shown that natural products from Lapland are better flavoured and more health-promoting than products from farther south. Product development and the creation of collection systems have been a major challenge in the field. Lapland is themain production area for wild berries in Finland. Volumes of other raw materials are small, but important, for example, in local food production. The role of local food is definitely on the rise, which is something the tourism industry should take into account. Lapland has seen great advances in small-scale reindeer meat processing. Rising prices have also improved the economic position of reindeer herders.

In terms of future development prospects, Lapland is a province full of potential. The North and the Arctic are of increasing interest. Lapland is a treasure trove for Finland, but with a vulnerable natural environment. We have responsibility to take advantage of our ability to contribute to the well-being of citizens. However, this must be done while securing the endurance of nature and the good condition of the environment.

The air quality of Lapland in the early 2000s

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Abstract

The current condition and development of air quality in Lapland were studied using long-term air quality monitoring results. Corresponding measurements from Finland and Europe were used as reference material. In Lapland, pollution levels are typically less than half of the background concentrations in the south, which are already very low on a European scale. However, emissions from the Kola Peninsula result in an east-west gradient of sulphur dioxide, copper, and nickel. Since the prevailing wind direction is south-south-westerly, however, most pollutants from the Kola Peninsula are carried away from Finnish Lapland. Thus, even in the worst affected eastern border, the sulphur dioxide concentrations reach only about the background concentrations found in southern Finland. Concentrations of nitrogen compounds from transport are very low in Lapland. The concentration of ozone is at an elevated level in Lapland, as elsewhere at high latitudes, but the unhealthy ozone episodes typical of the south do not occur in Lapland. In Lapland, concentrations of polycyclic aromatic hydrocarbons (PAH) from transport and small-scale combustion are only a fraction of those in southern Finland. Concentrations of other persistent organic pollutants (POP) are generally lower in Lapland than in the south. However, it is also evident that some POPs accumulate in Arctic ecosystems and, through evaporation, also cause elevated concentrations in the air in Lapland.

The trend in air quality in Finnish Lapland over the last 15 years has been quite favourable. Out of sixty pollutants studied, a statistically significant downward trend was seen in almost half. Downward trends were noted not only in sulphur dioxide and many heavy metal concentrations, but also in concentrations of some PAH compounds. Likewise, long-range transported sulphate and POPs were mostly decreasing in the air of Lapland. However, the situation with traffic-induced pollutants (nitrogen compounds, volatile hydrocarbons, and ozone), has remained largely unchanged over the past 15 years.

As a result of climate change, the Arctic Ocean ice cap could disappear entirely during summer in coming decades. In this case, increased shipping might increase the pollution load in the Lapland region. Current restrictions on sulphur emissions from shipping are likely to prevent growth in sulphur load, but at worst nitrogen oxide and particulate matter concentrations might double from the current level.

Lapland's air quality in a nutshell

- Lapland is home to two very well-equipped air quality monitoring stations, at Pallas, and Raja-Jooseppi
- Concentrations of pollutants in the air in Lapland are typically about half compared to southern Finland
- Trends in air quality in Lapland have been favourable over the last 15 years. About half of the studied air quality indicators have shown a downward trend, while the situation with other indicators has remained unchanged
- The concentration of heavy industry in the Kola Peninsula clearly has an effect on north-eastern Lapland. Thanks to prevailing south-west winds, however, concentrations are lower on average than in southern Finland
- Potential increases in shipping in the Arctic Ocean may increase the amount of traffic-induced pollution in Finnish Lapland.

Keywords

Air quality, air pollution, POPs, PAHs, heavy metals, trends, Kola Peninsula

Introduction

Winds can carry air pollution hundreds or even thousands of kilometres from emission sources. Some pollutants, in turn, will remain in the atmosphere sometimes for years, during which time they will spread in all parts of the atmosphere. Some air pollution, having left the atmosphere for soil or water systems, returns to the atmosphere through evaporation and thus continues to spread. So even sparsely populated Lapland is not safe from air pollution.

The concept of Lapland's purity faltered in the late 1980s, when Finns became aware of severe environmental damage from air pollution occurring in the cities of Nikel, Zapolyarny, and Monchegorsk, in the Kola Peninsula. Of course, air quality in Lapland had been monitored from the 1970's onwards. Monthly averages for sulphur dioxide and sulphate, as well as wet deposition, were measured at Kevo (Utsjoki) and Sodankylä using available methods (Laurila et al. 1991). The results quite clearly showed that concentrations and depositions in Lapland were the lowest in Finland. Measurement of short-term sulphur dioxide concentrations (i.e. hourly average) in Lapland began in 1990 on the east side of Lake Inari, in Soviet Rayakoski. The following year, corresponding measurements began at Raja-Jooseppi, Sammaltunturi, and Lake Sevettijärvi. These measurements quickly showed that high concentrations of sulphur dioxide sometimes spread in Finnish Lapland from the Kola Peninsula. These episodes, however, turned out to be so rare and of such short duration that the long-term average values remained low.

Today, there are numerically fewer air quality measurement stations in Lapland, but the numbers of measured variables, frequency of measurements, and sensitivity of the measuring equipment have undergone tremendous development. Also, research priorities have changed: in the 1980s and 1990s the incentive for research lay in monitoring the ecological impact of pollutants, today increasing attention is paid to the effects of pollutants on human health. In addition, comprehensive measurements seek better to understand the fundamental chemical-physical processes in the atmosphere, for instance for climate change studies.

This article will build on these very wide-ranging atmospheric measurements and research results. The perspective here is primarily to assess trends in air quality in the Lapland region over the last 10-20 years, and additionally to make comparisons with the rest of Finland and Europe, and with limit and target values for air quality.

Data and research methods

The Finnish Meteorological Institute (FMI) is responsible for monitoring the air quality in the so-called background areas in Finland, located far from emission sources, by maintaining a dozen measurement stations in different parts of the Finnish countryside. The most versatile and best equipped FMI atmospheric research station cluster is in Muonio, in western Lapland. It was founded in 1994 as part of the World Meteorological Organization (WMO) Global Atmosphere Watch network to provide information on global atmospheric conditions and changes. The focus is now in greenhouse gases and particulate matter, but the station continues also to produce other valuable information related to air quality. Air quality measurements are made at Sammaltunturi and Matorova, which are referred to here by their common name of Pallas. Lapland's second long-serving air quality station is located in Raja-Jooseppi, Inari, near the eastern border, where it monitors the impact of emissions from the Kola Peninsula.

In addition to FMI, the monitoring of air quality in Finland is handled by cities, often in collaboration with industry. There are about a hundred of these so-called city stations in Finland. Data from all of Finland's air quality monitoring stations will be used here as reference material for the Lapland data, in addition to corresponding air quality monitoring results from elsewhere in Europe.

Much of the basic material for this summary (air quality monitoring results) is derived from open national and international air quality monitoring databases. Data on Finnish air quality monitoring results was downloaded from the FMI air quality portal (http://www.ilmanlaatu.fi/tarkistetut_tulokset/) or obtained from ILSE, the FMI air quality monitoring data management system (heavy metals and PAH compounds). The monitoring results for persistent organic pollutants (POPs), were downloaded from the database of the Swedish Environmental Research Institute (IVL) (http://www3.ivl.se/db/plsql/dvspopluft$.startup). IVL and FMI are jointly responsible for POP measurements at Pallas: FMI handles maintenance and sample collection at the station, while IVL performs the chemical analyses. The other European monitoring results are derived from the Airbase database of the European Environment Agency (EEA) (http://www.eea.europa.eu/data-and-maps/data/airbase-the-european-air-quality-database-6).

Development trends in the air quality of Lapland are researched using time series analysis. The statistical analysis method used was **G**eneral **L**inear **R**egression, in which the autocorrelation of time series was eliminated by classical decomposition and autoregressive–moving-average (ARMA) error terms (Anttila & Tuovinen 2010). The method was applied to monthly average air concentrations calculated from hourly or weekly concentrations. The results charts show measured monthly average time series, the seasonal variations calculated from these using classical decomposition combined with a GLR-ARMA-trend, and as the trend alone. The results charts also show the statistical significance of the calculated trend, using * symbols as follows:

***: P <0.001, the trend is statistically very significant;

**: p<0.01, the trend is statistically significant;

*: p<0.05, the trend is almost statistically significant.

Results

Kola Peninsula pollution

The metal industry on the Kola Peninsula is still a major source of the emissions of sulphur dioxide (SO_2) and heavy metals, especially copper (Cu) and nickel (Ni). Figure 1 shows measured SO_2 concentrations in Europe in 2010. The highest annual means for SO_2 occur in South-East Europe while other areas have only “hot spots” caused by individual point sources of emissions. One of these is still the town of Nikel on the Kola Pen-

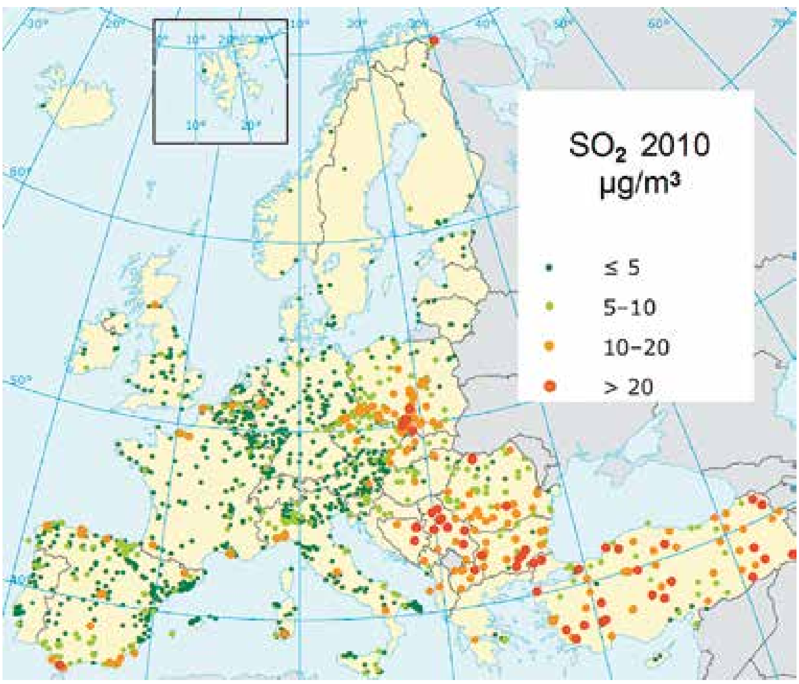


Fig. 1. Annual means of SO_2 concentrations in European air, 2010.

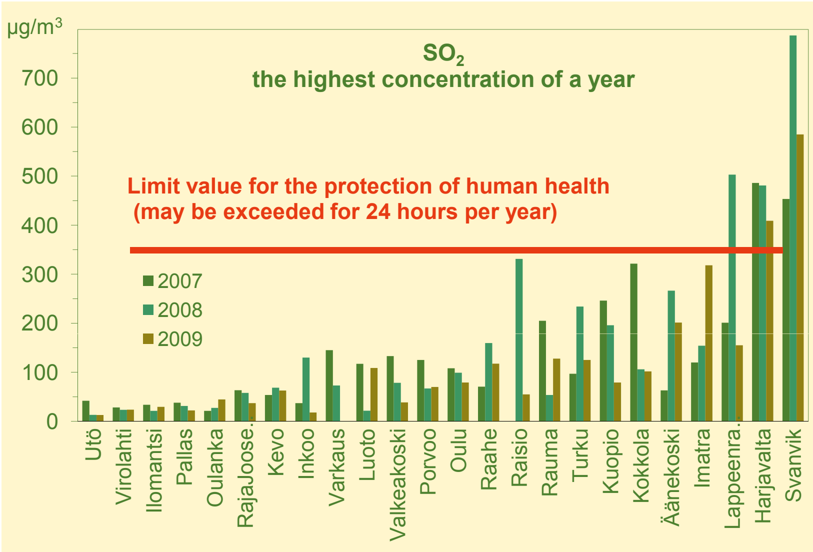


Fig. 2. The highest hourly mean of SO_2 for 2007-2009, detected at 23 measurement stations in Finland and in Svanvik, Norway. The EU limit value for the protection of human health is also shown.

insula, with its nickel-copper smelters. In Figure 1, a red dot in Norwegian Finnmark shows the concentration level of SO_2 at Karpdalen. The annual mean for SO_2 at Karpdalen was 20 micrograms per cubic meter of air (µg/m^3) in 2010. The station is situated about twenty kilometres to the north of the Nikel smelter. At the Svanvik station (9 kilometres west of the smelter), the monitoring result is much lower (8 µg/m^3).

On the Finnish side of the border at Raja-Jooseppi (120 kilometres southwest of Nikel) concentrations are lower still at 1.5 µg/m^3 while concentrations at Pallas are below 1 µg/m^3. Levels therefore decrease sharply with increasing distance from the emission source.

In the northernmost Lapland the short-term concentrations of SO_2 do not come anywhere near the EU limit values for the protection of human health (an hourly value of 350 µg/m^3 may be exceeded 24 times a year). Elsewhere in Finland, such high concentrations of SO_2 occur only in individual cases (Figure 2). The limits are not exceeded to such an extent at any station in Finland, nor were they exceeded at the Norwegian station at Svanvik in 2007-2010. However, the 2010 statistics for Karpdalen show the limit value being exceeded there.

From the viewpoint of Finnish Lapland, it is fortunate that the prevailing wind direction is from the south, which means that polluted air masses are mostly carried north (Figure 3) (Anttila et al. 2011). South winds occur about 37% of the time (10% +13% +14% = 37%, Figure 3). Northeast and east winds, which bring pollution from the Kola Peninsula to Finnish Lapland, are clearly less common (5% +4% +4% = 13%, Figure 3).

Changes in concentrations of SO_2 in the air have also been favourable (Figure 4). SO_2 concentrations at both stations in Finnish Lapland have been declining over the past fifteen years, Pallas by about 4 per cent yearly, and Raja-Joosep-

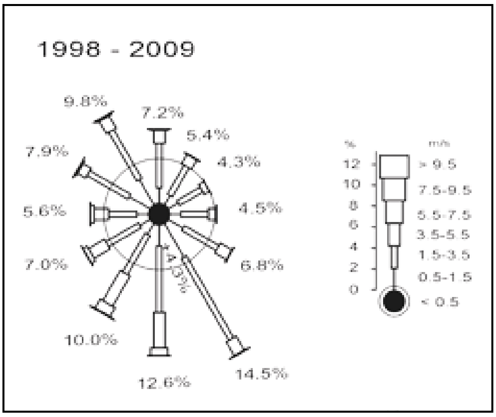
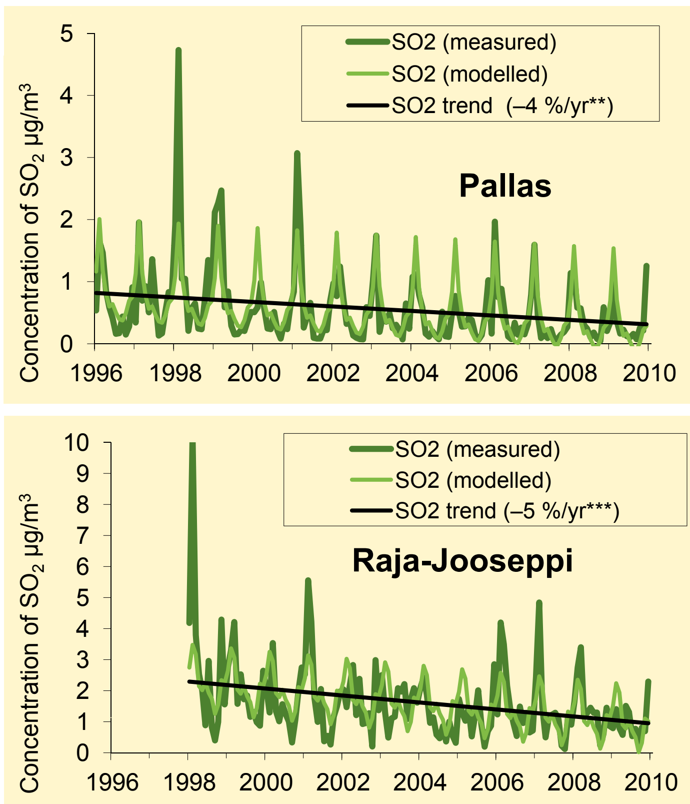


Fig. 3. The frequencies of different wind directions at Sodankylä, 1998-2009 (Anttila et al. 2011).

pi by 5 per cent. The series of SO_2 measurements at Pallas shows very regular seasonal variations, which is typical for a background area. SO_2 concentrations are at their highest during the winter season, when transformation to sulphate particles is the slowest. The annual cycle of SO_2 concentrations at Raja-Jooseppi is more irregular owing to the impact of industrial emissions from Nikel.

There is also a primarily downward trend in the airborne concentrations of heavy metals at Pallas (Figure 5). Concentrations of copper and arsenic in the air have fallen by four per cent yearly. There has also been a downward trend in cadmium content, but this is not statistically significant. The nickel concentration in the air has remained at late 1990s levels. On the whole, heavy metal concentrations in Lapland are far below the

Fig. 4. Trend of SO_2 concentration in the air at Pallas and Raja-Jooseppi.



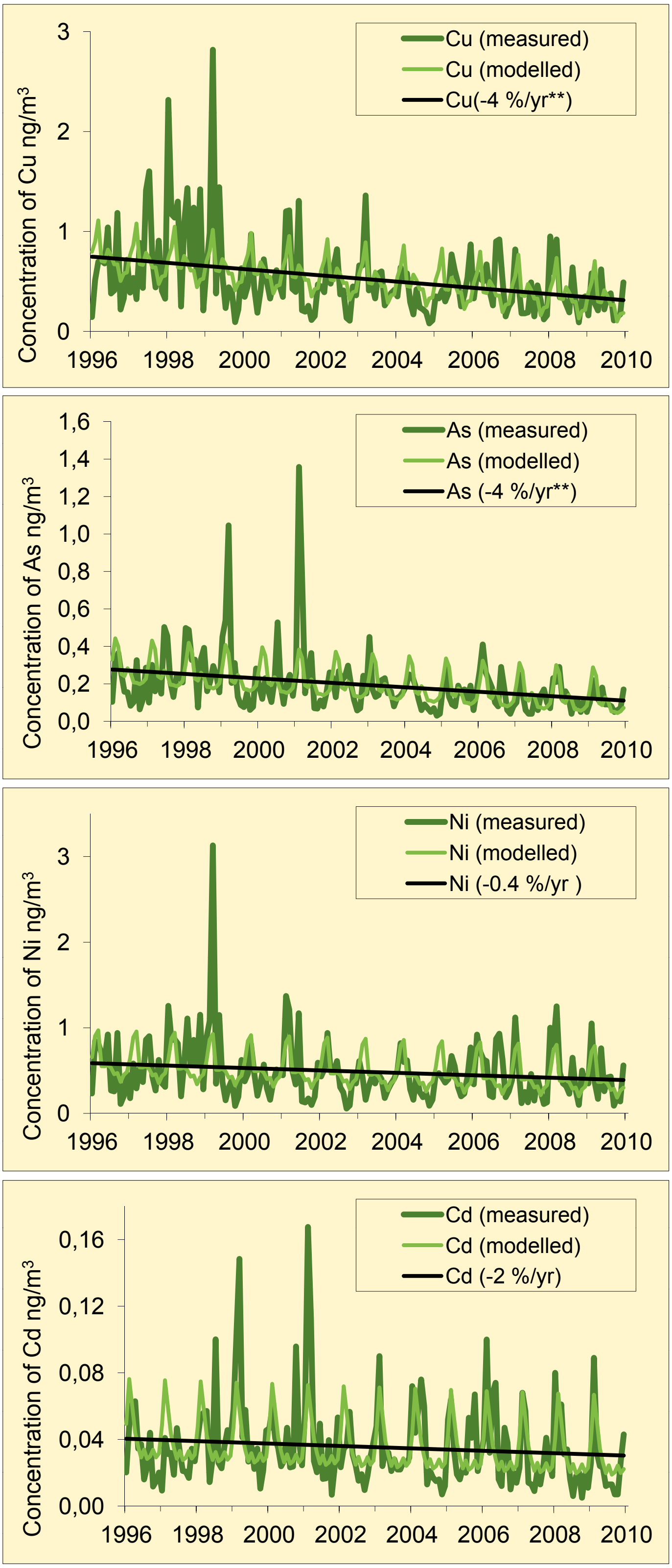
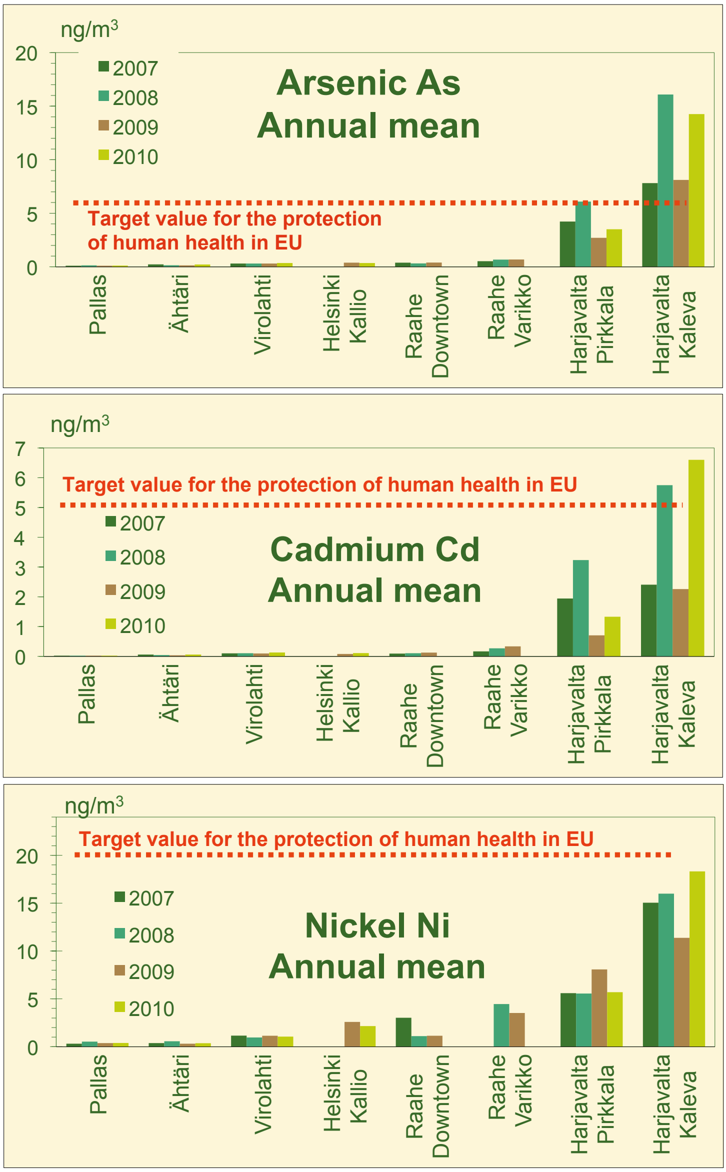


Fig. 5. Trends of Cu, Ni, As and Cd concentrations in the air at Pallas, 1996-2010.

Fig. 6. Annual means of arsenic, cadmium and nickel concentrations in the air at some Finnish measurement stations, 2007-2010.



target values for the protection of human health set by the European Union (Figure 6).

Nitrogen compounds, volatile hydrocarbons, and ozone

Nitrogen oxides (NO and NO_2) and volatile hydrocarbons (**V**olatile **o**rganic **c**ompounds, VOC) enter the air in large amounts from traffic exhaust fumes. In the atmosphere, these compounds react with each other to form gaseous ozone (O_3). Finally, the nitrogen oxides are converted into water-soluble nitric acid and removed from the air as deposits. In Lapland, emissions from transport are limited and the concentration of nitrogen compounds and VOCs in the air are very low. Long-range transboundary air pollution from the densely populat-

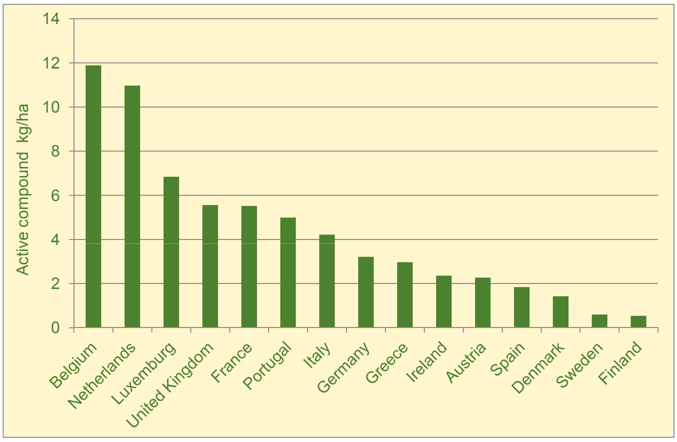


Fig. 7. Use of pesticides in some European countries at the end of the 1990's (Pesticide Action Network Germany, 2003).

ed areas of Europe rarely reaches as far as Lapland.

However, the elevated concentration of O_3 is a global air pollution problem. In the past hundred years, the mean concentration of ozone in the atmosphere has approximately tripled in the whole northern hemisphere, concerning also Lapland. Despite the elevated baseline, Lapland does not have the unhealthy high ozone episodes that are common in densely populated areas of central and southern Europe, where emission levels of nitrogen oxides and hydrocarbons are much higher.

Transport emissions have been limited in Finland and in Europe for decades, but reduction of air concentrations has proven to be very difficult. Concentrations of nitrogen compounds, volatile hydrocarbons and ozone have remained unchanged at Pallas since the mid-1990s (Anttila et al. 2010).

Persistent organic pollutants (POPs)

POP (**P**ersistent **O**rganic **P**ollutant) compounds are very persistent toxic compounds that can spread globally once emitted into the atmosphere. Some POPs are deliberately produced for a particular purpose, most commonly as pesticides (e.g. DDT), or as industrial chemicals such as PCBs. The remainder are impurities formed by chemical reactions or combustion processes (e.g. dioxins and PAH compounds). Today, the use and production of many commercial POPs is completely forbidden in many countries, but emissions from existing products still continue (SYKE 2006). In ecosystems, these fat-soluble materials accumulate in food chain organisms. Arctic areas are considered particularly vulnerable to these toxic compounds, because the northern soil has a little humus to retain organic compounds, while low temperatures mean that materials are broken down more slowly than in warmer regions.

In the north, agriculture and forestry use very little pesticide as compared to many other European countries (Figure 7). Nonetheless, POPs can be found in the air in Lapland, although there are no significant sources of emissions there. Once deposited on the ground, POPs may evaporate again into the air in more favourable, warmer conditions, and be transported by air currents into northern latitudes.

Trends in the concentrations of two POPs at Pallas are considered here. Polychlorinated biphenyls, or PCBs are very stable and heat-resistant, and they have been used mainly in capacitors and transformers. The manufacture, import, sale, or transfer of PCBs and products containing them was banned in Finland early in 1990. Today, the largest single source of emissions to the air comes from waste incineration. PCB compounds can enter the environment through old discarded electrical equipment and through transport emissions.

Gamma-hexachlorocyclohexane (γ-HCH) or lindane was a commonly used insecticide from the 1950s until the 1990s, but its global use is now slight. In Finland, it went out of use in the late 1990s. The use of other pesticides has also decreased in Finland since the peak years of the 80's (Figure 8).

The global decrease in the production and use of these compounds is also clearly visible from long-term measurements made at Pallas (Figure 9). The amounts of PCBs in the air have been reduced by 1-3 per cent yearly. Particularly evident is the decrease in the concentrations of lindane in the 2000s (Figure 9). The concentrations of compounds in the air are at their highest in the summer, due to their volatility characteristics.

Concentrations of other POPs have also declined at Pallas since 1996. Of 18 POP time series examined, 13 compound concentrations showed a statistically significantly decrease (five PCB compounds, α-and γ-HCH, α- and γ-chlordane, trans-nonachlor and three PBDE compounds), concentrations of four compounds had remained at the same level (two PCB compounds plus pp-DDT and pp-DDE) and the concentration of one compound had increased (pp-DDD) (Anttila et al. 2010). As a whole, therefore, global restrictions on the production and use of these toxic compounds have resulted in decreased background air concentrations in the northern hemisphere. However, a worrying aspect was that concentrations of

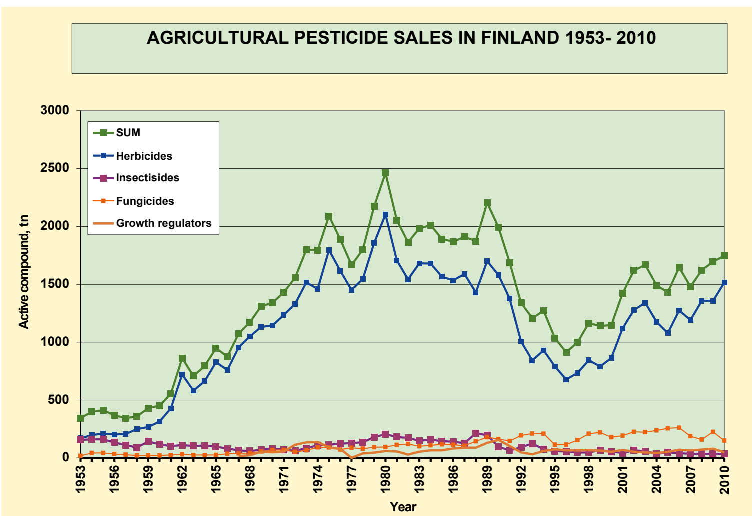


Fig. 8. Sales of agricultural pesticides in Finland, 1953-2010 (Tukes 2010).

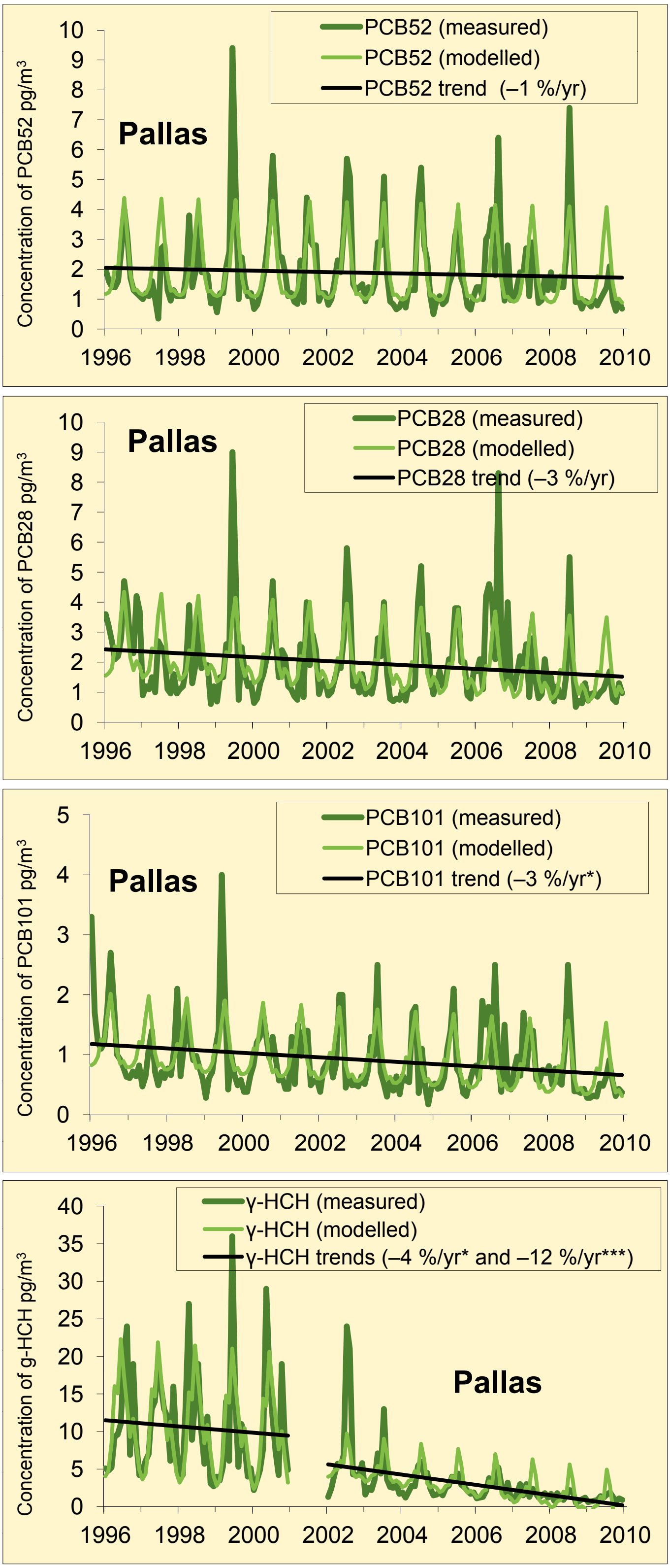
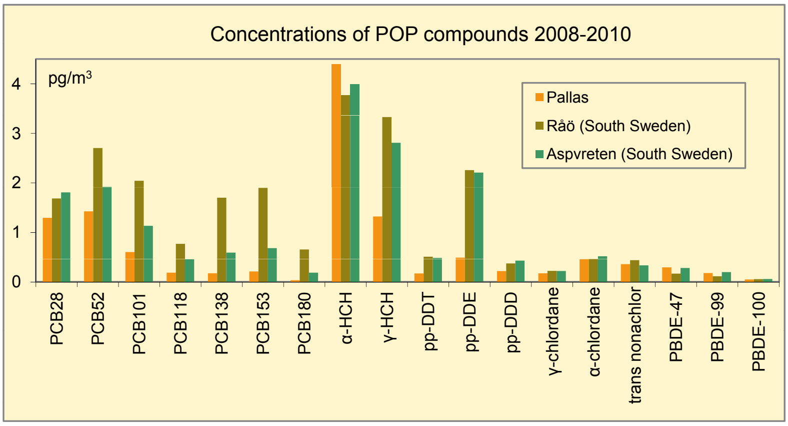


Fig. 9. Trends of some PCB's and lindane in the air at Pallas, 1996-2009. Source: IVL, Sweden

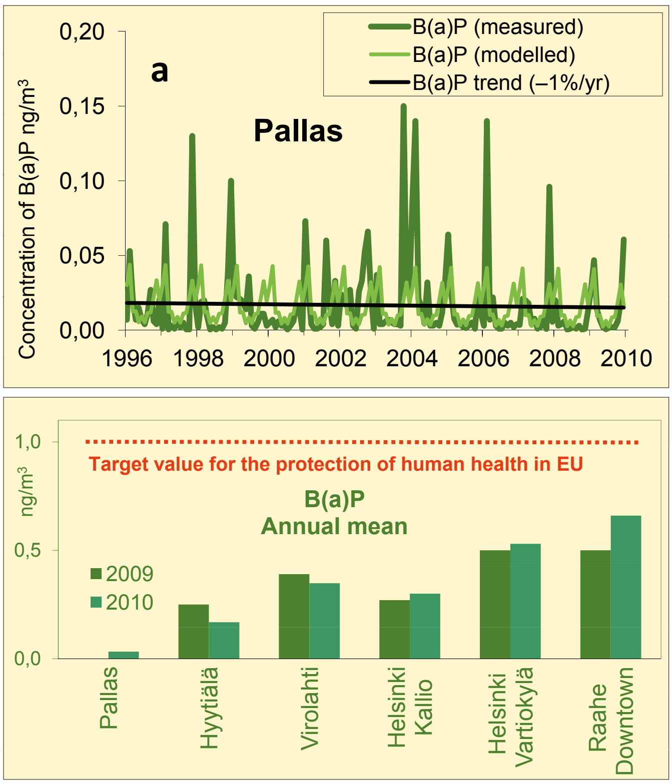
Fig. 10. Mean concentrations of POP compounds in the air at Pallas, Råö (Sweden) and Aspvreten (Sweden), 2008-2010. Source: IVL, Sweden, 2012



DDT and its decay products DDE and DDD were not decreasing (Anttila et al. 2010).

Finnish reference material is not available, but Figure 10 shows a comparison of POP concentrations at Pallas with concentrations at Råö and Aspvreten in Sweden. The latter are Swedish background stations, Råö on the south-west coast and Aspvreten in Central Sweden, 80 kilometres south of Stockholm. POP concentrations at Pallas are mostly much

Fig. 11. Trend of B(a)P in air at Pallas, 1996–2009 (a) and annual means of B(a)P in air at Finnish measurement stations in 2009 and 2010 (b).



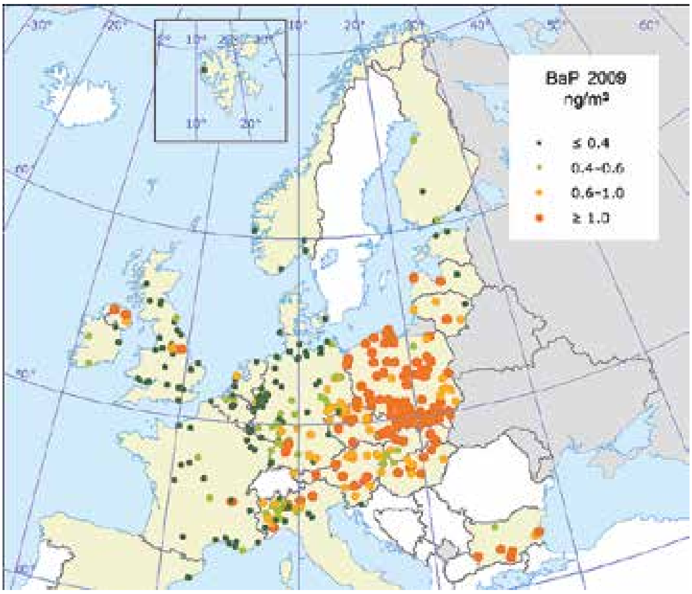


Fig. 12. Annual means of B(a)P in air in Europe in 2009. Source: Based on EEA, Airbase, 2012

smaller than in the Swedish reference material. However, a notable exception is α-HCH, a by-product of lindane production, concentrations of which at Pallas are higher than in the southern and central Swedish reference material (Figure 10). α-HCH is known to accumulate in particular, in Arctic seas, from which it may partially evaporate back into the atmosphere. Elevated α-HCH concentrations in the air at Pallas indicate how this compound travels with prevailing sea and air currents towards northern latitudes and accumulates in Arctic regions.

Polycyclic aromatic hydrocarbons, PAH

Polycyclic **a**romatic **h**ydrocarbons (PAH compounds) are also organic compounds, but not as persistent in the atmosphere as other POPs. They are released into the air especially by poor combustion processes. Small-scale wood combustion and traffic are the most significant sources of emissions in Finland. Globally, open fires (forest fires, controlled burning, and debris burning) are also important sources of emissions. PAHs are very harmful to humans, since they are often carcinogenic and mutagenic. Benzo(a)pyrene, B(a)P, has been selected to represent all PAH compounds and in the EU a target value has been set for its permitted concentration in the air.

Figure 11a shows the trend of B(a)P concentrations in the air at Pallas, 1996-2009. The concentration has remained at around the same level throughout the period. Concentrations are at their highest during the winter, partly due to higher emissions, but above all to slower transformation. Summer heat causes this substance to transform quickly in the air into other harmless compounds. Concentrations at Pallas are only a fraction of what they are in southern Finland (Figure 11b) and in comparison with the rest of Europe concentrations in southern Finland are also very low (Figure 12).

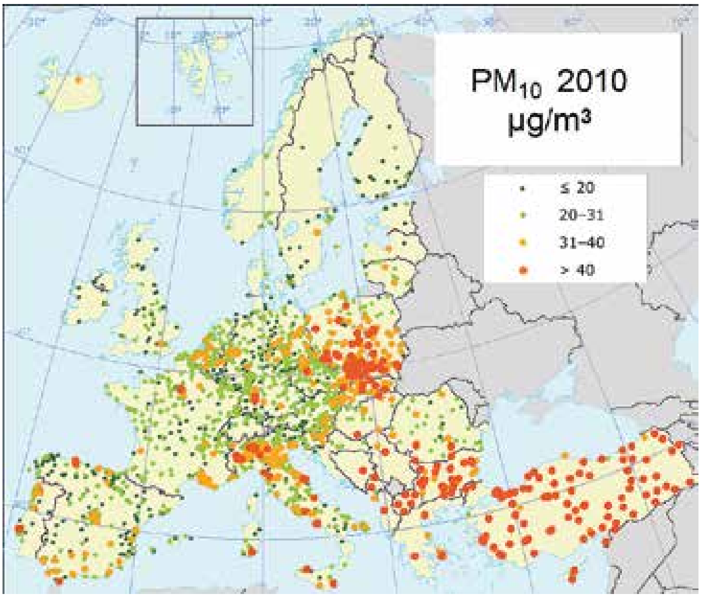


Fig. 13. Annual means of PM_{10} in air in Europe in 2010. Source: Based on EEA, Airbase, 2012

Particulate matter, PM_{10}

With the exception of gaseous sulphur dioxide, the pollutants described above typically occur in the air attached to tiny particles. The particles, which have a diameter of **10 µm** or less, enter the human body with breathed air and are called respirable suspended particles (**P**articulate **M**atter **PM_{10}**). Hundreds of different toxic and allergenic hydrocarbons, heavy metals, and other inorganic particles can adhere to these particles. It is seldom economically feasible to get detailed chemical analyses of the composition of particulate matter, so air quality monitoring generally measures the total content by the mass of PM_{10} particles (and $PM_{2.5}$ particles with a diameter of less than 2.5 µm) in the air as an indicator of the concentration of hazardous substances in the air. At Pallas and Raja-Jooseppi the annual averages of PM_{10} particles are in the order of 3-5 µg/m^3, which is an extremely low concentration level (Figure 13).

Reflections and conclusions

The Pallas research station has now yielded information on the state of the atmosphere for fifteen years, and this information has also been widely used in international research projects. Almost without exception, dozens of air quality projects have found that pollution levels at Pallas are the lowest in the research data, and in this sense, the phrase “the cleanest in Europe” is quite legitimate.

On the other hand, we know that there are major sources of sulphur dioxide emissions three hundred kilometres to the east of the Pallas station, associated with increased concentrations in the air on the Finnish side. Bioindicators still show elevated nickel and copper concentrations in the parts of Finland closest to these emissions (Poikolainen & Rautio 2012, this publication). Emissions of sulphur dioxide and heavy metals from the Kola Peninsula can certainly be detected from the east-west concentration gradient in the northernmost Lapland. However, even in the most severely affected area, close to the eastern border, sulphur dioxide concentrations are very low, at the same level as other Finnish background areas. On a European scale, these are very low concentration levels.

Sulphur dioxide concentrations have been declining for fifteen years in Lapland, which indicates that the Kola Peninsula emissions have been declining. On the other hand, potential increases of emissions in the Kola Peninsula in the future will be reflected in Finnish Lapland, too.

All in all, the trends of concentrations of nearly sixty different air pollutants from 1996 to 2009 at the Pallas measuring station were studied. Most of the studied concentrations remained unchanged in the long run, while the concentrations of nearly half of the pollutants declined. In addition to the sulphur dioxide and heavy metal concentrations from the Kola Peninsula, concentrations of a number of polycyclic aromatic hydrocarbons also declined. Likewise, long-range transported sulphates and persistent organic compounds also decreased in the air at Pallas. However, the situation with traffic-induced pollutants (nitrogen compounds, volatile hydrocarbons, and ozone) remained largely unchanged.

Climate change can cause the conditions for pollutant migration to change. Climate models predict that as the climate warms south-western and western winds will become more common while eastern winds decrease. In this case, fewer and fewer eastern pollutants will be transported to Lapland. However, the future changes in wind conditions predicted by climate models are so small that changes in concentrations in Lapland will amount at most to one or two percent by the year 2100.

Climate change might cause the pollution load in the Lapland region to increase, owing to greater emissions from shipping. By 2050, the ice cap could disappear entirely from the Arctic Ocean during summer. Increasing shipping in the area could also lead to rising concentrations of pollutants in the Lapland region. Current restrictions on sulphur emissions from shipping will prevent growth in sulphur load, but in the worst case, concentrations of nitrogen oxide and particulate matter might double from the current level (Anttila ym. 2011).

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The natural purity of the soil in Lapland and the factors affecting it

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Abstract

Geology and geological processes determine the physical and chemical composition of the soil. These factors are also the basis for the concentration levels of natural elements, which can vary widely in different regions and viewed on different scales. This is also the case in Lapland, where the composition of the mainly Archaean and Proterozoic bedrock varies greatly from granite and gneiss areas to schist belts formed from volcanites and sediments. As a result of weathering and the erosion, transport, and stratification of several glacial episodes, the bedrock is almost entirely covered by glacial tills and other ice age sediments.

Geochemical analysis of the soil shows that element concentration levels in Lapland are low in comparison with Europe and Scandinavia. A closer look, however, shows that regional differences are large and, for example, concentration levels can be significantly higher than background values in a number of critical ore areas. However, the concentrations of potentially harmful elements, such as heavy metals or radioactive elements, rarely reach levels harmful to humans and other organisms. Although the soil in Lapland can be considered naturally clean, human activity can disturb the natural balance and cause concentration levels to become harmful. These activities may include extensive earthmoving or mining for ores and rock materials. In these cases, the effect is usually local and temporary and has no significant impact, for example, on natural berries or mushrooms.

The purity of Lapland soil in a nutshell

- The Geological Survey of Finland (GTK) has been conducting geochemical surveys of the soil in Lapland since the 1970's.
- Repeated ice ages have been the greatest factor modifying the soil in Lapland over the last 2.5 million years.
- In the most common soil type, glacial till, concentrations of heavy metals rarely exceed levels harmful to humans or other organisms. Surface and ground waters are also very pure in Lapland.
- Extensive earthmoving can mobilize harmful elements, but these changes are generally local and temporary.

Keywords

Geology, soil, geochemistry, metals, minerals

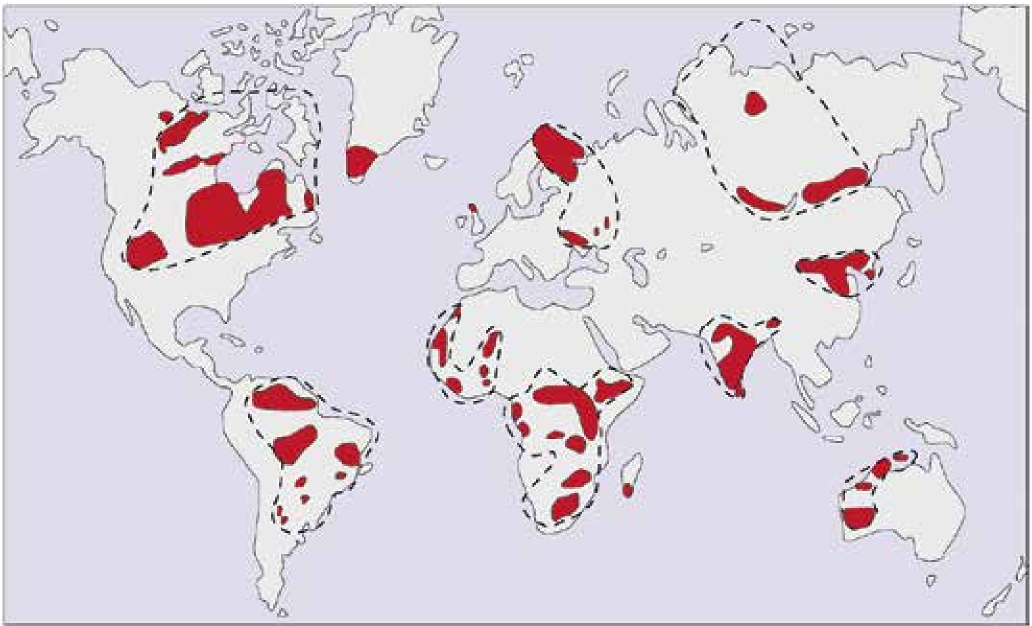
Introduction

Soil purity can be understood in two different ways: as natural purity and anthropogenic purity. The first of these is completely independent of humanity and the natural ranges caused by the geological development cycle in the Earth's crust and soil can be large. The physical and chemical processes affecting bedrock and soil can both enrich and dilute the amounts of elements or minerals and thereby cause concentration levels or areas of accumulation in the soil that are harmful to humans and organisms. In many cases, surface erosion, transportation, and stratification dilute the concentration levels and facilitate or improve the possibilities for life. In addition, different soil processes act as buffers, for instance, against stress from harmful substances coming from air or water.

The contamination caused or purity achieved as a result of human activity often differs from the natural purity generally produced by geological factors. This is an important issue, for instance in the design of urban areas or in other land use planning. High natural background values may, for example, exceed the permitted levels defined by the government many times over (Hatakka et al. 2010). For plants and wildlife, the situation is not quite so simple, because the characteristics of plant physiology vary considerably, and the amount and quality of nutrient that plants take from the soil are not necessarily directly correlated with concentrations measured from the soil.

The chemical composition of Finnish soil is most affected by the rock types forming the local bedrock along with the concentration of minerals and metals (mineralization). As bedrock composition and properties vary greatly, it is natural that the geochemistry of the soil should display large regional variations. The bedrock of Finland is part of the old Fennoscandian shield, which appears through the bedrock of the Cambrian and later (less than 550 million years old) periods (Lehtinen et al. 1998). Eastern Finland, from North Karelia to Lapland, forms a centre around which the shield's continental area has gradually been built up. These rocks are among the oldest in Europe, dating back to the Archaean eon and thus more than 2.5 billion years old (Figure 1).

The bedrock of the shield was formed mainly from the melting of rocks from the mantle and crust, the gravity-based enrichment of light rocks in the crust, tectonic plate movement, and sedimentary processes (Koljonen 1992). The Ladoga-Bothnian Bay zone divides the Finnish bedrock into northern and southern blocks, of which the northern consists mainly of Archaean granites, shales, and greenstones, while the southern consists of younger, Proterozoic (1.7-2.0 billion years old) bedrock. Proterozoic rocks appear also in south-western and western Lapland, mainly in the form of greenstone/schist belts consisting of volcanic and sedimentary rocks significantly different from the older granites and gneisses. These zones are characterized by volcanic and calcareous rocks, as well as the occurrence of various types of fine-grained shale, which makes the bedrock and soil nutrient rich. The bedrock of Finland contains only a few geologically



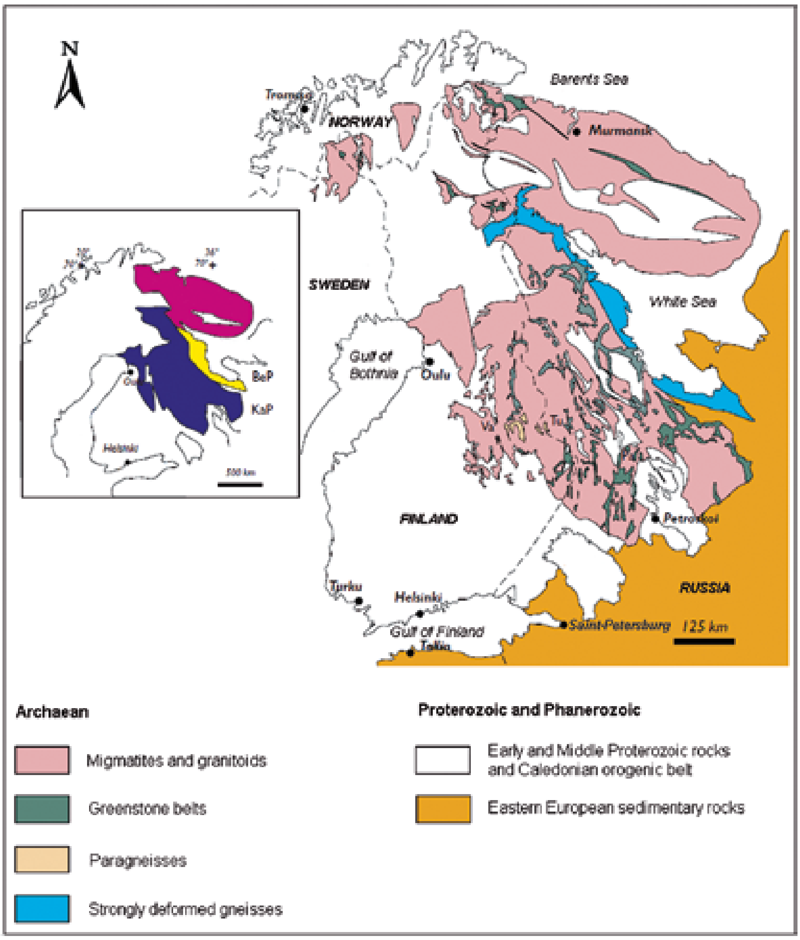


Fig. 1 a) Location of Finland in one of the Archeaen cratons (age over 2.5 bilion years, marked as red) and b) the occurrence of the oldest bedrock areas in Finland. Source: Luukkonen & Sorjonen-Ward (1998).

"young" formations, such as the roughly 350-360 million-year-old Sokli carbonatites and Iivaara alkali rocks (Vartiainen 1980). The Central Lapland region is also characterized by the presence of weathered bedrock (Hirvas 1991, Sarala & Ojala 2008). Rocks formed from different developmental stages differ in composition and form geochemically different source regions for soil processes.

The soil of Finland and Lapland, the regolith overlying the bedrock, consists mainly of soils deposited by continental glaciers during the successive cold periods of the Quaternary, or the last 2.5 million years (Johansson & Kujansuu 2005, Johansson et al. 2011). Large areas of the northern hemisphere have been covered many times by continental glaciers. Lapland was repeatedly located in the central area of the glaciers, where glacial erosion was often weak. This is evident, for example, from the appearance of preglacial weathered bedrock preceding the Quaternary, especially in Central Lapland, and also from the generally higher and more varied topography throughout Lapland. Glaciers and melt waters have eroded the bedrock and transported and deposited the detached material to create soils typical of Finland, consisting of till and stratified sand and gravel, with fine sediments in places. Large areas are also covered by peat layers of varying thickness. Bedrock areas make up only about three per cent of the surface in Finland and about five per cent in Lapland.

Following soil stratification, the surface has been and remains subject to various physical and chemical processes. Frost damage and decomposition of organic surface matter, the migration of dissolved substances and their precipitation in illuvial layers, and air-borne deposition all alter the chemical and mineralogical composition of the topsoil. In the damp, cool climate zone to which Finland belongs, podzol develops, which is common in forested lands. The creation of podzol is a slow process affected particularly by organic acids and carbon dioxide from humus.

Data and research methods

Geochemical research is one of the fundamental geological techniques, which involves studying the chemical composition of rocks, minerals, soil, surface and ground waters, and a variety of mineral and organic sediments. It is based on analysis of samples collected from geological strata, from which the appropriate parts are either sieved and dissolved in a variety of acids prior to chemical analysis, or from which elemental concentrations are measured directly, for example by X-Ray Fluorescence (XRF). The concentrations obtained reflect the composition of the bedrock either directly or indirectly through secondary dispersion. In Finland the soil, and usually till, is a commonly used ingredient in geochemical research, owing to its process of creation and the broad picture it affords of the bedrock over which glaciers have passed. This feature is used, for example, in prospecting for ores. The chemical composition of glacial till and soil in turn directly reflects its nutrient value.

Systematic geochemical mapping of Lapland/northern Finland has been conducted since the early 1970s. The work began in Central Lapland, using so-called line-sampling of the glacial till (Salminen, 1995). Regional, nationwide sampling was extended to a ¼ km^2 sampling frequency in the 1980s. In addition, the Geological Survey of Finland (GTK) has conducted a second national geochemical survey, a large-area survey with a sampling frequency of 1 sample/300 km^2 (Koljonen 1992). Nationwide geochemical soil surveys have used a till as the sample material. Both surveys collected soil samples only from the unchanged till material under the pedological soil, analysing a <0.06 mm grain size. The extraction process used in analysis was aqua regia. Besides soil, nationwide surveys have included stream waters and sediments (Lahermo et al. 1996), groundwater (Lahermo et al. 1990, Lahermo et al. 2002) and rock samples (Rasilainen et al. 2008). These surveys produced data from several thousand samples.

In the 1980's and 1990's, GTK participated in the joint surveys of the Nordic countries and Barents region, which included northern Finland. The collaborative projects involved were the Scandinavian Shield project (Bølviken et al. 1986) and the Kola Peninsula ecogeochemistry project (Reimann et al. 1998). In addition, the Barents ecogeochemistry mapping project covered almost the entire country (Salminen et al. 2004). There are also analysis results for the whole of Finland in the Europe-wide FOREGS geochemical survey publication (Salminen et al. 2005).

In 1996-1997, the international Baltic Soil Survey collected samples of about 130 soil profiles from agricultural lands. In addition to till, the sampling included fine soil types (clay, silt), rough sorted soils, and organic soils. The Baltic Soil Survey also differed from geochemical till surveys by taking the samples from topsoil as well as subsoil. Preliminary results for Finland, based on aqua regia extraction, were published in 1999 (Tarvainen & Kuusisto 1999). According to these results, the concentrations of many trace elements are higher on average in clay soils than in other soil types. In northern Finland, clay soils appear mainly in south-western Lapland, where they can increase the nutrient value of soils in some places.

The method of extraction by aqua regia is commonly used in analyses of soil samples for geochemical mapping projects and contaminated land assessments. Extraction by aqua regia describes the greatest concentration of elements that can dissolve from soil in the most extreme acidic conditions found in nature (Salminen et al. 2007). In other surveys, the methods used are various weak forms of extraction, such as ammonium acetate EDTA extraction (Tarvainen and Kallio 2002). The total concentrations of elements and the concentrations soluble in aqua regia or nitric acid, are much greater in natural soils than the metal concentrations available to plants or that easily migrate into groundwater. The metal concentrations available to plants may be judged using weaker extraction methods, such as for example, acidic ammonium acetate-EDTA extraction (Hatakka et al. 2010). The true total concentrations of elements can be determined, for example, by XRF.

The Government Decree on the Assessment of Soil Contamination and Remediation Needs (214/2007) defines more than 50 threshold and guideline values for potentially harmful substances. Background concentration refers to both natural and man-made elevated concentrations that occur in topsoil over a wide area. Information on background concentrations in soil is needed, among other things, in the assessment of soil contamination. If the concentration of any contaminant in the soil exceeds the threshold defined in the annex to the decree, the level of soil contamination and the need for cleaning will have to be assessed. GTK and the Finnish Environment Institute (SYKE) have compiled data on background concentrations in soil for a national geochemical baselines register (TAPIR 2012). The register collects data from various sources on concentrations of harmful substances such as arsenic and other metals, as well as PAH and PCB compounds. On the basis of background concentrations, regional baselines have been calculated for various substances, according to soil type, and these baselines are available from a web service. The national register is currently based on a sample of about 90,000 data points. National background concentration provinces have also been defined for various elements (Eklund 2008), where the background concentrations of these elements is higher than in surrounding background areas, and where exceeding the threshold values is more likely than elsewhere in the country. Results from GTK national geochemical surveys were used to demarcate the provinces (Koljonen 1992, Salminen 1995). For example, three arsenic provinces have been identified, of which the southern Finland Province (South and South-East Finland, and a large part of East Bothnia) is the largest and the Ilomantsi arsenic province on the eastern border and the Kittilä arsenic province in Lapland smaller.

Results

From a European viewpoint, the Archaean and Proterozoic rocks of Finland are reflected in the soil mainly as the low concentrations of elements. The concentrations of heavy metals such as arsenic, cadmium, and mercury are very low (Figure 2a; FOREGS Atlas 2012). Similarly, the concentrations of radioactive elements are low (Figure 2b) although the Finnish bedrock includes granites and granite gneisses, which in some places are known to contain high concentrations of radionuclides from the decay series of uranium and thorium. Instead, Proterozoic sedimentary and volcanic rocks lead, for example, to elevated concentration levels of magnesium, iron, and many base metals especially in northern Finland (Figure 3). These concentrations are not sufficient to be harmful, but they demonstrate the great ore potential of the north-western corner of Europe, not only for those metals, but also for many other elements.

Examination of a geochemical map of Finland shows significantly more regional differences than in the earlier small-scale view. Till geochemistry allows large bedrock areas to be clearly displayed. For example, the highest magnesium concentrations clearly reflect the occurrence of volcanic and sedimentary rock types (Figure 4a), and also the more nutrient-rich areas. These areas also hold

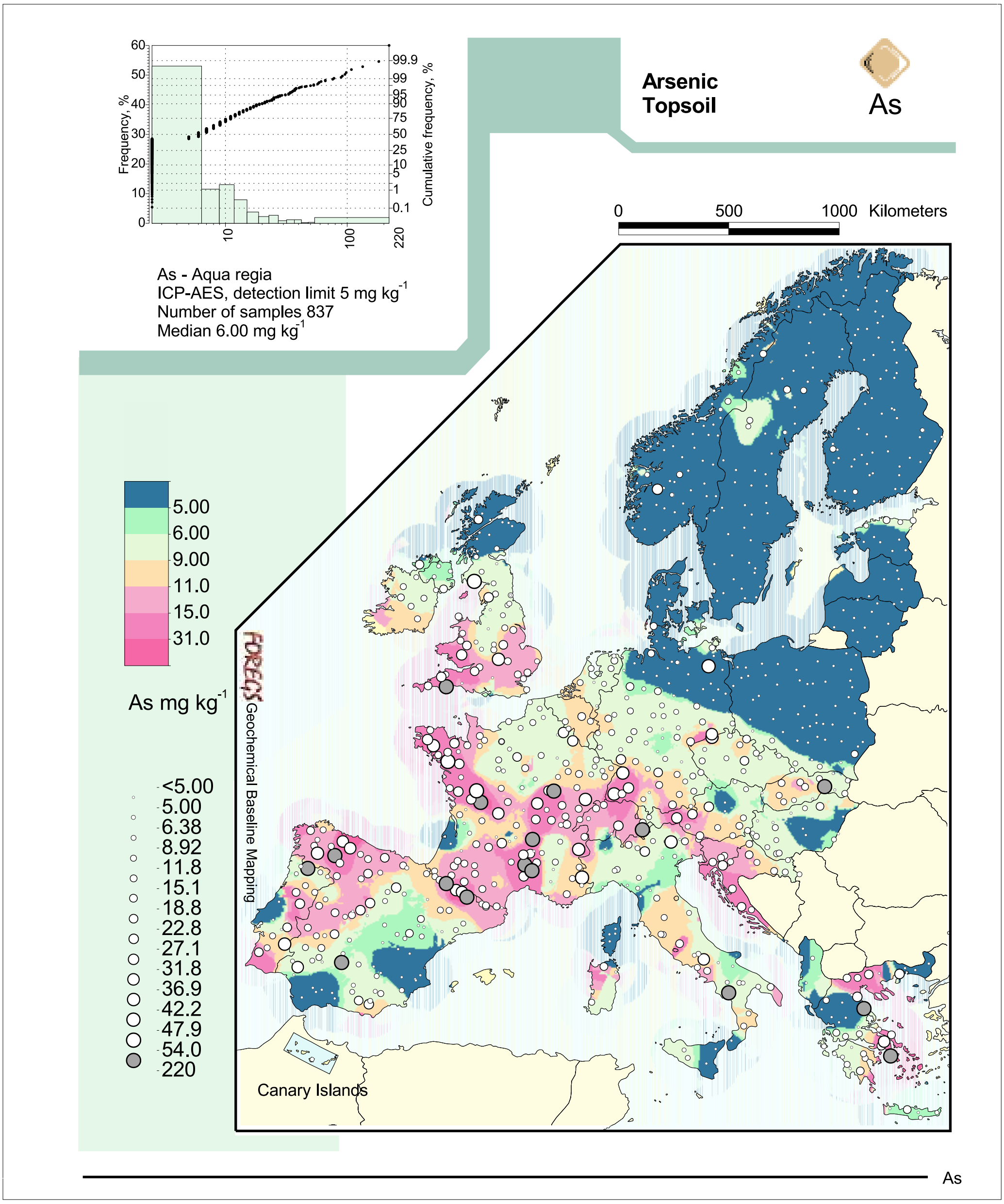
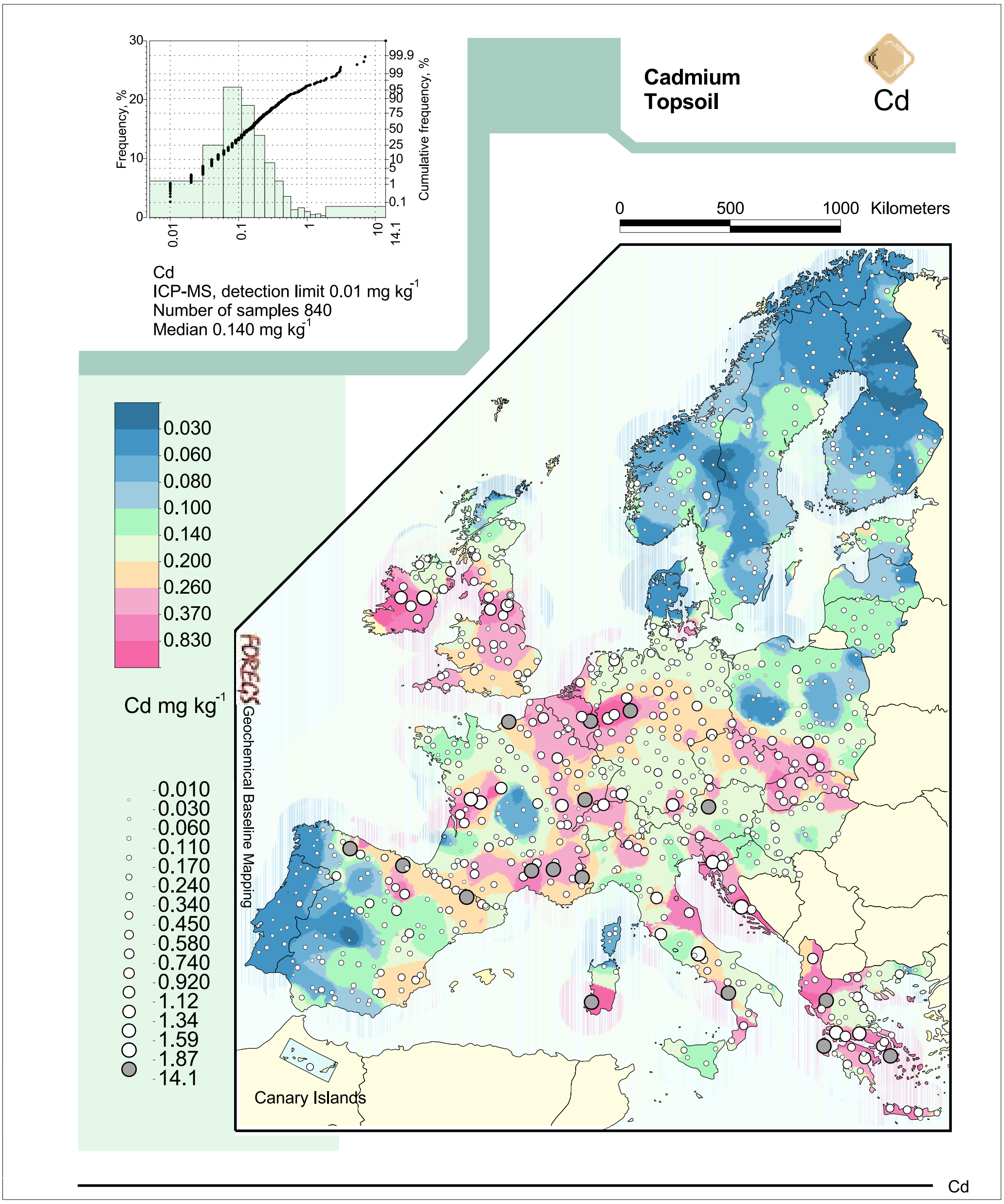


Fig. 2. Distribution of a) arsenic and b) cadmium in soil in Europe. Source: FOREGS Atlas (2012).



Cadmium
Topsoil
Cd
Frequency, %
Cumulative frequency, %
Cd
ICP-MS, detection limit 0.01 mg kg-1
Number of samples 840
Median 0.140 mg kg-1
0
500
1000
Kilometers
0.030
0.060
0.080
0.100
0.140
0.200
0.260
0.370
0.830
Cd mg kg-1
0.010
0.030
0.060
0.110
0.170
0.240
0.340
0.450
0.580
0.740
0.920
1.12
1.34
1.59
1.87
14.1
FOREGS Geochemical Baseline Mapping
Canary Islands
Cd

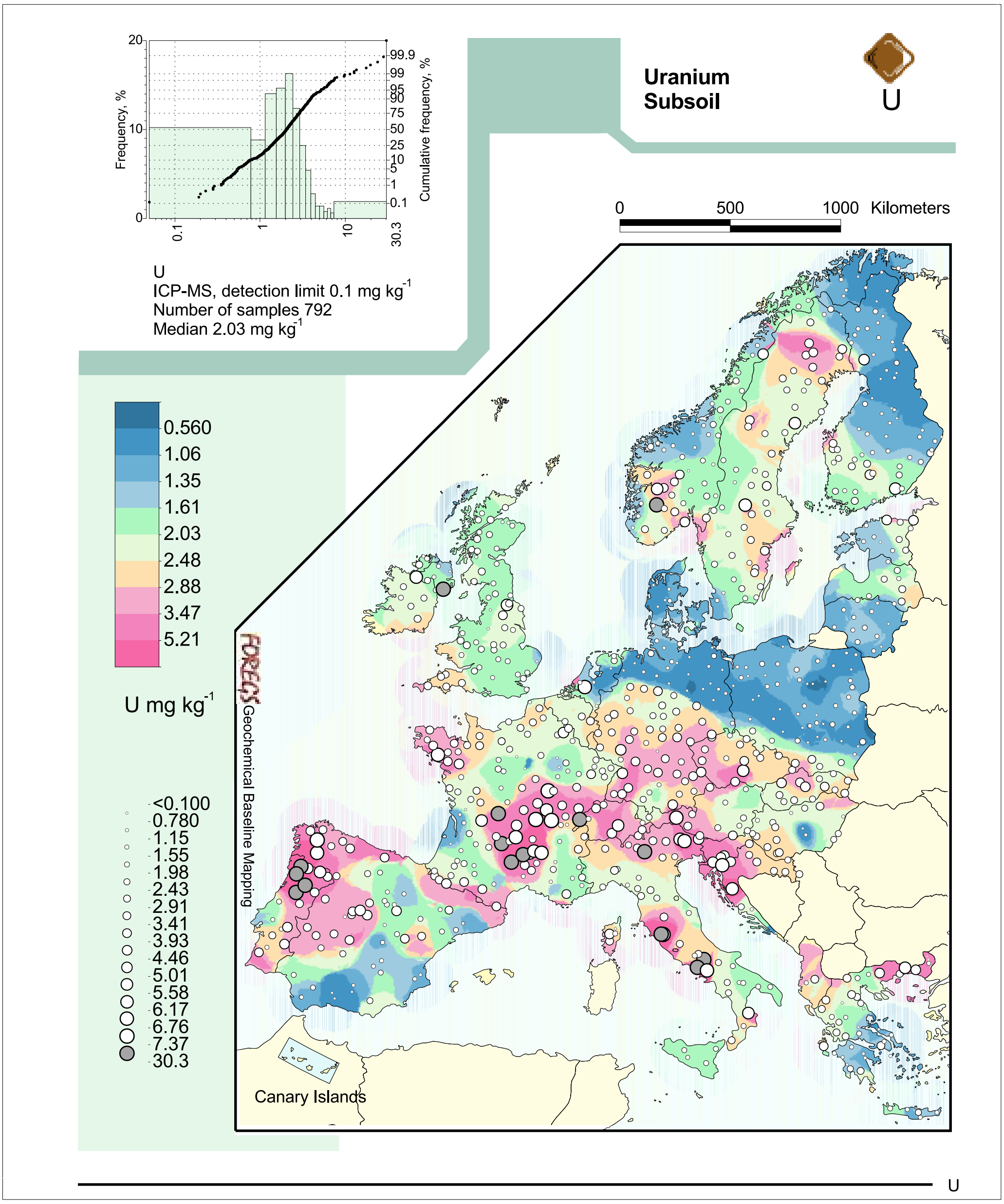
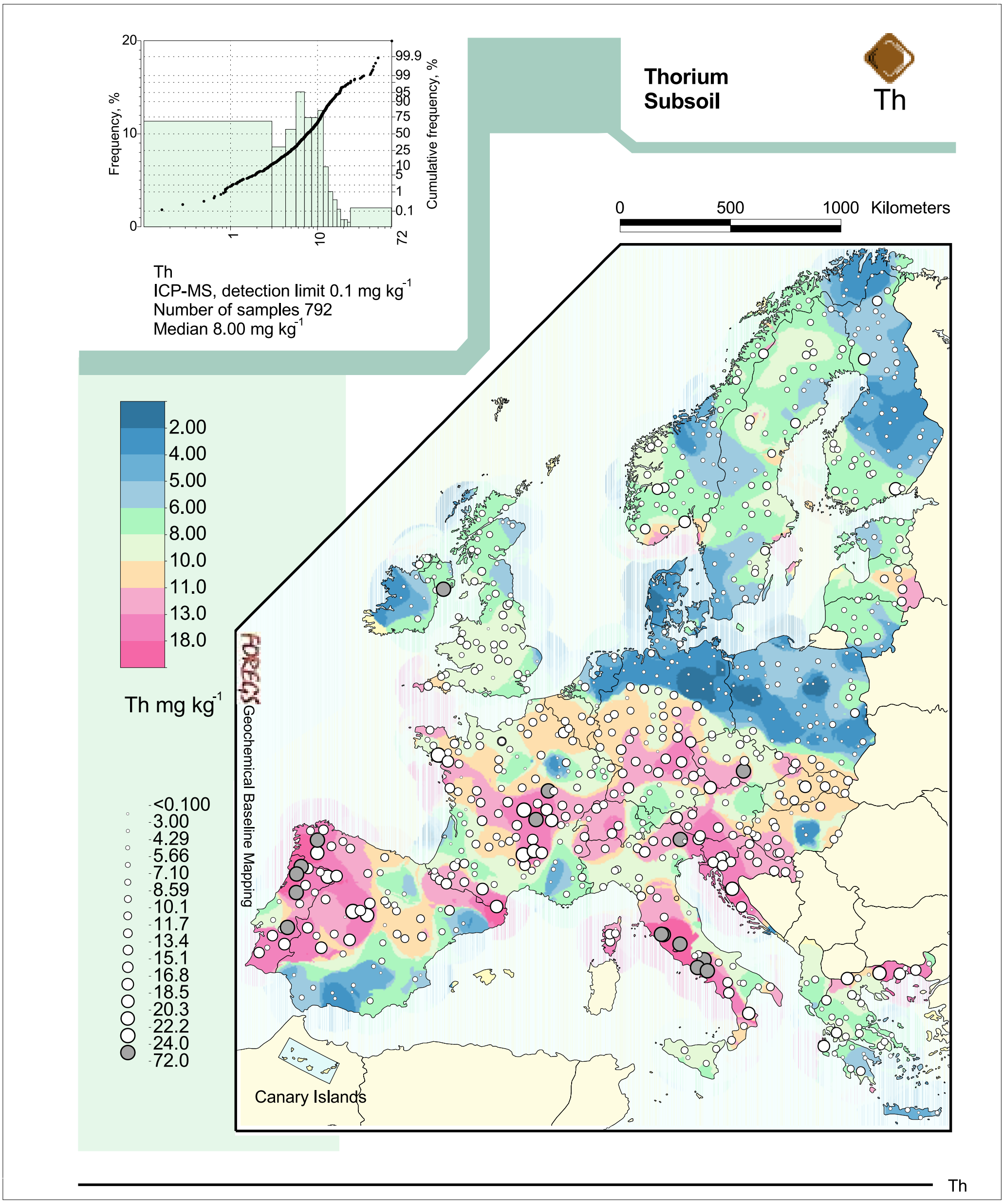
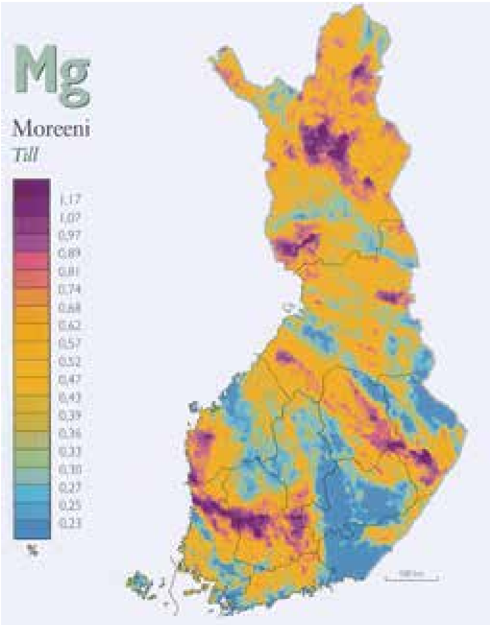


Fig. 3. Distribution of radioactive elements (3a: U and 3b: Th) in soil in Europe. Source: FOREGS Atlas (2012).


Thorium
Subsoil
Th
20
10
0
Frequency, %
Cumulative frequency, %
99.9
99
95
90
75
50
25
10
5
1
0.1
1
10
72
Th
ICP-MS, detection limit 0.1 mg kg-1
Number of samples 792
Median 8.00 mg kg-1
0
500
1000
Kilometers
2.00
4.00
5.00
6.00
8.00
10.0
11.0
13.0
18.0
Th mg kg-1
<0.100
3.00
4.29
5.66
7.10
8.59
10.1
11.7
13.4
15.1
16.8
18.5
20.3
22.2
24.0
72.0
FOREGS Geochemical Baseline Mapping
Canary Islands
Th



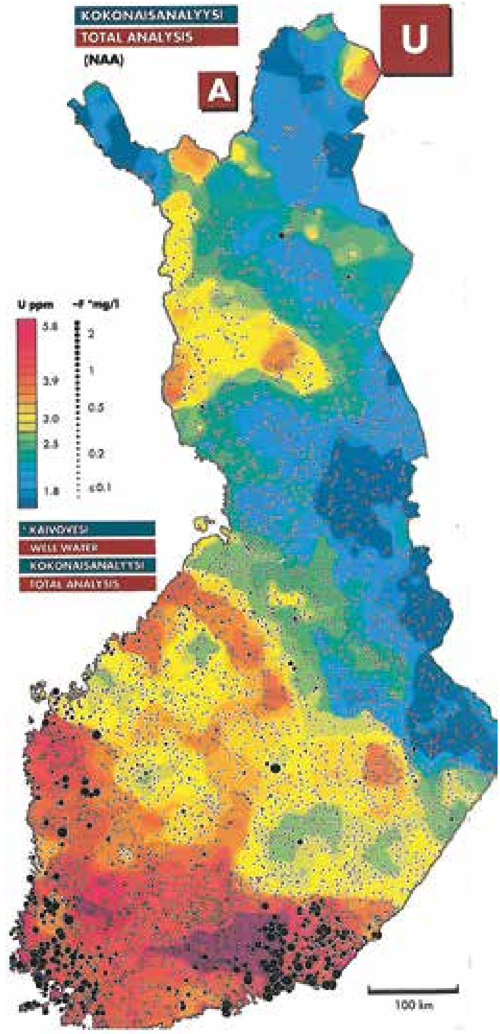


Fig. 4 a) Magnesium content of till in Finland after Salminen (1995), and b) uranium content of till after Koljonen (1992).

the highest concentrations of many metals. Granite and gneiss areas generally stand out as background concentration areas for most metals and only a few areas besides southern Finland show clearly elevated levels of radioactive elements, though not enough to be harmful to humans or other organisms (Figure 4b).

Locally, the different types of rock units and/or the elevated concentrations of elements from related mineralisations may also be reflected in clearly anomalous, elevated concentrations in the soil. For example, the rapidly varying rock units of the Peräpohja schist belt in south-western Lapland, and the related variations in nickel concentrations, are very closely reflected in the till (Figure 5). For this reason, the concentrations of different elements including harmful heavy metals can vary considerably in soil, and this may have a local effect on wild berries and mushrooms, as well as on the concentrations of contaminants in water. However, the phenomenon is natural and rarely causes significant damage to plants or organisms.

Hydrological conditions can be considered quite uniform at the catchment area level, but they can vary significantly even within a small area, owing to the topography, underlying bedrock structures, and characteristics of the soil. These factors directly affect the quality of surface

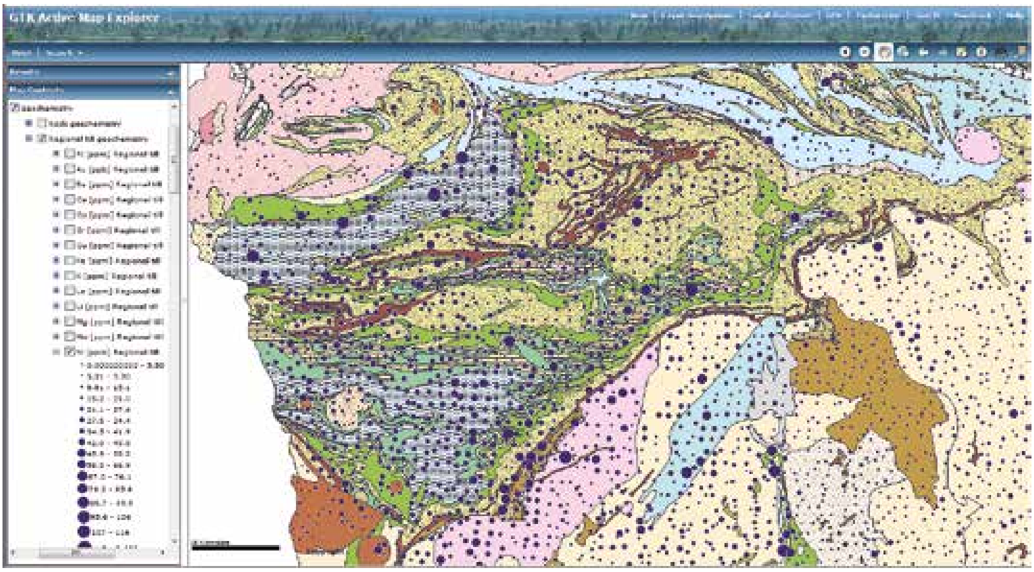


Fig. 5. Distribution of nickel (circles on the map) in the till of south-western Lapland. For example, the southwest - northeast oriented zone of layered intrusions in the bedrock is seen on the map as a clear nickel anomaly. Source: GTK Active Map Explorer web service (http://www.geomaps2.fi/activemap/).

water and groundwater, but the composition of the water also reflects large-scale structures in the bedrock, which can be clearly seen, for example, in the magnesium content of groundwater (Figure 6a). It should be noted, however, that even if the concentrations are elevated in a region, the buffering and cleansing effect of the soil will dilute the concentrations, for which reason elemental concentrations are uniformly very low in Lapland. For example, at their highest nickel concentrations are only around 10-20 mg/l (Figure 6b). Long-term reviews of water quality have shown that it remains good (cf. Tenhola & Tarvainen 2008).

Reflection

From the viewpoint of nutrients and trace elements taken up by plants, the surface layer of mineral soil is significant. In reviewing data, it is essential to take into account the fact that the national till sample material was collected from unchanged till (average depth one or two meters from the surface), that is, from the C-horizon podzol. Thus, it does not directly describe the initial concentration of elements in the soil surface, where plant roots are mainly found. However, these data provide a good overview of the soil chemistry. In contrast, the amount of organic matter in the soil affects the soil's ability to bind multiple elements to itself. When the proportion of organic matter in the soil increases, amounts of most elements will increase, particularly in the topsoil for all soil types (Tarvainen 2006).

The behaviour of elements varies according to soil types, soil processes, and rocks. For major elements, the differences between soil types are significantly less

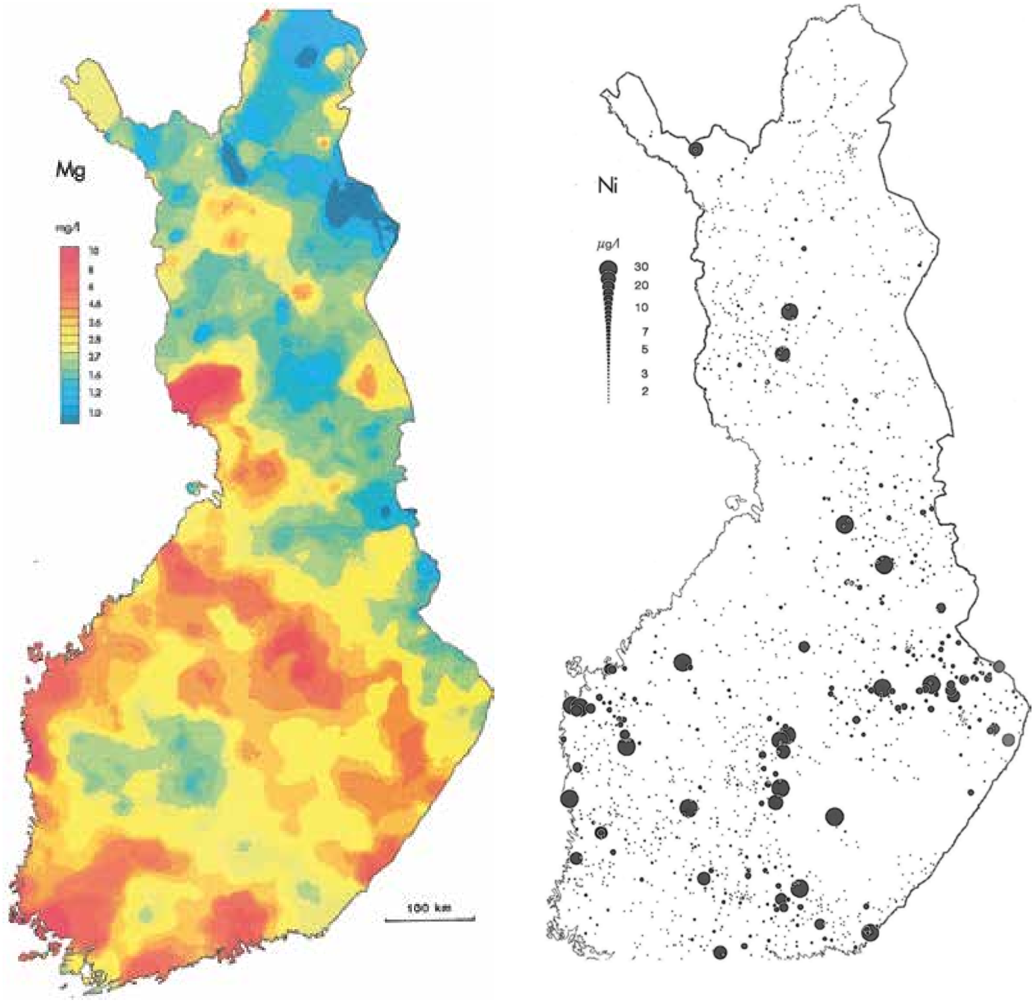


Fig. 6 a) Magnesium and b) nickel content of ground water in Finland. Source: Lahermo et al. (1990).

and the concentration level is determined by the principal mineral composition of the soil type, which is influenced mainly by the relationship between feldspars and dark minerals (Salminen et al. 2007). These in turn are determined by the geology of the area. Trace elements occur mainly adsorbed on the surfaces of mineral grains (mainly mica) or in precipitates. In sand, gravel, and other rough grain sizes, suitable adsorption sites are scarce, whereas in clays, for example, the element concentrations may be up to ten times greater than in sands. This is an essential factor for example in Central Lapland, where one of the starting materials in the till is highly weathered bedrock, rich in fine material.

The heavy mineral concentrations in the soil are an essential factor in the purity of plants and berries. The humus layer on the surface collects heavy metals from the underlying soil and their concentrations may be significantly higher in the humus than in mineral soil. A significant portion of the heavy metals will also come from the air through rain and bind to the humus (Mannio et al. 2002), but in Lapland, this effect is non-existent, except on the border of Northeast Lapland, in the vicinity of the Pechenga smelters. The prevailing south-westerly winds also keep North-East Lapland mainly free from atmospheric deposition.

Arsenic concentrations in Central Lapland are remarkably high in unchanged till samples (Loukola-Ruskeeniemi & Lahermo 2004). However, this is not necessarily a cause for concern, for example, for plant species, since Backman et al. (2007) found e.g. arsenic concentrations to be significantly lower in topsoil. Arsenical minerals on the surface disintegrate and are then dissolved and washed away into the deeper soil layers. They also estimate that of the arsenic on or near the surface 25.7-66.8 per cent was in a biologically available form. With increasing depth, the amount of more easily soluble arsenic decreased to under 3.77-21.0 per cent of the total amount of arsenic. The reduction in concentration of the most easily soluble arsenic with depth suggests that arsenic in deeper, oxygen-poor soil layers adheres to sulphide minerals which are only slightly weathered. On the other hand, digging and turning land alters its natural stratigraphy and creates a new geochemical situation that allows many harmful elements, such as arsenic, to change, in aerobic conditions, into a more easily soluble form and mobilise e.g. as surface runoff (Hatakka et al. 2010). Equilibrium is eventually reached, but for arsenic and other harmful substances this may take a long time.

Lapland and northern Finland are currently subject to very intensive ore prospecting owing to the great mineral potential of the area and international interest. Ore exploration cannot be considered having a significant impact on natural purity, because the effects of geological examination, sampling, and drilling are restricted to very small areas for limited periods. More extensive targeted studies, involving, for instance, the evaluation of mineral deposits or test quarrying, may have a local effect. More significant and lasting impact arises only when mining begins. The nature and amount of the effect will depend on the scope of infrastructure building and the actual form of mining, as well as its extent. For example, open-cast mining for ores has a much greater environmental impact than underground mining operations. In any case, the most important threats to the environment around a mining area are dust, surface and groundwater runoff, and emissions from the enrichment process. However, these threats are mainly local and the effects will decrease rapidly outside the actual operating environment. The resulting risks can be minimized by careful planning and monitoring, which is required by the Finnish legislation.

Summary

Lapland is located in the oldest bedrock area in Europe, which is very heterogeneous in terms of its rock types and chemical characteristics. This has also led to large fluctuations in concentrations in the glacial soil of the area. Although Lapland has great potential as an ore prospecting area owing to its numerous varieties of ore, concentrations in the most common (till) soil types seldom reach levels harmful to humans or organisms. Similarly, the surface and ground waters in Lapland are very pure. Occasional high concentrations are natural and human-generated factors are minimal. Possible risk factors include aerial deposition, mobilization of elements through earthmoving and processing, and the environmental impact caused by mining activities.

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Environmental radioactivity surveillance in Lapland

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Abstract

The regional laboratory of the Radiation and Nuclear Safety Authority in northern Finland carried out environmental radiation surveillance between 1971 and 2012 by collecting and analysing samples from Lapland and Oulu. The collected samples represent the flora and fauna of different northern ecosystems over a long period. Analysis of the samples makes it possible to evaluate changes in radioactivity from man-made radioactive substances. Special features of northern conditions cause radioactive materials to migrate and accumulate differently in ecosystems, so changes in the northern environment can be verified only by making a sufficient number of repeated measurements using appropriate methods.

The analysis method used accredited gamma spectrometry to distinguish between the very low levels of radioactivity in the sites studied. The analysed results are shown graphically as time series for various classification criteria. The time series allow for the examination of temporal changes in the monitoring results over a period extending from the baseline to the present.

The results show that concentrations of ^{137}Cs, the most important man-made isotope of a radioactive element, from a radiation protection viewpoint, have decreased significantly during the period. Concentration levels are well below the export limit of 600 Bq/kg fresh weight set by the European Commission for natural products. In fact, the results show the gradual elimination of man-made radioactive substances from the natural cycle.

Monitoring Lapland's radioactivity in a nutshell

- The Northern Finnish laboratory of the Radiation and Nuclear Safety Authority has monitored radioactivity in the environment of Lapland since 1971.
- The most significant cause of increased radioactivity in the Lapland region was atmospheric nuclear weapons testing.
- The Chernobyl power plant accident affected the level of radiation in the environment for a few years. The reduction of radioactivity levels in reindeer meat after the accident ranged from one reindeer herding cooperative to another, but in general radioactivity in reindeer meat decreased to pre-accident levels in about ten

years. Radioactivity in reindeer meat is now lower than before the accident.
- Levels of radioactivity in natural products (berries, mushrooms) are well below the recommendations for use.

Keywords

Radioactivity, radiation surveillance, radiation protection, natural food, food chain

Introduction

Environmental radioactivity was monitored in Lapland from the 1960s until 1970 by the Helsinki University Department of Radiochemistry, since when the principal responsibility for research and environmental monitoring has lain with the Northern Finland regional laboratory of the Radiation and Nuclear Safety Authority. Over the years, tens of thousands of environmental samples from the Provinces of Lapland and Oulu have accumulated, with the highest numbers of samples coming from reindeer, lichen, a variety of plants, soil, air and water. In terms of quality, the samples represent almost all the flora and fauna of the northern environment that relates in any way to food chains, such as lichen - reindeer - human, water - fish - predatory fish - human, or feed - cow - milk - human (Salomaa 2011). The primary purpose of this work has been to protect people from the harmful effects of radiation. The emphasis in monitoring of northern radioactivity during the 1970s and 1980s was on man-made radioactive materials, the majority of which derived from the atmospheric nuclear weapon tests of the 1950s and 1960s. Study and environmental monitoring of the radioactive materials released into the atmosphere by the Chernobyl nuclear power plant accident in spring 1986 continues in Lapland to the present day. In terms of radiation protection, the most significant man-made radioactive material is caesium, of which the longest-lived isotope has a half-life of 30 years. Figure 1 shows the concentration of the radioactive caesium isotope ^{137}Cs in several Chernobyl fallout zones in the Provinces of Lapland and Oulu in 1986.

In southern Finland, the effects of the Chernobyl accident were significantly greater than in Lapland, with the worst

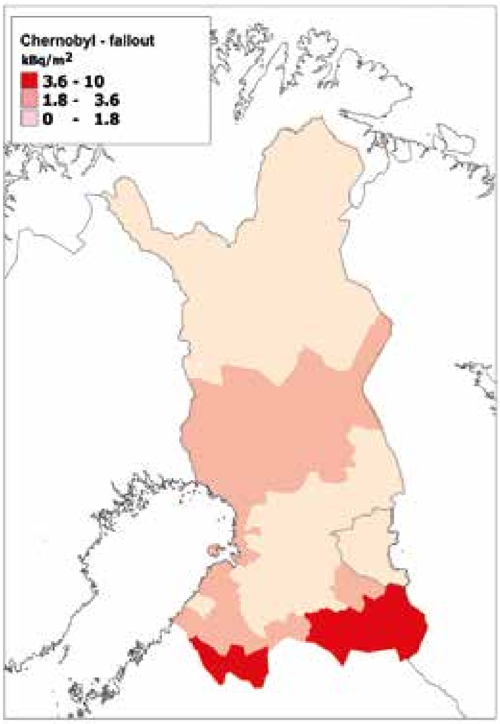

Fig. 1. Chernobyl fallout in the reindeer herding area in 1986 (Ylipieti & Solatie 2007).

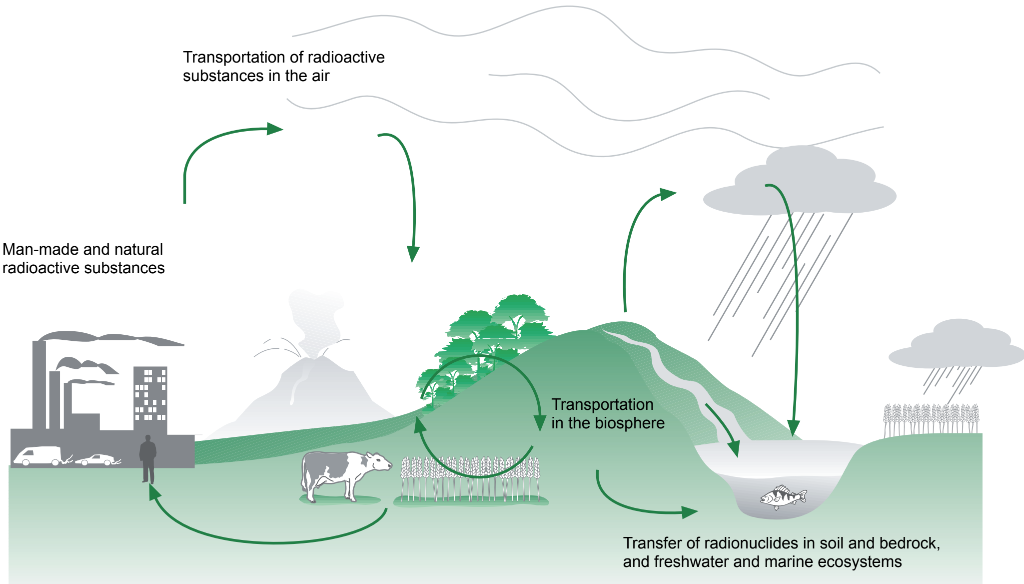

Fig. 2. Radiation and radioactive materials are a natural part of our environment (Pöllänen 2003).

fallout levels more than ten times higher than corresponding levels in northern Finland (Arvela et al. 1990, Ylipieti et al. 2008a). Lapland received more fallout during the 1950s and 1960s due to atmospheric nuclear weapons tests, but a decrease in radioactive caesium in the environment through leaching, dilution and radioactive decay, means that levels have fallen in all natural products. This paper aims to review radioactivity studies from Lapland by category and to present the results of these studies in terms of long-term monitoring.

Radiation in the environment

Man-made radioactive substances are a by-product of energy production in nuclear reactors. The release of these substances into the environment is prevented by all practical means available. Facilities that handle radioactive substances in production (nuclear power plants, reprocessing plants and manufacturing facilities for radio-isotopes) cannot in practice operate with fully closed processes; small quantities of material must be released, in a controlled manner, into the environment. Emissions from Finnish nuclear power plants have been significantly below emission limits (Alm-Lytz 2004). Radioactive substances can be carried by air currents or water far from the emission site, and cause exposure only when radiation occurs in the body or in its immediate vicinity (Figure 2). From a radiation exposure viewpoint, it is particularly important to know where the radioactive materials in our environment originate from and where they accumulate (Pöllänen 2003).

Man-made radioactivity in northern Finland

Atmospheric nuclear weapons tests released large quantities of radioactive material into the environment in the 1950s and 1960s. In terms of global exposure to radiation, the amount of radioactive materials released in nuclear weapons testing is much more significant than the emissions from all nuclear reactor accidents to date. Only in exceptional cases, such as the Chernobyl or Fukushima accidents, the quantities of radioactive material released to the environment in nuclear accidents become significant in terms of global exposure. In the long term, the important nuclides in relation to radiation exposure are, for instance, strontium-90 (^{90}Sr), caesium-137 (^{137}Cs), caesium-134 (^{134}Cs), and the transuranic element plutonium-239 (^{239}Pu) (Pöllänen 2003).

The former provinces of Lapland and Oulu represent almost half the area of Finland. The region can be divided into several vegetation and climate zones, but generally speaking, as one moves north from the more fertile southern areas, the vegetation becomes poorer due to the low level of nutrients in the soil and the shortening of the annual growing season. On the other hand, the short season is somewhat balanced by the summer "midnight sun" period during which the north catches up with the plant growth that began earlier in the spring in the south. The length of the growing season matters from the radioactivity perspective, but plants' supply of nutrients from the ground is more important. It is most important to know the characteristics of the soil, the conditions the plants live in, and how they get their nutrients. In the north, the poverty of nutrients in the soil relates primarily to a lack of potassium. Potassium is a radioactive element that occurs naturally in the soil. For plants, it is vital as a water regulator and as an enabler of photosynthesis. In terms of chemical properties, however, potassium is close to man-made radioactive Cs, so when plants need to correct a lack of potassium, they will increase their Cs uptake either from the soil through their roots or from the air if there is no root system in the soil. In northern regions, long-term study of radioactivity focuses precisely on monitoring the concentration of Cs in plants. A special feature in the north is the lichen - reindeer-man food chain, into which Cs is efficiently transferred.

Monitoring radiation in Lapland

Radiation monitoring can be divided into three parts, depending on where the sample is taken. First, dust samples comprising a filter and the particles attached to it can be taken from the air. This kind of monitoring is now performed regularly in Lapland at three collection centres. In addition, fallout sampling can be conducted using rainwater collected from the same localities. The real-time radiation situation for external dose rates can be found on the STUK website (http://www.stuk.fi/sateilytietoa). Radioactive particles entering soil and water from the air are monitored at regular intervals using samples taken from the soil and its different layers, as well as from lake and river waters. The radioactivity determined for these samples can be used in the assessment of local radiation levels, and combining local information provides data on the wider regional radiation situation. Monitoring results

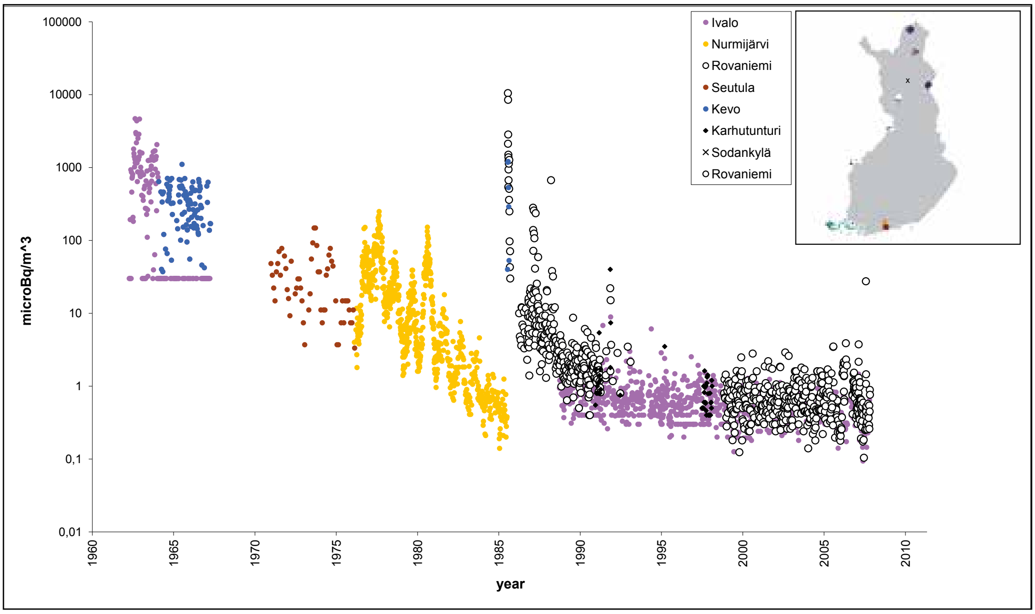

Fig. 3. ^{137}Cs concentration in outdoor air at seven sites, 1960-2010.

can be used to calculate radiation exposure for terrestrial and aquatic plants and organisms, and thus indirectly determine the migration of man-made radioactivity in food chains, such as lichen - reindeer - human or water - fish - predatory fish - human. Direct measurements from organisms and plants provide information that complements and corrects differences in indirect calculation models. Differences are often due to the diversity of local habitats and, for example, initial discrepancies in the global or local fallout situation. Monitoring of human radiation exposure focuses on control of natural foodstuffs consumed by humans. Monitoring of radiation levels in these situations is controlled by national and international laws, and is reported annually, for instance, in a publication on environmental radiation surveillance by STUK. In addition, various regulations restrict the sale and export of natural products, to the extent that man-made radioactivity is detectable from them.

Results

The results are presented either as time series, with time of measurement on the horizontal axis and concentrations, for example, as annual averages, on the vertical axis, or as thematic maps in which the concentration in analysed samples from a single sampling point is represented by a symbol that varies in size and colour according to the classification scale. Another presentation mode used is classification by area, in which the concentration value for an area is the average of all values within the area. The unit used in results is the Becquerel (Bq) measure of activity. One Becquerel means that one instance of nuclear decay (triggering of an excited state in the core) occurs in the radioactive material each second. A nu-

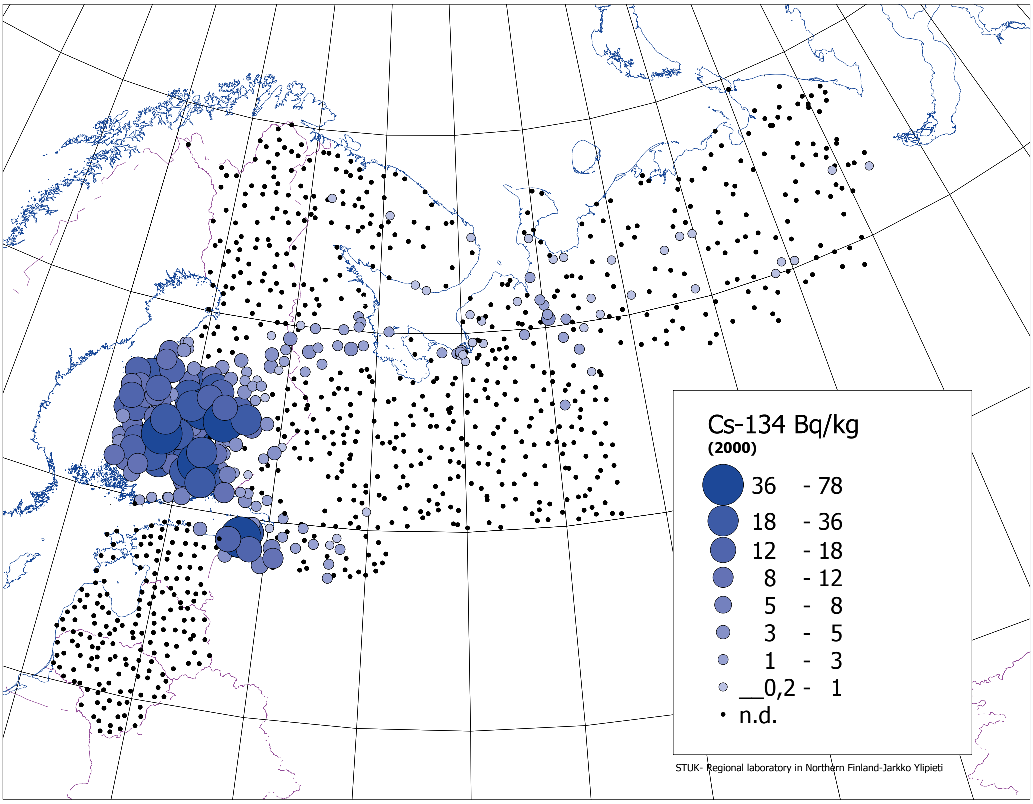

Fig. 4. ^{134}Cs concentrations (Bq/kg DW) in the 0-3 cm part of the humus layer in 2000 (Ylipieti et al. 2008).

clide is a type of atom, such as caesium, while a gamma nuclide is a type of atom that emits gamma radiation, in this case, ^{134}Cs and ^{137}Cs.

Fallout

Environmental radioactivity is monitored in Lapland using continuously operating Geiger detectors and regularly changed particle filters for air collectors. The resolution of the particle filter is as good as one microBq/m^3 of air. Figure 3 shows the concentration of ^{137}Cs radioactivity in the air on a logarithmic scale for seven different localities: Ivalo, Nurmijärvi, Rovaniemi, Seutula, Kevo, Karhutunturi and Sodankylä. Monitoring results for Ivalo, Rovaniemi, Karhutunturi and Sodankylä are produced by STUK, the others by the Finnish Meteorological Institute.

The time series clearly shows the effect of nuclear weapons tests and the increased concentration of ^{137}Cs caused by the 1986 Chernobyl nuclear accident. The concentration of ^{137}Cs in outdoor air is now about 1 µBq.

Soil

A survey of the gamma nuclide concentrations of humus layer samples from Finland, Northwest Russia, and the Baltic countries was conducted as part of the Barents Ecogeochemistry project which was designed to provide information on the state of the environment in

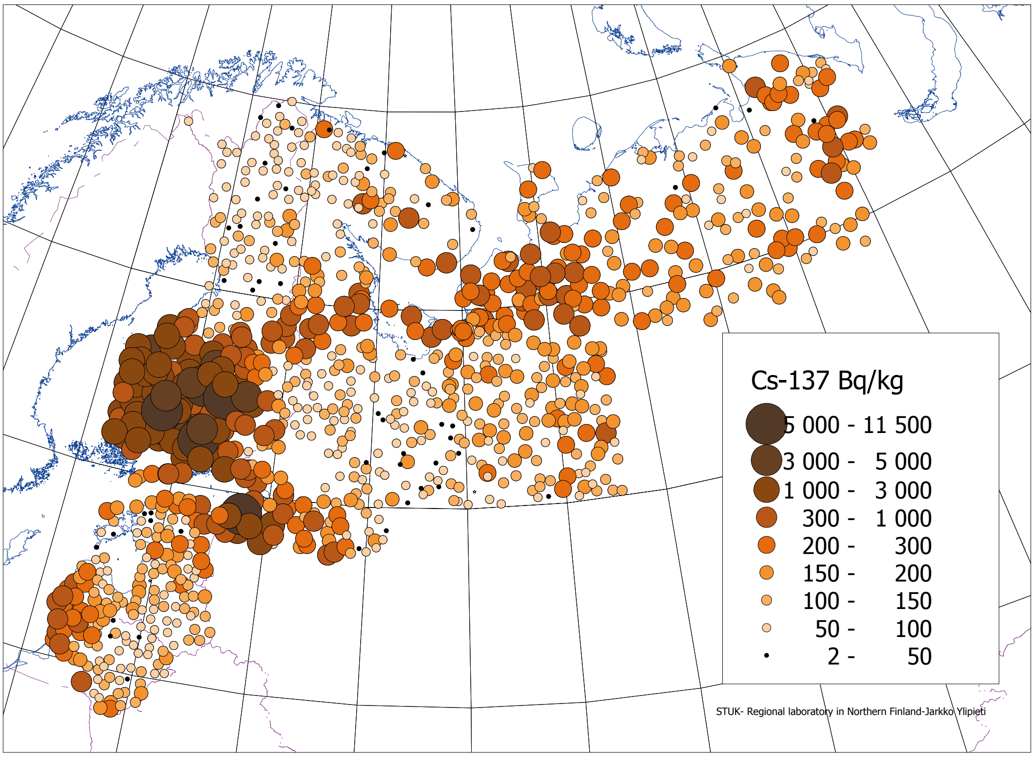

Fig. 5. ^{137}Cs concentrations (Bq/kg DW) in the 0-3 cm part of the humus layer in 2000 (Ylipieti et al. 2008).

Northwest Russia (Salomaa 2004). The collection of humus layer samples (0-3 cm) from 1,550 locations, conducted in 2000-2001 by the Geological Survey of Finland (GTK) with Russian cooperation, covered north-western Russia as far as the Urals, as well as Finland and the Baltic countries. The physical half-life of the short-lived ^{134}Cs isotope from Chernobyl is two years while that of the longer-lived ^{137}Cs isotope is thirty years. Concentrations of ^{134}Cs and ^{137} Cs in the humus layer, for the year 2000, are shown in Figures 4 and 5. Besides the regional situation for the year 2000, these figures show the path of radioactive fallout during the Chernobyl nuclear accident. ^{137}Cs concentration also includes earlier material from the 1950s and 1960s.

Plants and Animals

STUK has monitored ^{137}Cs concentrations in plants, including lichen, wild berries and mushrooms. In animal world, there has been extensive monitoring of reindeer meat, cow's milk, and fish. In addition, so-called whole-body measurements have been used for continuous monitoring of humans. Among northern inhabitants, the group under investigation has especially involved Saami reindeer herders.

Wild berries

Figures 6-8 show concentrations of caesium isotope ^{137}Cs [Bq/kg fresh weight] in wild berries (bilberry, cowberry, also known as lingonberry, and cloudberry), as a function of time since 1980. The highest concentrations have been meas-

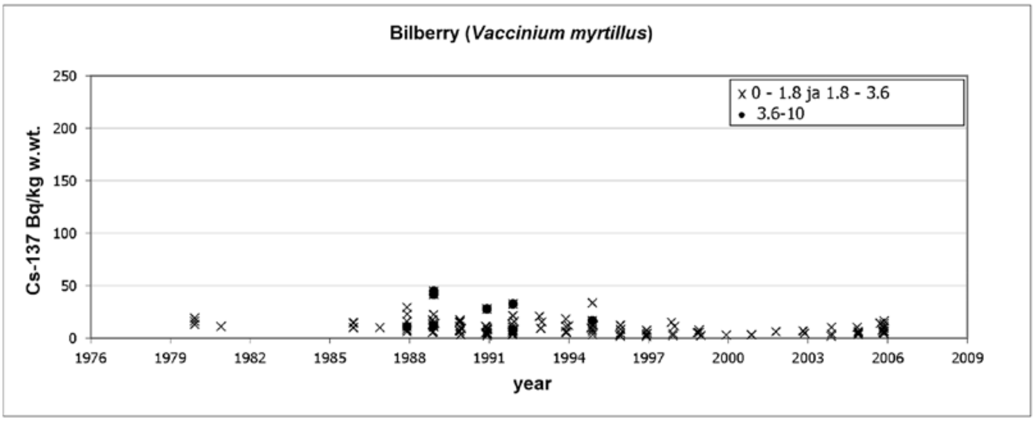

Fig. 6. ^{137}Cs concentrations in bilberry (Ylipieti & Solatie 2007).

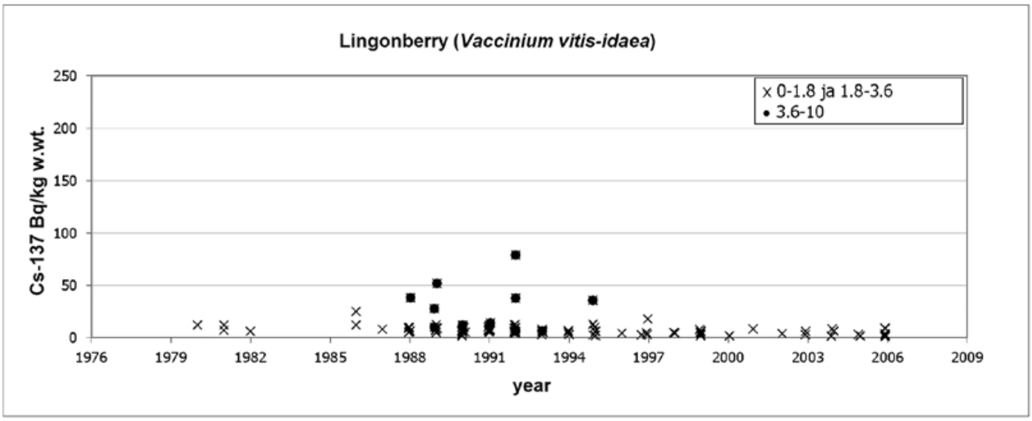

Fig. 7. ^{137}Cs concentrations in cowberry (Ylipieti & Solatie 2007).

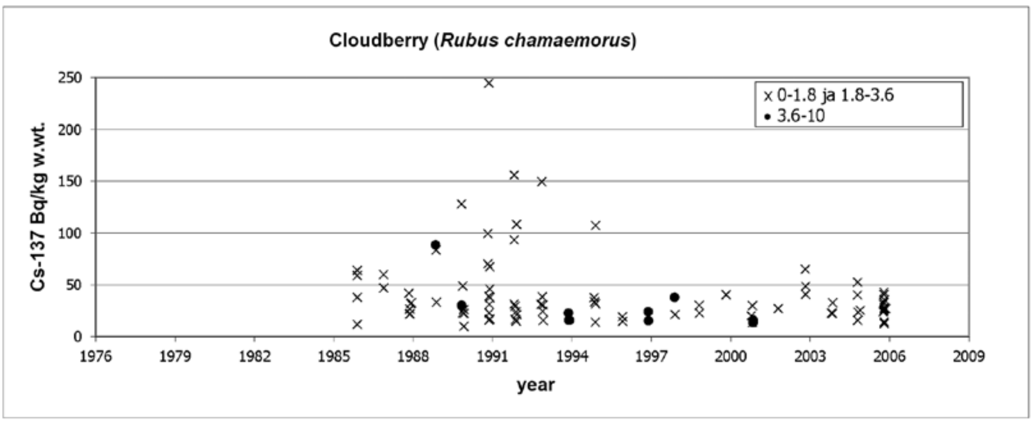

Fig. 8. ^{137}Cs concentrations in cloudberry (Ylipieti & Solatie 2007).

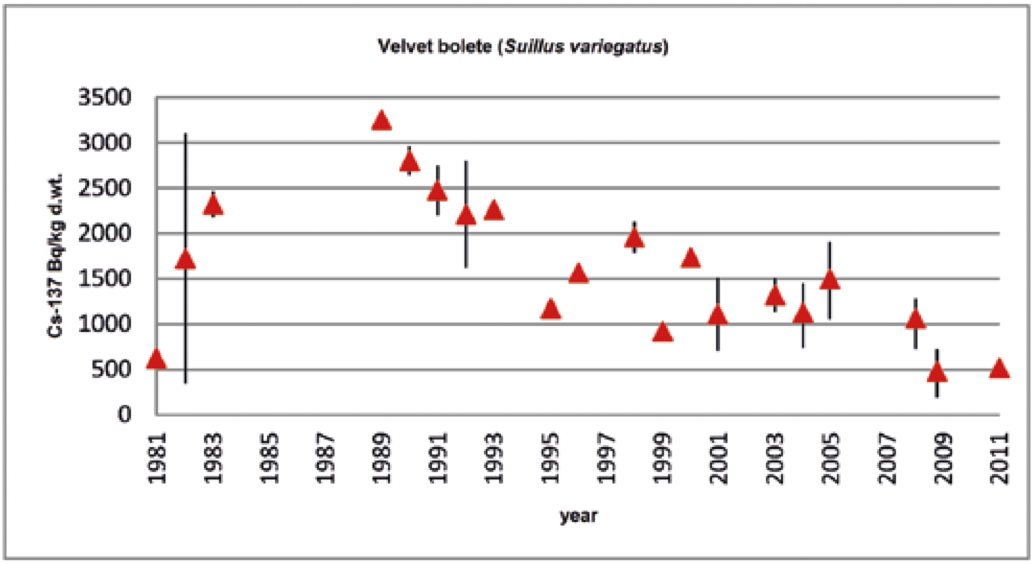

Fig. 9. ^{137}Cs concentrations in Suillus variegatus (Ylipieti & Solatie 2007).

ured in the swamp-growing cloudberry. The results are classified below (Figures 6-8) using the fallout zones from Figure 1. In 2006, the caesium-137 concentrations of all wild berries were below 50 Becquerels per kilogram of fresh weight. The lowest concentrations were measured in cowberry and bilberry.

Wild mushrooms

Radioactivity levels in wild mushrooms have been studied both before and after the Chernobyl accident. A total of 669 mushroom samples were analysed for northern Finland in the period 1981-2008. Mushrooms are sorted by genus, and by collection place

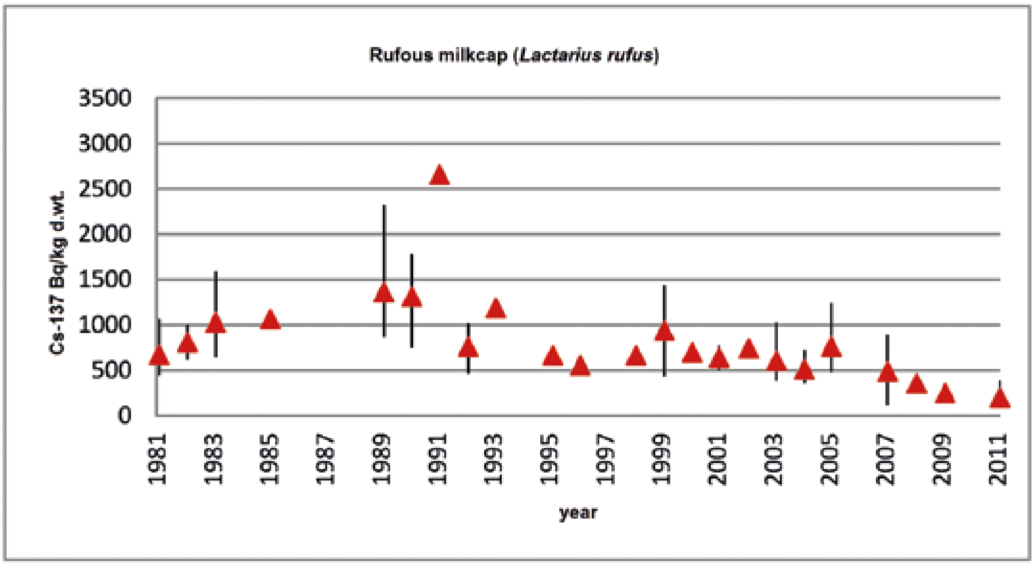

Fig. 10. ^{137}Cs Concentrations in Lactarius rufus (Ylipieti & Solatie 2007).

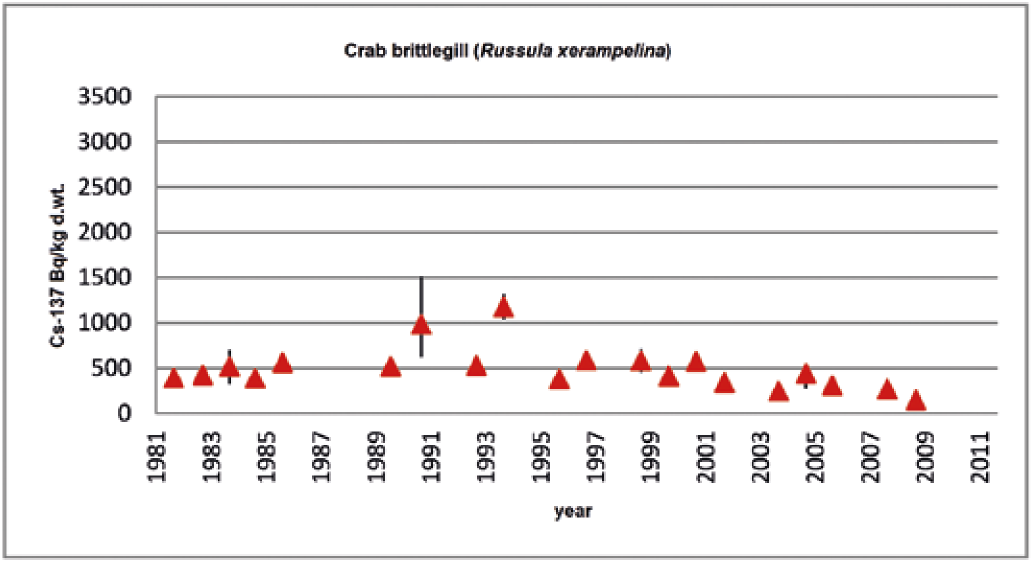

Fig. 11. ^{137}Cs Concentrations in Russula xerampelina (Ylipieti & Solatie 2007).

into samples from Kivalo or elsewhere (Kostianen & Ylipieti 2010). Figures 9-12 show ^{137}Cs concentration in Bq/kg dry weight of velvet bolete (*Suillus variegatus)*, rufous milkcap (*Lactarius rufus)*, crab brittlegill (*Russula xerampelina)*, and red-banded cortinarius (*Cortinarius armillatus)*, at the Forest Research Institute plot at Kivalo, 1981 - 2011 (Ylipieti & Rissanen 2012).

^{137}Cs concentrations are given for dry weights (DW), which means that the figures are approximately ten times higher than corresponding fresh weight results. Thus, in 2010-2011, the results for velvet bolete, rufous milk cap, and crab brittlegill

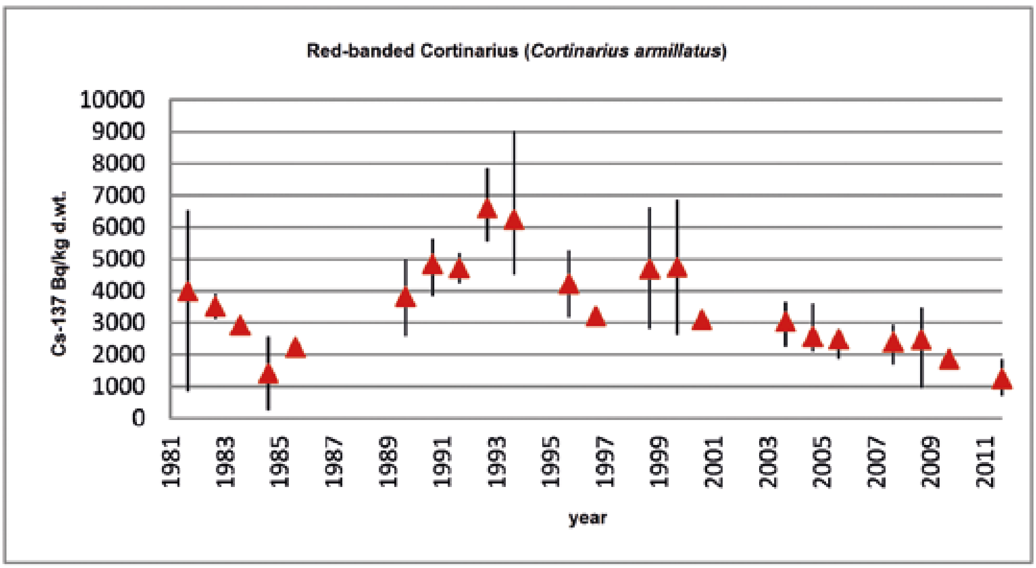

Fig. 12. ^{137}Cs Concentrations in Cortinarius armillatus (Ylipieti & Solatie 2007).

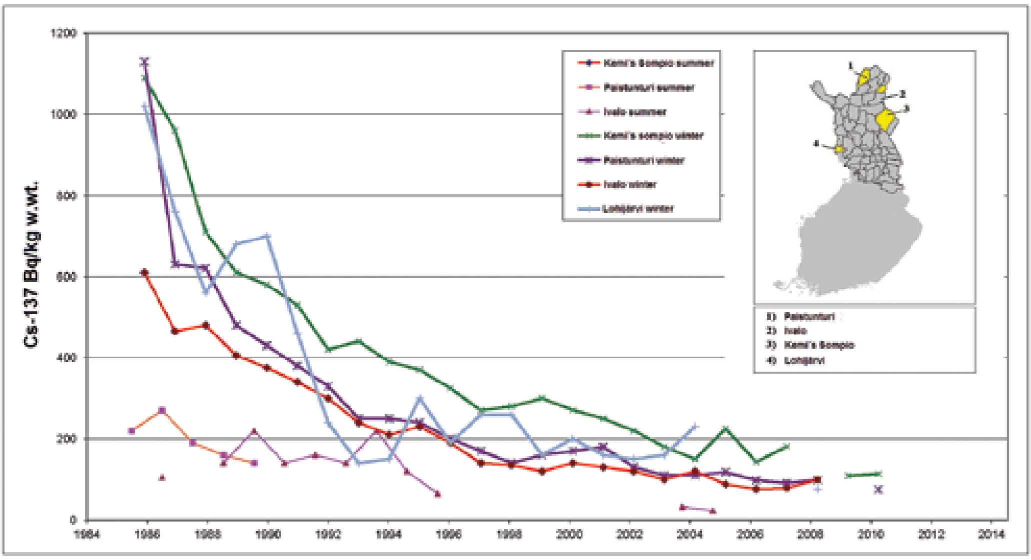

Fig. 13. ^{137}Cs concentrations in reindeer meat (Leppänen et al. 2011).

are under 100 and for red-banded cortinarius less than 200 Bq/kg fresh weight.

Reindeer meat and lichens

Reindeer meat has been one of the most closely monitored natural product since the Chernobyl nuclear accident. The average concentration of ^{137}Cs in reindeer meat was highest in 1965 and 1966, i.e. 2,500 - 3,000 Bq/kg fresh weight (FW). However, the concentrations decreased over time, so that in the year preceding the Chernobyl nuclear accident the average was less than 500 Bq/kg. After Chernobyl, the concentration in reindeer meat in certain places was more than a thousand Bq/kg FW. Figure 13 shows the ^{137}Cs concentration in reindeer meat for three different reindeer herding cooperatives, for summer and winter, 1986-2011. ^{137}Cs concentrations fell sharply in the ten years following the accident, after which the rate of decline slowed, the concentration being about 100 Bq/kg fresh weight in 2011. Differences between summer and winter reindeer are due to the reindeer diet. In winter, the reindeer eat more lichen, while in summer there are a lot of alternative foods available, such as the leaves of deciduous trees, vascular plants, and fungi.

Concentrations of ^{137}Cs in summer reindeer food crops have been studied in the Finnish reindeer herding area e.g. by Anttila et al. (2011). Reindeer make use of more than 300 plants for summer food. However, lichen is the main food source in most northern reindeer herding cooperatives during the winter. Concentrations of ^{137}Cs in lichen have been followed at Kaamanen, in the municipality of Inari, both before and after the Chernobyl accident. In 1965 and 1966, when the highest concentrations were measured in reindeer meat, the concentration of ^{137}Cs in lichen was under 2,500 Bq/kg DW, while immediately after the Chernobyl accident in 1987, it was just over 1,500 Bq/kg DW. However, Chernobyl fallout in the reindeer herding area was very un-

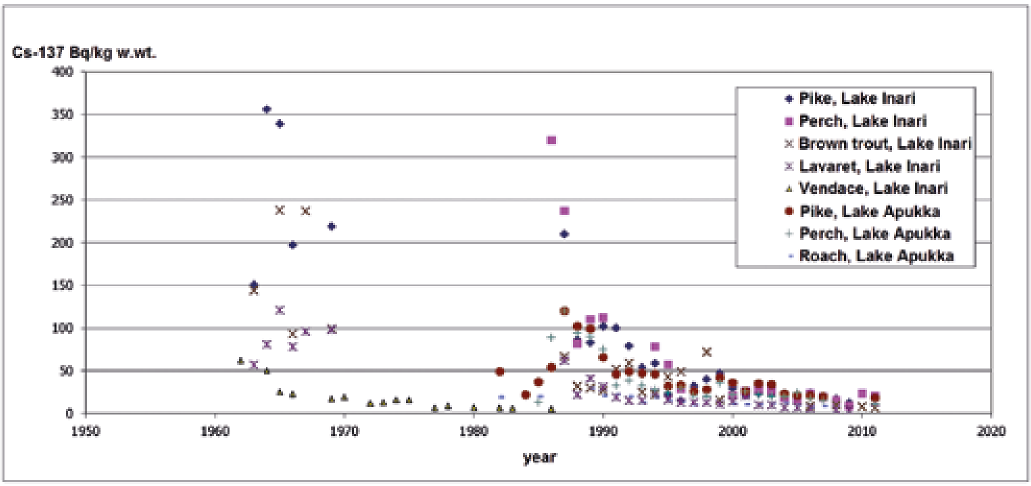

Fig. 14. ^{137}Cs concentrations in fish from Lake Inari and Lake Apukka, 1960 -2009 (Tuovinen et al. 2010, Ylipieti & Solatie 2007).

even (Figure 1), so there are considerable regional variations for caesium concentrations in lichen. In addition, in the 1950s and 1960s the fallout in northern Finland from nuclear weapons tests must be taken into account in assessing the origin of ^{137}Cs concentrations.

Reindeer herders

Concentrations of ^{137}Cs in reindeer herders from the northernmost municipalities have been measured since 1962. Measurements were made every year until 1977, with the following measurements being made, by chance, three weeks prior to the Chernobyl nuclear accident. The average whole body concentration of ^{137}Cs was 4,500 Bq/kg before the accident and slightly over 10,000 Bq/kg in the years following the accident. In 2005, the level was slightly less than 2,000 Bq/kg (Leppänen et al. 2011).

Freshwater fish

Research conducted in 2008 examined Cs concentrations in two different types of northern lake, Lake Inari, and Lake Apukka, Rovaniemi (Ylipieti & Solatie 2008). Finland's third-largest lake, Lake Inari is not only a major site for fish production and recreational fishing; it is deep, and has both a low level of nutrients and many different species of fish. Lake Apukka is small, shallow, and rich in nutrients. Caesium concentrations in fish from Lake Inari were compared with corresponding concentrations in fish from Lake Apukka in the years 1985-2008. In both lakes, the highest concentrations were found in the predatory fish, pike and perch. Caesium was found least in whitefish, vendace and roach. Caesium levels in predatory fish in the 1960s and immediately after the Chernobyl accident ranged from 150 to 350 Becquerels per kilogram. In other fish, concentrations remained below 100 Becquerels per kilogram at respective times. The most recent results are from spring 2008, when the caesium concentration in Lake Inari pike and perch was 20 Becquerels per kilogram. The caesium concentrations in both lakes were monitored for the

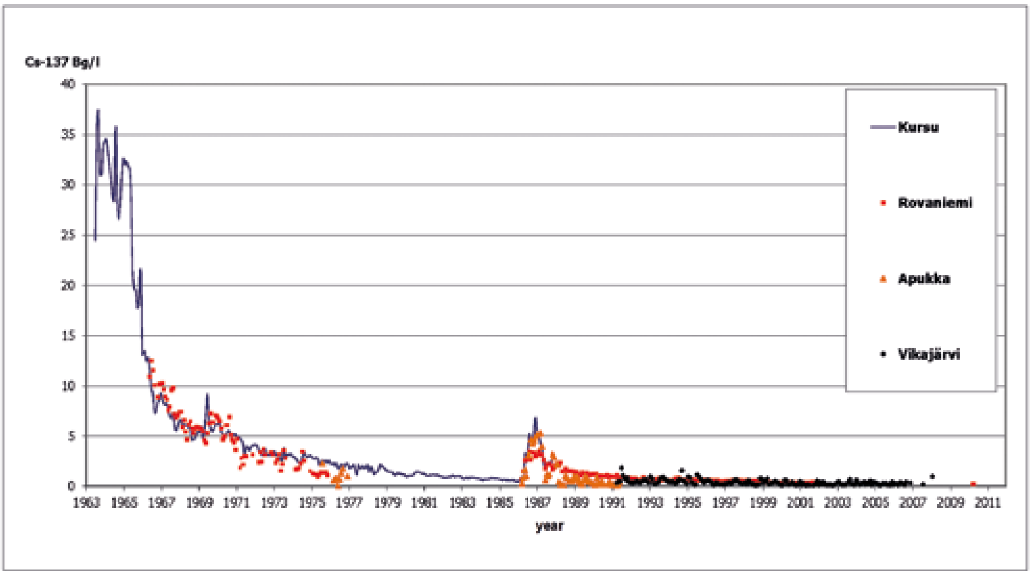

Fig. 15. ^{137}Cs concentrations in cow's milk (Solatie et al. 2008).

period following the Chernobyl accident (Figure 14).

Cow's milk

The soil - grass - milk food chain is an important route via which people can be exposed to radiation. Milk samples have been collected from dairies and farms in northern Finland since 1963; samples were collected from Kursu from 1963 to 1987 and from Rovaniemi from 1966 to 1975 and again from 1986 onwards. Farm-specific milk samples come from Apukka and Vikajärvi in the Rovaniemi area. The ^{137}Cs concentrations in milk are shown in Figure 15 by place of collection. ^{137}Cs concentrations in milk were highest in the early 1960s; the Chernobyl effects were smaller.

Conclusions

The environmental effects of atmospheric nuclear weapons testing in the 1950s and 1960s were greater than those from any later accidents or events related to radiation use. As a single accident, Chernobyl had a temporary effect that elevated the level of radiation in the environment only for the first few years afterwards. However, of the long-lived radionuclides, ^{137}Cs is still measurable with sensitive measuring equipment. Although Lapland has only small amounts of man-made radioactive materials, long-term monitoring shows that their removal from the natural cycle takes time. The longest ecological half-lives can be close to 20 years.

Owing to its growth site, the common cloudberry from the marshes of northern Finland is more sensitive to radioactive fallout than other berries. Results also show that caesium concentrations may vary significantly within a fallout area, depending on local growing conditions. In mushrooms, concentrations vary even within a small area and there may be year to year differences in moisture conditions and growth areas, since growth areas vary with moisture. In drier autumns with low precipitation, mushrooms grow on the edge of marshes in spruce forests, or on shady northern slopes rather than in dry peaty forests. These different growth conditions cause annual variations in mushroom ^{137}Cs concentrations.

Average ^{137}Cs concentrations in reindeer meat have decreased steadily in certain reindeer herding cooperatives while in others the decrease in concentrations was very fast at first and slowed down at a later stage. The most likely cause of disparities in ^{137}Cs concentrations is the intake of lichen which varies from one reindeer herding cooperative to another due to the differences in pasture utilization. Cs concentrations in reindeer herders are currently low due in part to the fact that increasing numbers of young reindeer are slaughtered before they use lichen for food. However, reindeer herders are still the Finnish group that receives, on average, most radiation from food during the year.

Examination of lake fish showed little variation in the reduction of caesium concentrations, according to lake type or fish species, in the first years following the accident. Instead, there was a significant difference in predatory fish eight years after the accident. The Cs concentration in the meat of pike from Lake Inari decreased more than fifty percent faster than for Lake Apukka pike. One explanatory factor is thought to be the lake water that has been studied in parallel with the Cs concentration of fish meat. In Lake Inari, the concentration has fallen together with that of fish meat, faster than the equivalent concentration in comparable water from Lake Apukka. Lake-specific differences in the elimination of Cs-concentrations from fish meat may be considerable because of the ecology of the lakes and the surrounding countryside.

The European Union's recommended limit for radioactivity in traded natural products is 600 Bq/kg fresh weight (2003/120/EC). The reported results for natural products such as wild berries and fish are generally very low, and well below the EU recommendation. Looking forward, it will be essential in future to monitor naturally occurring radioactivity in case of fresh nuclear accidents, but also increasingly the migration of natural radioactive substances, for example as a result of mining activities. Monitoring environmental radioactivity in northern Finland will therefore focus on the supervision of two different industries: energy and mining. On the other hand, the construction of additional nuclear power plants at Pyhäjoki will require investment in environmental monitoring of man-made radioactive materials as well as assessment of the environmental impact of new mining projects, and monitoring of their impact on radioactive materials in nature.

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Environmental pollution in Lapland on the basis of bioindicators

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Abstract

Heavy metal deposition have now been monitored in Finland every five years for 25 years, using moss samples. Based on the concentrations in moss samples, deposition of all monitored heavy metals other than nickel, copper, and chromium (i.e. cadmium, iron, mercury, lead, zinc, vanadium and arsenic) in Lapland is so low that their deposition does not generally pose a significant risk to the environment or human health. Emissions from the mining industry in the Kola Peninsula significantly raise the concentrations of nickel and copper in depositions in the eastern parts of Inari. However, the concentrations of nickel and copper decrease rapidly west of the border. Close to the border, indications have been found of the environmental impacts of heavy metals and sulphur. Nevertheless, heavy metal emissions from the Kola Peninsula do not affect concentrations in berries and mushrooms in eastern Lapland; rather, concentrations reflect those in local soils. Chromium emissions from the Tornio steelworks are mirrored in concentrations in moss samples collected in the Tornio region. However, these levels are quite low and the chromium appears mainly in the form of nontoxic chromium (III) oxide, so the deposition does not pose a significant risk to human health. Chromium deposition is low elsewhere in Lapland.

Results from bioindicators in a nutshell

- Mosses efficiently collect atmospheric pollutants, so they are well suited for air quality monitoring
- Heavy metal concentrations in mosses are widely monitored in Europe; in Finland, the Finnish Forest Research Institute has monitored heavy metal concentrations in mosses for 25 years
- Heavy metal depositions are low in Lapland, and generally decreasing
- In the easternmost parts of Inari in consequence of emissions from Kola Peninsula and near the Tornio steelwork, heavy metal concentrations in mosses are relatively high. The above-mentioned facilities have no apparent effect on concentrations of heavy metals in mushrooms and berries
- The mining industry, and an increase in traffic, may result in increased heavy metal emissions in Lapland

Keywords

Heavy metals, monitoring, mosses, berries, mushrooms

Introduction

Lapland has traditionally been considered a clean area in relation to atmospheric pollutants. Lapland's own emissions are negligible and only the forestry and steel industry emissions from around the Bay of Bothnia have had any significant harmful effects. However, Lapland receives long-range depositions of sulphur and heavy metals from outside Finland, from the production facilities of the mining industry in the Kola Peninsula and from elsewhere in Europe. The following uses bioindicators to examine air-borne heavy metal deposition in Lapland and its importance to the environment and human health.

Heavy metals are ubiquitous in nature: in soil and bedrock, air, water, and living organisms. Emissions of heavy metals spread to the environment from natural sources (such as volcanoes and forest fires) and human activities (such as oil, coal, and waste burning, metal production, and transport). Heavy metals are environmental toxins. Their toxicity and effects depend, among other things, upon their amount, form, and exposure time. Heavy metals are not merely detrimental to the environment; many of them, such as copper, zinc and iron, are essential trace elements for humans and other organisms. Others, such as mercury, lead, and cadmium, are toxic even in small quantities. The harmfulness of heavy metals is increased by their persistent nature and their accumulation in food chains. Harsh conditions in northern regions may make their harmful effects greater than in southern latitudes.

These metals pass from the air into soil, water, and vegetation, and for instance in food to animals and humans. When the deposition is large enough, heavy metals in the soil displace important plant nutrients, tree growth weakens, the most sensitive plant species disappear, and the fauna changes. At worst, heavy metal emissions lead to the creation of so-called "industrial deserts" around emission sources. At this point, if not earlier, heavy metals become seriously harmful to human health.

The deposition of heavy metals can be mapped using concentrations in mosses

Concentrations of airborne heavy metals reaching the ground can be measured directly as wet and dry deposition. In wet deposition, substances reach the ground in rain, while in dry deposition they arrive with dust or in gaseous form. Direct measurements, however, are expensive and measurement stations are few and far between. Therefore, efforts have been made to find cheaper ways of monitoring deposition. Measuring concentrations from mosses has proven to be a good monitoring method (Rühling & Tyler 1968, Poikolainen 2004). Mosses take nutrients primarily through the air from rain water and particulate matter, so that they accumulate airborne pollutants at the same time. However, heavy metals do not accumulate in mosses in the same proportion as they exist in deposition, since the efficiency of absorption depends e.g. on the structure of the moss and the nature of the deposition (Zechmeister et al. 2003). Concentrations give a relative picture of deposition.

The Finnish Forest Research Institute has monitored heavy metal deposition in Finland by means of mosses every five years since 1985 (Metla, MetINFO 2012). Today, they are part of a monitoring system that covers almost the whole of Europe (Harmens et al. 2008, 2013). In Finland, mosses were collected until 2005 from the permanent plots of the 8th National Forest Inventory (NFI 8). In 2010, samples were collected from the same plots in Lapland, but elsewhere in southern and central Finland, from the plots of the 11th National Forest Inventory (NFI 11). In Satakunta, samples were collected from both the plots of NFI 8 and NFI 11. Owing to the reduced set of sample plots (NFI 11) the effects of small emission sources on concentrations in mosses did not stand out in the 2010 survey in southern and central Finland as well as in previous survey years. Samples were collected from either stair-step moss (*Hylocomium splendens*) or red-stemmed feather moss (*Pleurozium schreberi*). Moss analyses have included cadmium, chromium, copper, iron, nickel, lead, vanadium, and zinc concentrations from the beginning, and arsenic and mercury concentrations since 1995. Arsenic is a metalloid, but it has been included in surveys owing to its toxicity. Samples have not been collected in the close vicinity of emission sources. The goal is to get an overview of heavy metal deposition and its temporal changes.

In order to assess the impact of heavy metal deposition on concentrations in picking products, in 2005, besides moss samples, berries (cowberry, bilberry, and crowberry) and mushrooms (boletus, milk cap and russula) were collected from Central and Eastern Lapland. Berry samples were also collected from the Russian side.

Long-range transport has a major impact on heavy metal deposition in Lapland

Heavy metal emissions from the Kola Peninsula have not decreased as expected

Long-range transport from outside Finland, especially from the mining industry of the Kola Peninsula, has a greater impact on heavy metal deposition in Lapland than Lapland's own emissions. Heavy metal emissions from the production facilities of the Pechenga nickel mine near the Finnish border have fluctuated depending on production volumes. The concentration plant and roasting plant at Zapolyarny and the smelter at Nikel mostly emit nickel and copper into the air. The nickel emissions of the factories decreased in the 1980s by over 500 tonnes to 300 tonnes and the copper emissions by about 300 tonnes to 200 tonnes, since when no significant decrease has occurred in emissions (Paatsjoki programme 2008). Most of the metals reach the ground within 10 kilometres from the smelters. Deposition decreases rapidly with distance. Emissions from the smelters are transported mainly to the north and north-east, but east winds also spread heavy metals all the way to Lapland.

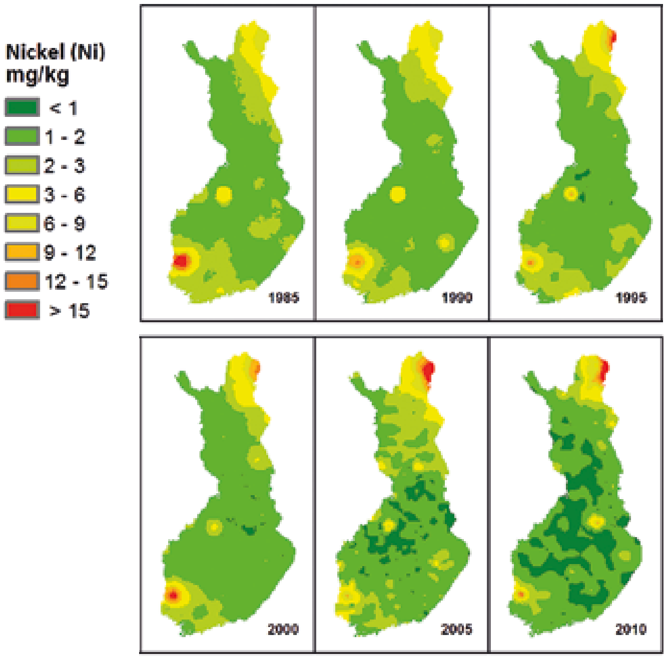

Fig. 1. Nickel concentrations in mosses in Finland, 1985-2010. Maps Jouni Karhu.

Nickel emissions from the Kola Peninsula can be seen in moss samples as higher than background concentrations roughly on a line between Salla and Angeli (Metla, MetINFO 2012). Relatively high concentrations of nickel have been observed only in the easternmost parts of Inari. In 2005 and 2010, concentrations increased near the border to higher levels than in previous years (Figure 1). This indicates a rise in emissions, which is also confirmed from periodical measurements of high concentrations of nickel in wet deposition at Svanvik, Norway in 2005 - 2010 (Grenseområdene Norge-Russland TA 2838/2011). In 2010, the highest nickel concentrations in mosses were about 40-90 mg/kg close to the border, about 10 mg 20 - 30 kilometres from the border, and only about 5 mg/kg around the Inari urban district (Figure 1). In western Lapland, they were at the same level (1-2 mg/kg) as in most of Finland. In Sweden, Estonia, and Scotland, concentrations in 2005 were generally less than 1 mg/kg (Harmens et al. 2008, 2013). Elsewhere in Europe, the concentration ranged from less than 1 mg to more than 15 mg per kg. In areas with concentrations of less than 2 mg/kg, nickel deposition belongs in the clean background class and is not really harmful to the environment. In contrast, the highest concentrations (> 15 mg/kg) in the region are usually within the vicinity of a large source of emissions, near which nickel deposition rises so high that it already has harmful effects.

On the basis of concentrations in mosses, copper deposition from the smelters on the Kola Peninsula has not changed a great deal over the years. The area affected by copper emissions, in which the concentration is greater than 5 mg/kg, has been reduced during the monitoring period, but in the eastern parts of Inari concentrations have in-

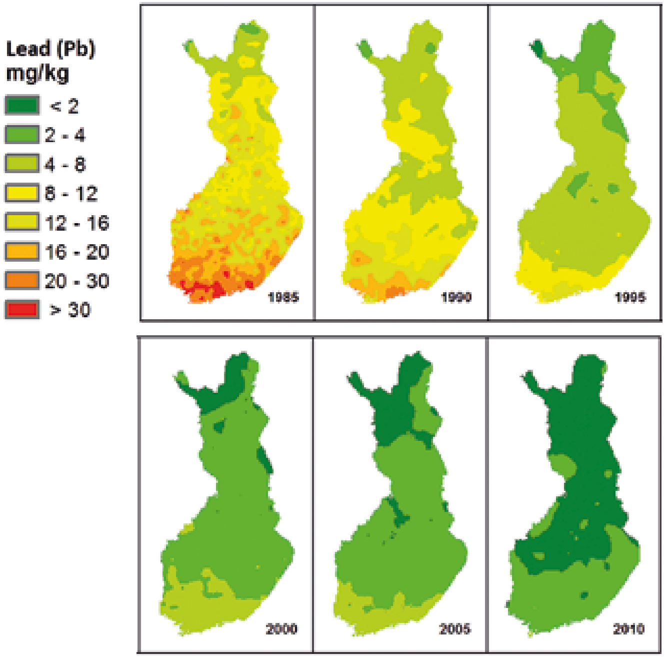

Fig. 2. Lead concentrations in mosses in Finland, 1985-2010. Maps Jouni Karhu.

creased in the most recent surveys. In 2010, the highest concentrations were about 30-50 mg/kg on the border. In southern and western Lapland, they were less than 5 mg/kg, i.e. at the same level as the rest of Finland with the exception of the Harjavalta region in south-west part of Finland. In these areas, the copper concentrations in 2005 were as low as, for example, in Sweden and Norway (Harmens et al. 2008, 2013).

Deposition of the most harmful heavy metals in Lapland is among the lowest in Europe

Heavy metals are transported to Lapland from the Kola Peninsula, but also from elsewhere in Europe and even from Asia. The ones that spread most easily are lead, cadmium, and mercury. However the effect of long-range transport and local emissions on their deposition in Lapland is at the present minimal. In particular, lead and cadmium emissions have been considerably reduced throughout Europe in the last 20 years, as cleaning technologies in emission sources have improved.

Lead is the best example of the impact of cleaning on emissions. The sale of leaded petrol ended in Finland and most other European countries in the early 1990s, and industrial lead emissions also decreased. As a result, the lead concentration in mosses decreased rapidly in the 1990s in almost all of Europe. The lead concentration in Lapland varied from about 2 mg to over 14 mg per kilo in 1985, but in 2010 the concentrations in Lapland were generally less than 2 mg/kg (Figure 2). Lapland, together with the northern parts of Sweden and Norway, is one of the cleanest areas in Europe in terms of lead deposition (Harmens et al. 2008, 2013). In most parts of western Europe lead concentrations in mosses in 2005 were less than 10 mg/kg, but in eastern and south-eastern Europe

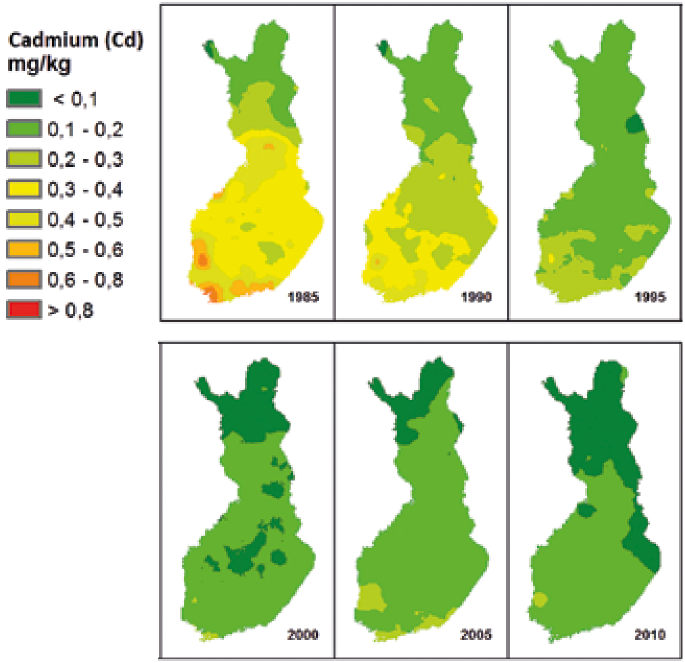

Fig. 3. Cadmium concentrations in mosses in Lapland, 1985-2010. Maps Jouni Karhu.

they rose in places to more than 30 mg/kg. In those areas, the deposition of lead, especially in urban areas, is so high that it may have effects on human health.

Efforts to reduce emissions of cadmium from industry and to ban the use of cadmium e.g. in dyes and coatings have also reduced cadmium depositions. Cadmium concentrations in mosses in Finland fell throughout the 1990s, but since then there have been no major changes (Metla, MetINFO 2012). In 2010, in Lapland, concentrations generally remained below 0.10 mg/kg and even the highest concentrations were under 0.20 mg/kg (Figure 3). These are the lowest concentrations to be measured in Europe, but the difference compared with western European countries is not very large (Harmens et al. 2008, 2013).

Mercury is an unusual heavy metal that occurs as a liquid at room temperature, but mainly in gaseous form in the atmosphere. Thus it is carried by air currents for thousands of kilometres from emission sources. Some of the mercury in the atmosphere reaches the ground, from which it evaporates again when the temperature rises. However, moss concentrations in Lapland suggest that no significant accumulation of mercury occurs. Concentrations throughout the monitoring period have generally been below 0.05 mg/kg in Lapland and about 0.05-0.15 mg/kg in southern Finland (Metla, MetINFO 2012). In the 2005 survey, mercury concentrations in other parts of Europe ranged from under 0.03 mg to over 0.20 mg per kg (Harmens et al. 2008, 2013).

Lapland's own heavy metal emissions are minor

Lapland has few major sources of heavy metal emissions that might have signif-

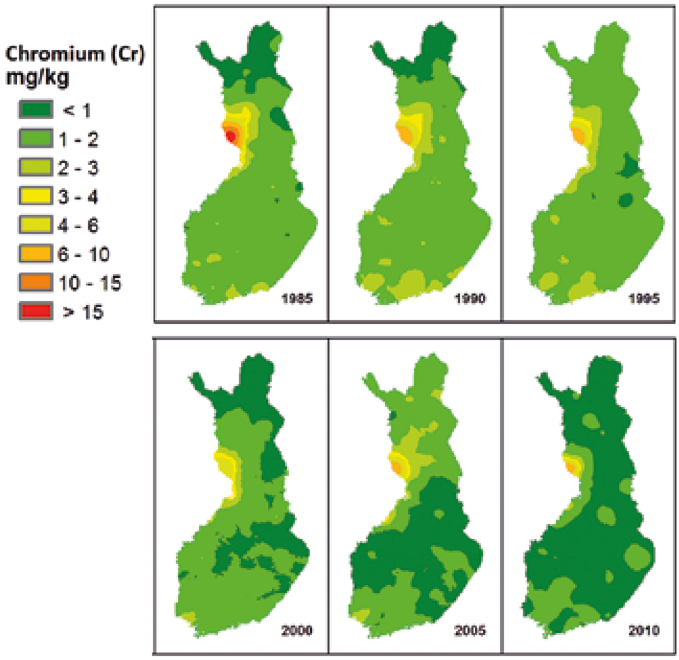

Fig. 4. Chromium concentrations in mosses in Lapland, 1985-2010. Maps Jouni Karhu.

icant effects on the state of the environment or on human health. The only sources of emissions worth mentioning are in the Kemi - Tornio region, where the greater part of Lapland's industrial production is concentrated. Of the industrial plants in this area, Outokumpu's Tornio steelworks has long been Finland's largest source of chromium emissions. However, chromium emissions to the air from the steelworks have decreased in the last 30 years from about 30 tonnes to less than 10 tonnes per year, despite increased production. In 2002, however, emissions of chromium increased for some reason to more than 20 tonnes. The factories also emit some other heavy metals, such as nickel, zinc, and mercury.

The chromium emissions from the steelworks have appeared in mosses throughout the monitoring period as moderate to high levels in the Tornio region (more than 10 mg/kg) and as lesser increases in concentrations as far as Central Lapland (2-6 mg/kg) (Figure 4). Concentrations have decreased during the monitoring period in Lapland, except in 2005. Above-average chromium emission in 2002 contributed to a significantly higher average in 2005, since concentrations in mosses are always analysed from the three years of growth preceding the year of collection. In 2010, the chromium concentration for almost the whole of Lapland was less than 1 mg/kg, but in the Tornio region the highest concentrations were still about 10 mg/kg. Chromium concentrations in other parts of Lapland resembles those in most of Sweden, Norway, and the Baltic countries, where the concentrations in 2005 were among the lowest in Europe (Harmens et al. 2008, 2013).

Concentrations of other heavy metals analysed in moss (iron, zinc, vanadium and arsenic) are low in Lapland and have fallen to varying extents in the past 25 years (Table 1). Their deposition is mainly due to Lapland's own emission sources.

The effects of heavy metal deposition on the state of the environment and human health in Lapland

Concentrations measured in mosses do not directly reflect the harmfulness of deposition. However, on the basis of moss concentrations, heavy metal deposition in Lapland, with the exception of the eastern parts of Inari and the bottom of the Bay of Bothnia, is among the lowest in Europe. This is also shown by deposition measurements from EMEP stations in northern Finland (Aas & Breivik 2011). Deposition in background areas has no significant harmful effect on the environment or on human health. Locally, concentrations may rise significantly above background levels, however, in the vicinity of industrial plants, heating plants, and landfills.

The forest damage project of the early 1990s in eastern Lapland found that in the eastern part of Inari, sulphur and heavy metal emissions from the Kola Peninsula smelters had caused, inter alia, damage to needles and epiphytic lichens, as well as changes in the soil. No obvious harmful effects on human health from heavy metals have been reported even from the Norwegian side of the Paatsjoki river valley, an area more densely populated than eastern Lapland with higher levels of heavy metal deposition. Heavy metals arrive from the Kola Peninsula only occasionally, which reduces heavy metal exposure.

Chromium emissions from the Tornio steelworks have also sometimes raised concerns for human health. Several chromium compounds, in particular, hexavalent chromium, are carcinogenic. However, chromium occurs naturally mainly as the trivalent oxide, which is not dangerous to humans and animals. In 2010, a study carried out in Tornio and Haparanda for the city of Tornio,

Table 1. Average concentrations of heavy metals in mosses in Lapland and whole Finland in 1985 – 2010

		As	Cd	Cr	Cu	Fe	Hg	Ni	Pb	V	Zn
		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
1985	Lapland	-	0.19	1.86	5.10	219	-	2.58	9.04	2.25	30.7
	Finland	-	0.37	1.49	5.99	379	-	2.24	15.50	4.76	38.1
1990	Lapland	-	0.16	1.64	5.16	234	-	2.58	6.70	2.54	31.3
	Finland	-	0.28	1.59	5.98	405	-	1.97	10.20	3.48	36.5
1995	Lapland		0.14	1.74	4.92	185	0.037	2.79	4.19	1.47	33.6
	Finland	0.26	0.18	1.54	5.28	331	0.053	1.94	6.22	2.39	38.4
2000	Lapland		0.10	1.29	3.81	124	0.033	2.62	2.30	0.81	24.3
	Finland	0.19	0.12	1.25	3.96	259	0.048	1.83	3.37	1.45	28.8
2005	Lapland		0.11	1.91	4.29	129	0.025	3.73	1.97	0.80	27.9
	Finland	0.12	0.15	1.13	4.11	236	0.044	1.87	2.96	1.43	32.9
2010	Lapland	0.072	0.08	0.97	5.10	130	0.039	4.00	1.44	0.73	28.2
	Finland	0.103	0.11	0.94	4.70	235	0.043	2.32	2.01	1.10	30.7

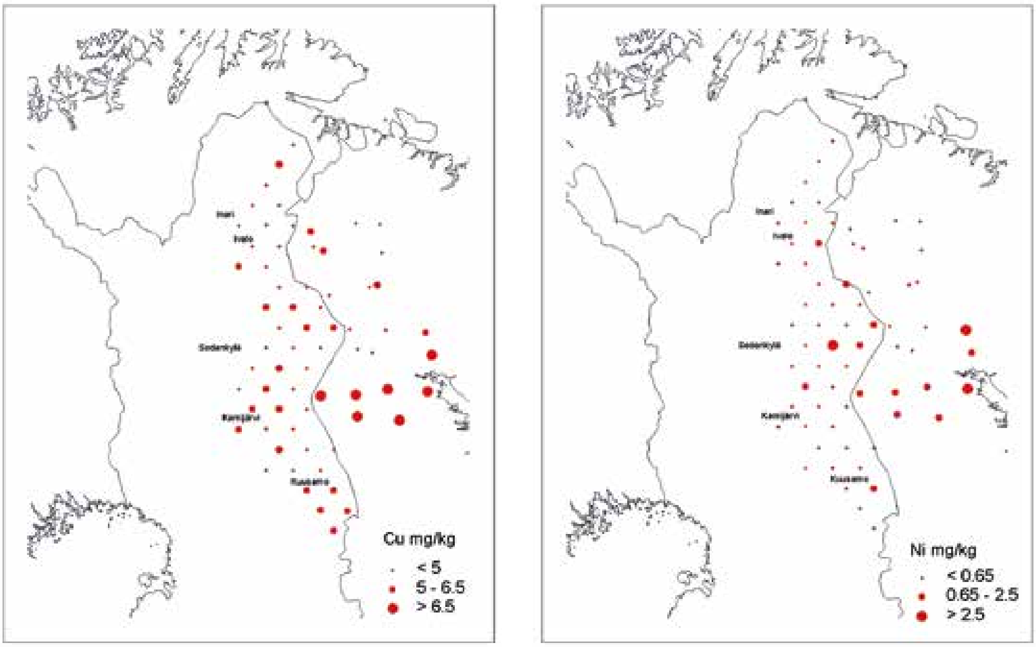

Fig. 5. Copper and nickel concentrations in cowberry (Vaccinium vitis-idaea, mg/kg dry weight) in eastern Lapland and the western Kola Peninsula (Paatero et al. 2008).

showed that cowberries collected in the Tornio and Haparanda areas may be eaten without risk of poisoning (Virtanen 2011). However, picking cowberries from the immediate vicinity of Outokumpu's Tornio steelworks is not recommended, although the concentrations even there (about 10 mg/kg), do not exceed the limit values for chromium concentrations in natural products.

Emissions from the Kola Peninsula do not affect heavy metal concentrations in Lapland berries and mushrooms

Although concentrations in mosses reflect heavy metal deposition, similar correlation is not necessarily visible in other plants and fungi in the same location. For example, copper and nickel concentrations in cowberry (Figure 5) clearly show that the concentrations observed are not related to the distance from the Kola Peninsula smelters at which the samples were collected. Small and large concentrations may be found from both the Finnish and the Russian sides.

Nor do copper and nickel concentrations measured from mushrooms show a clear correlation with Kola Peninsula emissions (Figure 6); rather, the concentrations are most likely indicative of local soil chemical composition.

The copper and nickel concentrations found in mushrooms and berries are generally very small. In terms of fresh weight, even in the sample plots where the heaviest concentrations were measured it would be necessary to eat several kilos of picked mushrooms or berries every day before the accepted safe limits

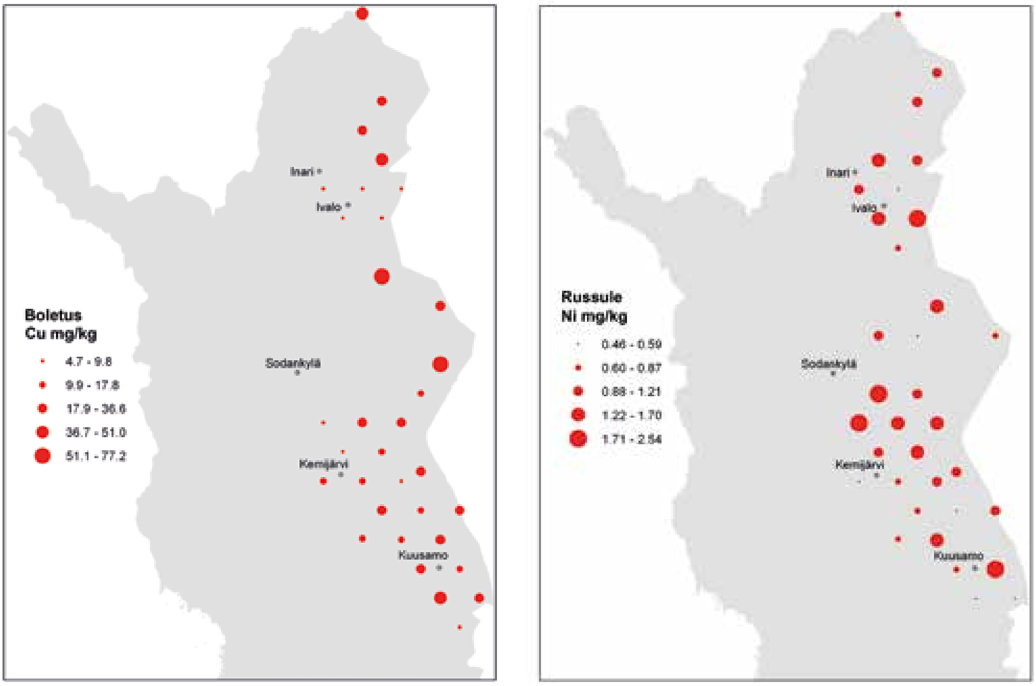

Fig. 6. Copper and nickel concentrations in mushrooms (left: boletus, right: russula, mg/kg dry weight) in eastern Lapland. Maps Kari Mikkola.

for copper and nickel would be exceeded.

No serious threats apparent in the near future

There is no evident prospect of new threats in the near future that could have wide-ranging effects on heavy metal deposition in Lapland. Certainly, heavy metal emissions from the mining industry of the Kola Peninsula will continue to have adverse effects on the environment in the eastern parts of Inari, unless the production facilities can be renewed. Heavy metals have accumulated in the soil throughout the operation of production facility and it will be a long time before concentrations decrease, even if emissions from these facilities are reduced. Plans to modernize the production facilities at the Pechenga nickel mine have been around for a long time, but the improvements have been delayed from year to year even though, for example, Norway has offered to provide funding for modernization.

Heavy metal emissions to the air from the mining industry are likely to increase in northern Finland. There are currently several new mining projects in Lapland as well as planned extensions to existing mines (Riihimäki 2011) which will affect future heavy metal deposition in the region. Dust emissions from mines have mainly local effects on heavy metal deposition. The greatest environmental damage is caused by mine drainage water entering the waterways.

Tourism and new mines will cause increasing traffic on the roads of Lapland. Dust spreading from roads contains a wide variety of compounds emitted from cars and the road surface. Car exhausts, tires, and wear and tear on metal components will spread heavy metals along the roadsides, including zinc, cadmium, copper, nickel, chromium, and lead, as well as the so-called platinoids, used in catalytic converters to control emissions. The amount of heavy metals on roadsides is directly proportional to the volume of traffic. Concentrations are highest on the verge, but fall away rapidly within a few tens of meters from the road. Vehicular emissions mainly cause restrictions on picking berries and mushrooms in the vicinity of roads. In picking wild berries, it is recommended that the distance from main roads should be at least 100 meters, from dusty village roads and forest roads at least 50 meters, and from other roads 10 - 50 meters depending upon traffic density, quantity of dust, and possible protection from trees.

Conclusions

A 25-year time series based on moss samples shows that as a rule, heavy metal deposition in Lapland is at a low level, and that concentrations of most metals in mosses have fallen over the years. The decrease in lead concentration in mosses has been particularly strong, owing to the ending of leaded petrol sales in the early 1990s.

Emissions from the Kola Peninsula mining industry raise nickel and copper concentrations in mosses to moderately high levels in the eastern parts of Inari, but the concentrations fall away rapidly towards the west. There has been no decline in concentrations over the years; they have even risen in recent years in the vicinity of the border. Emissions from the Kola Peninsula do not appear to affect heavy metal concentrations in the edible berries and mushrooms of Eastern Lapland. Their concentrations reflect rather local soil and bedrock properties.

The Tornio steelworks has long been Finland's largest source of chromium emissions. Judging from concentrations in mosses, chromium deposition has decreased in Lapland, so that relatively high concentrations of chromium are now found only in the Tornio region. Chromium from steelworks emissions occurs in nature mainly in the form of a trivalent compound which is not a health risk to humans.

There is no evident prospect of factors that might significantly increase heavy metal deposition in Lapland in the near future. New mines will increase the heavy metal load from local dust emissions into the air. The greatest harm to the environment is caused by mine drainage water entering the waterways. Tourism and new mines will cause increasing traffic on the roads of Lapland, increasing the amount of heavy metals on roadsides.

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The purest reindeer, game, and fish from changing Lapland

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Abstract

Lapland's scenery and environment are fragile and threatened by pollution. As a result of reindeer grazing, fell areas, large national parks and nature reserves, and wilderness areas are very worn, sometimes more than areas outside them. Grazing has been the biggest factor in changing vegetation and has caused erosion in some areas. The condition of winter pastures and their continual change for the worse show that maintaining the current number of reindeer is no longer possible with natural winter food. Reindeer and moose meat are not organic products, and reindeer husbandry based on feeding and heavy technology now has a large environmental impact and carbon footprint. Meat produced on natural pastures is rich in protein, minerals, and vitamins, with low fat content and an excellent fatty acid composition.

In Lapland, the concentrations of heavy metals have been greatly reduced. Cadmium levels in reindeer, moose, and mountain hare meat are low and close to the limit of quantification (0.001 mg/kg fresh weight). The cadmium concentration in reindeer liver has fallen further and is now below the recommended limit (0.5 mg/kg). However, cadmium concentrations in adult moose liver and kidneys exceed the recommended limits. Cadmium levels in the liver and kidneys of mountain hare, and farther south also brown hare, are too high. The lead concentration of reindeer meat is low and that of reindeer and moose liver and kidneys has decreased and is below 0.05 mg/kg. Reindeer meat has high selenium concentrations, especially in the northern part of the reindeer herding area.

In Lapland, mercury concentrations in pike are lower than in Finnish Lakeland. In lakes and also in the Tornio River, it is less than 0.5 mg/kg fresh weight. Mercury levels in whitefish and Arctic char are also low, and the concentration in vendace from Lake Inari is on average only 0.16 mg/kg. Vendace from Inari and Arctic char from Lapland also contain some dioxins and furans, while dioxin concentrations in Tenojoki River salmon are significantly lower than those in Baltic salmon. The meat of adult reindeer and moose contains small amounts of dioxin and PCBs; in reindeer calves the toxic equivalent (TEQ) averages 3.2 pg/g fat. The concentration of caesium-137 in moose and reindeer meat is under 100 Bq/kg fresh weight. On better lichen pasture in Kuhmo, the concentration in wild forest reindeer has been 1,000 Bq/kg, and in Suomenselkä up to 3,000 Bq/kg. Salmon from the Tenojo-

ki River, and from the Tulomajoki River of the Kola Peninsula, have the caesium-137 concentrations of less than 0.3 Bq/kg. The concentration in salmon rising from the Baltic Sea to the Kemijoki, Simojoki, and Tornionjoki rivers is 30 to 60 Bq/kg.

The purity of Lappish reindeer, game, and fish in a nutshell

- Several research groups and authorities follow concentrations of pollutants in reindeer and game meat, natural grazing, and wild fish.
- Concentrations of heavy metals in the meat of a number of game animals have decreased significantly, close to the limit of quantification. However, concentrations in the viscera of some game animals are above the recommended values.
- Concentrations of heavy metals in wild fish are lower in Lapland than in southern Finland.
- In Lapland, radioactivity in moose and reindeer meat is well below the recommendations for use.
- The growth of reindeer husbandry has led to excessive erosion of natural pastures in some areas.

Keywords

Lapland environment, reindeer herding and conservation areas, reindeer, game and fish, heavy metals, environmental toxins and caesium-137

Preface

In speaking of the northernmost regions of the Earth we usually mean the Arctic area, defined, for example, in terms of temperature (June +10°C isotherm), permafrost, sea ice, the tree line, the Arctic Circle, or even the homelands of indigenous peoples (AMAP 1997). Finland does not contain any specifically Arctic areas, and permafrost is found only in a few palsa mires in Lapland. Politically, the Arctic region is defined as lying north of the Arctic Circle (66° 32'N), although an important part of Finland belongs in scientific terms to the subarctic climate zone. In the north, the tree line often shows a clear transitional zone from southern forest to treeless tundra. The tree line follows the climate zone in which cold Arctic and warm southern air masses meet. In Lapland, the tree line is formed from pine while elsewhere spruce generally grows farther north than pine. The mountain birch zone lies to the north of the coniferous forest, before the treeless tundra. In winter, the forest area provides important shelter and food for many animals, such as reindeer and moose.

The environment of the Arctic region, and of Lapland, is fragile and threatened by pollution. Key problems include increased traffic and the environmental impact of increasing resource exploitation, erosion of reindeer pasture, decreasing biodiversity, long-range deposition of heavy metals and environmental toxins, nuclear safety, and climate change, with its many potential effects (Lappi Ympäristön Tila [State of the environment in Lapland] 2008).

The sensitive vulnerability of the northern environment is related to the specific conditions in which plants and animals must survive. The number of species capable of surviving in the region is limited by cold, drought, quantity and quality of light, strong seasonal variations, and the short growing season. The transport of environmental pollution is influenced by the global climate system, in which air and sea water warmed in southern regions cool when they reach the Arctic and Lapland. Moisture content falls to earth as rain or snow, carrying with it the impurities carried in the air. Pollutants are carried by melt water to plants and further into food chains. In Lapland, food chains are fairly simple, the best known being the lichen-reindeer-human food chain. In order to survive the cold, dark winters, animals gather and store energy in fats. Many environmental toxins are fat-soluble and easily accumulate in food chains. An example is provided by the effect of PCB on birds of prey and the breeding problems of the Baltic Sea seals in the 1970's and 80's.

Lapland has a tradition of fishing in lakes and rivers, reindeer herding, and commercial hunting of grouse in the north. Today, more than 130,000 local people and 260,000 guests practice recreational fishing. The yearly fish catch is about 3.5 million kg, with a value of more than 5 million euro. For example, there are still 15-20 commercial fishermen on Lake Inari. The importance of hunting in Lapland is nowadays more social and cultural. There are about 31,000 hunters, and thousands of guests also hunt in the region. The most important game animals are moose, mountain hare, grouse, bean goose, and water fowl. The total value of the annual catch is 3-8 million euro, mainly depending upon the varying number of moose killed. Of Lapland's close to 10 million hectares of forest, about half is also suitable for forestry, and the average amount harvested each year is approximately 4 million m^3. Wild berries, mainly cowberries, bilberries and cloudberries, as well as mushrooms, are collected in large quantities for personal use and for sale. About a third of Finnish wild berries are collected in Lapland. Nowadays, Lapland has a lot of tourism companies and ski resorts, which operate almost all year round. The mining industry has also grown in recent years. Reindeer herding is still an important business that supports many jobs in Lapland and northern Finland.

In this paper, I deal with the natural conditions and the state of the environment in northern Finland and Lapland. Attention is drawn to the condition of reindeer grazing in the reindeer herding area and also of many conservation and wilderness areas, as well as changes in livelihood. Particular attention is paid to the sensitive and vulnerable environment of the north and the potential effects of pollution and climate change. I present earlier results on concentrations of heavy metals, organic environmental toxins, and radioactive caesium-137 in reindeer, game and fish. The results are compared with corresponding concentrations in other parts of Finland and the Nordic countries.

Nature, reindeer herding, and protected areas in Lapland

Lapland is the northernmost part of Fennoscandia. Here, Finnish Lapland is usually meant although in wider terms Lapland also includes the northern parts of Sweden, Norway and the Russian Kola Peninsula. Lapland is the largest province in Finland, comprising about 29% of the country's surface. It can be divided into southern, central and northern Lapland. The boundary between the middle and northern boreal climate zones runs through southern Lapland, with the south-western corner of the province belonging to the middle boreal zone. The northern boreal zone covers the rest of the province of Lapland. The north-west of Enontekiö, or the fells of Käsivarsi (north-western Lapland, between Sweden and Norway), are within the dwarf plant area of the hemiarctic zone.

Lapland's most favourable climate is in southern Lapland, on the coast of the Bay of Bothnia and near Sea Lapland. The fell area of Salla is already continental and the most inhospitable region of southern Lapland. Central Lapland is the most continental part of Finland, being located far away from both the Gulf of Bothnia and the Arctic Ocean. Typical of the region are extensive aapa mires and large river valleys. These cover up to 60% of the area. There are a few natural lakes in Central Lapland, but the northern parts of the area contain the large reservoirs of Lokka and Porttipahta. The largest fells are Ylläs and Pallas in the west and Sokosti in the northeast, to the south of Saariselkä. Northern Lapland is dominated by extensive fells, of which the most rugged are the high fells of Enontekiö. The large Lake Inari and its surrounding shallow shore areas make up their own special area. Northern Lapland also has major valleys, carrying rivers such as Ivalojoki, Inarijoki-Tenojoki, Utsjoki, and Könkämäeno-Muonionjoki. In the vicinity of the Arctic Ocean, in the north-western part of Enontekiö and around Utsjoki, the climate already has marine features.

The zero boundary for average annual temperature runs across southern Lapland. In Central Lapland, the average temperature drops almost two degrees when approaching Kittilä and the northern part of Sodankylä. In northern Lapland, in the environment around Lake Inari and in the northern part of Utsjoki it is a little milder, with an average temperature of around -1 °C. The coldest place is usually Enontekiö, where the average temperature is often as low as -3 °C. Yearly precipitation in southern Lapland is 500-600 mm, with the lowest figure on the Bay of Bothnia coast and in the Torniojoki and Tenniöjoki river valleys, and the highest among the tree-covered hills of Ranua and Poiso and the fells of Salla. Central Lapland often receives 450-550 mm of precipitation, and the southern edge of Saariselkä about 600 mm per year. The driest areas are the large river valleys of Ounasjoki and Kitinen while the highest precipitation is found among the fells. Northern Lapland usually receives 400-550 mm of rain, but the fells of Käsivarsi 600-700 mm yearly.

The reindeer herding area comprises the province of Lapland and part of the former county of Oulu, and has a surface area of about 122,890 km^2 of which 115,500 km^2 is land. The area is about 36% of Finland's surface area. There are 56 reindeer herding cooperatives, and fewer than 4,600 reindeer owners. There are about 550 households in full-time reindeer husbandry and 250 part-time. The maximum permitted number of living reindeer is 203,700, and the amount of reindeer meat produced annually is 2-2.5 million kg. The reindeer herding area is located quite far north, between 65 and 70 degrees north latitude. In northern Siberia, northern Canada and Alaska, conditions at the corresponding latitudes are already very arctic. The warm Gulf Stream makes the climate milder throughout north-western Europe and in northern Finland it is calculated to raise the annual average temperature as much as 11 °C. The prevailing winds are favourable, blowing predominantly from the southwest, while the Köli Mountains provide shelter from winds blowing from the Arctic Ocean. The slopes in Lapland also often face in a favourable direction, from the viewpoint of growing conditions. Reindeer have free grazing rights over the whole reindeer herding area regardless of land ownership or tenure (Act on Reindeer Husbandry, 1990), and reindeer herding is also allowed in conservation areas with the exception of Malla nature reserve in Käsivarsi.

The annual average temperature over the extensive reindeer herding area is about 0 °C. However, there is considerable seasonal variation, and the climate becomes increasingly extreme towards the north. In July, the maximum temperature averages 12-16 °C while January averages an equal amount of frost. The Finnish cold record, -51.5 °C, was measured on 28 January 1999 at Pokka, in Kittilä. The effective temperature sum (more than +5 °C) used to describe growth conditions is about 1,000 d.d. (degree days) in the southern parts of the reindeer herding area, and in northern Lapland only 400-700 d.d. In the higher regions at the bottom of Käsivarsi, daily heat seldom reaches this limit. The thermal growing season (average daily temperature greater than +5 °C) is 100-145 days in the reindeer herding area.

The annual precipitation in the reindeer herding area is 300-550 mm, and 40-60% of precipitation falls as snow. The climate is humid, and the low temperature means that evaporation even in summer is usually less than the amount of precipitation. As a result, there are many swamps in the reindeer herding area, covering well over one-third (34.5%) of the land area (Nieminen 2008). Permanent snow cover in the reindeer herding area usually lasts 5-7 months, and longer in the fell areas. Maximum snow depth is nearly a meter, and even more in the forested eastern hills. Snow is a good thermal insulator, under which, for example, lichen does not freeze even in the coldest weather. Under the snow, the temperature rarely falls below -2 °C. As is common in extreme areas, the temperature and the depth and duration of snow cover vary considerably from one year to another. Winds in Lapland are about 40% from the south and south-west in winter and 10% in summer.

The reindeer herding area alone has 620 protected areas (total area 31,830 km^2) under the control of Metsähallitus (Finnish Forest and Park Service). There are a few private protected areas. The protected area covers about 28% of the reindeer herding area and 30% of the surface area of Lapland. For example, conservation areas cover about 14% of the total. Although the number of protected areas declines from south to north, their surface areas increase. Eighty percent of Fell Lapland are already protected to some degree. In Inari, 53% of forest land is protected. Seven national parks in the reindeer herding area cover 81% of the combined surface area of Finland's 35 national parks. Finland's largest national parks, Lemmenjoki (2,856 km^2), Urho Kekkonen (2,541 km^2) and Pallas-Yllästunturi (1,020 km^2), are located in an area set aside especially for reindeer herding. In northern Finland, only the Bay of Bothnia National Park, covering the outer archipelago of Tornio and Kemi, lies outside the reindeer herding area, and of its surface area of 157 km^2 only 2.5 km^2 is land. National parks elsewhere in the reindeer herding area are Pyhä-Luosto and Oulanka (both 142 km^2), Riisitunturi (77 km^2) and Syöte (294 km^2) (Nieminen 2010).

There are 10 nature reserves in the reindeer herding area (total surface area 1,426 km^2), covering about 93% of all Finland's 19 nature reserves. Paljakka (30 km^2) extends only partly into the reindeer herding area on the southernmost Halla reindeer herding cooperative. Nature reserves are more strictly protected, and recreation and free movement are not allowed elsewhere than in Kevo, Malla, Sompio and Paljakka nature reserves. These reserves have public trails, from which visitors cannot turn off, as in national parks. Founded in 1938, Malla (30.5 km^2) is one of Finland's oldest nature reserves and is now also the only conservation area that is closed to reindeer husbandry. The fencing of Malla, and its protection from reindeer, is currently being planned. In nature reserves, all construction without a permit, and all activity that might damage or disturb the environment, is prohibited.

In 1991, 12 natural wilderness areas were set up specifically for reindeer herding in order to protect traditional sources of livelihood. In order to preserve the character of the wilderness, road construction in these areas is prohibited, but natural forest management, or thinning, is allowed. Nowadays, there is no commercial forestry in wilderness areas.

Data and research methods

Since the 1970s, the Finnish Forest Research Institute (Metla) has systematically studied the condition of heathland pasture in the whole reindeer herding area in connection with the National Forest Inventory (NFI), (Mattila 1981 2006a and b, Mattila & Mikkola 2008). Since 1995, the Finnish Game and Fisheries Research Institute (FGFRI) has inventoried the condition of lichen pastures, mainly in the northern part of the reindeer herding area, and has also examined summer pastures using satellite image interpretation (Kumpula et al. 1997, 1999, 2009). Research has also been conducted in the condition of conservation and wilderness areas, as well as changes in reindeer husbandry and the development of supplementary feeding (Nieminen 2006, 2010).

The heavy metal content of lichens has been clarified in several investigations for FGFRI (Nieminen & Heiskari 1989 Lodenius & Nieminen 2000), and concentrations in moss in Metla monitoring studies (Kubin et al. 2000). Concentrations of heavy metals and organic environmental toxins in reindeer, game (mainly moose and hare) and fish have been measured by the Finnish Food Safety Authority (Evira) (Venäläinen 2007, Suutari et al. 2012) and FGFRI (Nieminen 1989, Nieminen et al. 1989, Vuorinen et al. 1997). The Radiation and Nuclear Safety Authority (STUK) has monitored radioactivity levels in food since the 1960s (Saxén et al. 2003). Since 1993, the Finnish Environment Institute has monitored the concentration of man-made pollutants in the Arctic region and in Finnish Lapland (AMAP 1997, AMAP II 2002).

Changes in pastures and reindeer herding

Reindeer use up to 350 different food plants, favouring fresh plant foods in summer pastures, which offer the best levels of nutrients (Nieminen & Heiskari 1989). Nutrition affects reindeer growth and the good composition of reindeer meat. Daily grazing time increases from ten hours in late spring to nearly twenty hours in summer. In summer, reindeer eat a lot of leaves from mountain birch and dwarf birch as well as willow. One reindeer is estimated to eat about 25 kilos (dry weight) of birch leaves during the summer. Prolonged and intensive summer grazing greatly reduces the leaf biomass of birches, willows, and bog bilberry, and the result in the fell area is often an "apple-tree" birch forest with birch leaves growing only above 120-150 cm. Loss of shoots also occurs in bog bilberry, dwarf birch, and willow owing to continuous leaf-eating (Kumpula et al. 2004a). Birch shoots growing from tree stumps provide a popular food for reindeer. Intensive long-term summer grazing, especially in fell areas, has an impact on the structure and renewal of mountain birch forests. In Norway, it has also been found to affect grouse populations. In areas with strong and continuous reindeer grazing, birch forests do not regenerate. However, bilberry, wavy hair-grass, and herbaceous plants can proliferate despite intensive summer grazing.

Also, in some places in the fell areas, the caterpillars of the autumnal moth (*Epirrita autumnata*) and winter moth (*Operophtera brumata*) have destroyed birch forests in recent years. A lot of birch forest was destroyed by the autumnal moth as early as 1965-66 at Utsjoki (about 600 km^2), and in 2003-05 in the Kilpisjärvi area (34 km^2). During the period 2006-07, the winter moth caused extensive damage at Utsjoki, in the Nuorgam and Polmak areas. Altogether geometric moth caterpillars have destroyed nearly 2,500 km^2 of the birch forest around Käsivarsi and Utsjoki. This destruction in turn negatively affects reindeer herding since recovery is slow. For example, of the beech areas destroyed earlier at Utsjoki, half have not yet recovered; these areas remain treeless and bare. Changing climate may cause fresh and widespread birch destruction to occur in future.

In places, marshlands provide important reindeer grazing areas throughout the year; they provide especially important pasture for both moose and reindeer during the summer. There are about 4 million hectares of swamp in the reindeer herding area, or 35% of the land area (Nieminen 2008). For example, in the fell areas and Inari basin, around Lake Kemijärvi, and in western Lapland, there are areas where the marshes make up only 10-20% of the land area. The most important summer pastures for reindeer are the marshes, alluvial meadows, and mountain birch forests of the northern boreal zone. However, more than 20% of swamps in Lapland have already been drained. The best areas for drainage are often also the best for reindeer grazing. After drainage, important food plants for moose and reindeer, such as marsh trefoil, marsh cinquefoil, water horsetail and sedges have either decreased or disappeared completely. These changes have led to a vegetation cover chiefly of bilberry and cowberry, in which the share of sedges and grasses has declined sharply. The significance of clear-cut logging areas as both summer and winter pasture has increased in recent decades. In the central and southern parts of the reindeer herding area, clear-cut logging areas are among the most important summer pastures for reindeer. In ploughed areas, the principal plant species are more often dwarf plants than in clear-cut logging areas.

Mushrooms provide rehabilitation and fattening feed for reindeer, and partly for moose, in late summer and autumn. Mushrooms are rich in easily digestible proteins, sugars and other carbohydrates, as well as minerals and vitamins. Particularly pleasing to reindeer are very high protein and easily digestible boletus (*Boletus* sp.), but reindeer also eat a lot of milk caps and Russula. Red fly agaric mushrooms also appeal to reindeer (Norberg et al. 1995).

In winter, reindeer graze mostly on moorland, of which there are nearly 7 million hectares in the reindeer herding area. The quantity of moorland increases towards the north, and for example, at Utsjoki it forms as much as 85% of forest, scrub, and waste land. In the late 1990's we still had about 1.8 million hectares of actual lichen grazing in the whole reindeer herding area (15% of the land area). Lichens (*Cladonia*, *Cladina* sp.) are everywhere an important source of energy for reindeer in winter. Reindeer prefer to eat the *Cladonia rangiferina* and *Cladonia stellaris* lichens, which are common throughout the reindeer herding area (Danell & Nieminen 1997). In some circumstances, reindeer also eat *Stereocaulaceae* and *Cetraria nivalis*. On good pasture, the reindeer rumen contains as much as 85% easily digested lichen in winter and 5-20% even in summer. On worn lichen pastures, the share of lichen falls below 15%.

The tree-growing beard lichens (*Alectoria* and *Bryoria* sp.) provide emergency food for reindeer in the coniferous forest area, especially in late winter, when drifting snow prevents them digging for other lichens. The reindeer eat black and grey beard lichen from spruce and pine trees, Wila from the best lit pine stands, and witch's hair (*Alectoria sarmentosa*) from old spruce copses. On the snow-free ridges of the fells, reindeer also eat ground-growing *Alectoria nigricans* and various forms of lichen from the trunks of mountain birches. The most important beard lichens are *Usnea dasypoga* and *Usnea hirta*. In the central and southern parts of the reindeer herding area, reindeer also dig in felling sites for wavy hairgrass (*Deschampsia flexuosa)* in the winter.

Especially in the northern parts of the reindeer herding area, intensive reindeer grazing has led in many places to the almost complete disappearance of lichen cover. Grazing has reduced the amount of circulating nutrients in the organic layer by 30-60%, and only substantial supplementary feeding with hay adds nutrients to the soil (Väre et al. 1996). Grazing and trampling have also changed the landscape and caused erosion in some areas (den Herder et al. 2003). Lichen pastures had most lichen in the late 1990s in the reindeer herding cooperatives of northern Lapland and in Halla, Kainuu (Kumpula et al. 1999). Lichen was easily found only at Inari, from the lichen pastures of Paatsjoki, Vätsäri, and Muddusjärvi. However, a new inventory in 1999-2003 showed a decrease in the amount of lichen at all Inari reindeer herding cooperatives with the exception of Näätämö, and also at Paistunturi, Utsjoki. In reindeer herding cooperatives of the central area, the condition of lichen pastures was still poor (Kumpula et al. 2004b).

Fig. 1. In the reindeer husbandry area and also in national parks, strict nature reserves, and wilderness areas, the lichen pastures are generally strongly or very strongly worn (lichen biomass < 100-300 kg dry weight/ha). Lichen is abundant only in small enclosed areas unaffected by grazing reindeer, as in the picture from the Muotkatunturi reindeer-herding cooperative (lichen biomass > 8,000 kg/ha). Photo Mauri Nieminen.

During the period 2005-07, inventories showed the continued degradation of lichen pastures in lichen-bearing podsol in almost all the northern and central reindeer herding cooperatives. The quantity of lichen had decreased greatly in the northern part of the reindeer herding area (Kumpula 2009). Inventory data from Metla showed that the condition of lichen pastures had collapsed in dry peaty forests over the whole reindeer herding area. Over the past 25 years, old-growth forests had been reduced by 28%. There had also been strong regeneration in heaths, which was especially evident in the young forests in the centre of the reindeer herding area. In the central and southern parts, the quantity of lichen had fallen by 80-90% due to reindeer grazing. Even the highest average biomass for lichen on moorland was less than 50 kg dry weight/ha on the forest soil of the reindeer marking district of Sodankylä (Mattila 2006a). At Kainuu, the maximum biomass of reindeer lichen was below 400 kg/ha, and there was on average seven times less lichen than outside the reindeer herding area (Mattila 2004). Outside, there was also more *Cladonia stellaris* lichen, which is less able to sustain grazing. For example, fenced enclosures at Inari still had more than 8,000 kg and the Kola Peninsula more than 10,000 kg dry weight/ha of lichen (Figure 1).

The current condition of winter pastures and the continual change for the worse in the central and southern parts of the reindeer herding area show that maintaining the current number of reindeer is no longer possible with natural winter food (Mattila 2006a). Reindeer grazing has caused severe wearing on fells, and to conservation and wilderness areas (Nieminen 2010). One sign of worn winter pasture is considered to be spreading moss, which only the Svalbard reindeer is able to make use of even when starving. In northern parts, reindeer feed more on poorly digestible mosses and dwarf shrubs. The coarser food weakens the condition and dentition of reindeer (Kojola et al. 1993). Calf yields and carcass weights can be maintained in the north with supplementary feeding. A worn lichen pasture grows only 1-2 mm per year, and overgrazed lichen pastures need at least 7-15 years of recovery time before they can even withstand grazing. Without reindeer grazing, the drier forests on lichen-bearing podsols and the bare heights of fells above the tree line would be covered within 30 years in an almost uniform bed of lichen more than 10 cm deep. Such lichen pasture would grow at approximately 6 mm per year (Kärenlampi & Kytöviita 1988). Even if grazing were completely stopped, the recovery of our existing lichen pastures to a more productive condition would take more than 20 years.

At the end of the 1990's beard lichen and beard lichen grazing were most common in the central and southern spruce stands of the reindeer herding area. There was about 9.6 million kg dry weight of beard lichen in the reindeer herding area. In the Inari area, the availability of beard lichen that reindeer could reach (at heights of under 2 metres) averaged only 1.3 kg/ha in dry and barren pine forests, 1.7 kg/ha in fresh and semi dry pine forests, and 5 kg/ha in spruce stands. In 1999-2003 beard lichen grazing areas had decreased most in those reindeer herding cooperatives that had the strongest forestry industry, and reindeer had limited access to beard lichen in all the herding cooperatives of Inari. In the reindeer herding cooperatives of Kaldoaivi, Vätsäri, and Lappi, there was very little beard lichen in the tree stands and available to reindeer (Kumpula et al. 2004b). In 2007, there was still very little beard lichen in the lichen-rich sample areas of the Inari reindeer herding cooperatives. In Fell Lapland, at Paistunturi and Kaldoaivi, beard lichen did not occur at all in the sample areas (Kumpula et al. 2009). At Lemmenjoki National Park, only 1-2 kg of beard lichen was within reach for reindeer in different heaths, with 5-18 kg at heights of 2-4 metres and 23-120 kg/ha for entire trees. At Pallas-Ounastunturi the amount of beard lichen within reach of reindeer was 3-4 kg/ha. At Oulanka National Park only 1-7 kg/ha of beard lichen was available to reindeer in different types of forest (Jaakkola et al. 2006). The annual harvest of beard lichen was earlier estimated as 15 kg/ha (Kuusinen & Jukola-Sulonen 1987), but only a part of this provides nutrition for reindeer. Even in the fine old beard lichen spruce stands and pine forests of Inari (320-420 kg dry weight/

ha of beard lichen for whole trees) only a little lichen fell to reindeer in winter. A female reindeer could live for just one day solely on the beard lichen from one hectare (1.4 -1.6 kg dry weight) (Nieminen 2007a).

As a result of reindeer grazing, mountain areas, large protected areas, national parks, nature reserves, and wilderness areas are heavily worn, in some places even more than outside areas (Nieminen 2010). Reindeer grazing has been the biggest factor in changing vegetation and causing erosion in nature reserves (Heikkinen & Kalliola 1989). Heikkinen (1997) believes that the wear on pastures at Kevo is particularly evident in vegetation on eskers, where the land is worn almost bare in some places. In the fell area too, the summer pastures are partly overgrazed and there are not enough suitable wetlands available to provide summer grazing (Colpaert et al. 2003). Nature conservation has had a little impact on the preservation of the natural environment even in nature reserves, the most strictly protected zones. As a result of overgrazing, the nature conservation values at Lemmenjoki National Park seem to be in danger, and protection has not been sufficiently effective especially on the side facing the Sallivaara reindeer herding cooperative (Nieminen 2010). Elsewhere in the reindeer herding area, at Oulanka National Park, the condition of lichen pasture is poor; in drier heaths there is less than 260 kg dry weight/ha of lichen. In recent years, the condition of lichen pastures has improved slightly, since 90% of the Alakitka reindeer are now kept in winter corrals. Earlier, an international panel of experts drew attention to wear and tear in conservation areas, stating that overgrazing by reindeer was the most serious threat. The experts' group recommended reducing the effects of overgrazing and encouraging sustainable use also in protected areas.

Climate warming is expected to be strongest in northern regions. The temperature will rise, especially in winter, and vegetation zones will gradually shift northwards. Precipitation will also increase, and in northern regions the amount of winter snow will evidently increase. The increase in temperature, and in particular the changing weather conditions in early winter, might also increase freezing of worn reindeer pastures. Reindeer food intake may thus in some places become even more difficult in winter due to increased snow cover and layers of ice. However, in the spring, snow will melt earlier than at present and conditions for reindeer will become more favourable.

Higher temperatures in spring and summer will extend the growing season, and evidently forest growth will accelerate. The amount of summer food available to reindeer will also increase, but the quality will deteriorate. Reindeer herding problems caused by insects will increase. In fell areas, birch damage caused by various geometrid moth caterpillars may become more common and even expand. Places in the fell area where snow continues to lie after winter, and which are important to reindeer, will lessen and disappear. There will also be a reduction in the lush summer food crops that grow around their edges, and reindeer will suffer increasingly from insect nuisance. The hot mid-summer and bloodsucking insects at worst may cause greater calf mortality and reduce the autumnal carcass weight (Weladji et al. 2002). Evidently also new parasites, such as the deer fly (*Lipoptena cervi*) will spread north, causing harm to reindeer and reindeer herding. Warm and rainy autumns may impair the reindeer rut and diminish reproduction. Climate change will also encourage other industries, such as tourism, forestry, and agriculture in northern areas. Other land use may increase, and reindeer grazing areas will contract even further. Climate change may thus have both negative and positive effects although there are as yet no obvious results of climate change in reindeer herding.

Wear and loss of grazing land has meant that supplementary feeding of reindeer has increased in the entire reindeer herding area, with the exception of North Salla, and it has become a major cost factor especially in southern and central areas. With supplementary feeding, reindeer can be kept in winter on old forest lichen pastures, or else they are tended in corrals. We use more than 40 million kg of reindeer feed, measured in dry hay. On this amount of feed, all living reindeer would survive for three winter months (Nieminen 2006). Feed costs alone amount to about 28% of the value of slaughtered reindeer (a total of about 15 million euros). Feeding has not been able to save winter pastures, and the profitability of reindeer husbandry is still poor.

Semi-domesticated reindeer are classified in the EU as game animals. Feeding has already changed the reindeer and reindeer herding, by reducing the dependency of the industry on winter pastures and natural conditions. It has also undermined free grazing rights. Feeding and taming nowadays bring reindeer increasingly close to built-up areas, roads, and courtyards, adding greatly to accidents and to some extent also to predator damage. Each year an average of 4,000 reindeer are lost in traffic alone and the compensation paid is greater than the total annual return from slaughter for all reindeer husbandry (Nieminen 2012). Neither reindeer nor moose meat can be considered an organic product (Figure 2). Feeding is not generally used for calfs intended for slaughter, but adult reindeer (almost 1/3 of those slaughtered) have already been in frequent feeding. In terms of environmental impact, reindeer husbandry based on feeding and heavy technology now leaves a large ecological footprint on worn-out pastures, while its carbon footprint is increased by fertilizers, feed production, and purchased feed, as well as various vehicles and other machinery.

Game meat is as ecological as mushrooms and forest berries and its carbon footprint can be calculated by multiplying kilometres driven per kilogram of game by a factor of 0.17. For example, if you are traveling from the south to Lapland for bird hunting, the carbon footprint for one kilogram of black grouse is easily more than for a kilogram of beef (15-20 kg of harmful emissions/kg). Catching wild fish reduces nutrients and eutrophication. Their carbon footprint is lower than that of farmed fish, although in Finland the carbon footprint for rainbow trout is only 1/6 of the carbon footprint for beef. In winter, a reindeer on easily digestible lichen feed (rich

Fig 2. About two million kilos of reindeer and moose meat are produced every year in Lapland. The chemical composition of meat from pure natural pastures is excellent. The concentrations of heavy metals, environmental toxins, and caesium 137 in meat are very low. Photo Mauri Nieminen.

in lichenins) would be almost one-bellied (like a pig), and would not require the rumination that produces so much methane gas (CH_4). Methane is a 25 times worse greenhouse gas than carbon dioxide (CO_2). Without expensive supplementary feeding, reindeer husbandry and its meat production would be more ecological and ethical than at present. The carbon footprint of reindeer would then be similar to that of hunted deer, and significantly lower than that of other ruminants. This would have great value for the image of all Finnish reindeer husbandry. Traditional methods and an EU designation of origin for Lapland reindeer meat would also be useful. Reindeer meat would then be better than organic, as "natural meat". Reindeer meat produced on natural pastures is high in protein, mineral, and vitamin content, with low fat content and an excellent fatty acid composition (Nieminen 1994 2007b)

Long-range deposition and heavy metals

Increasing human activities also increase the risk of environmental contamination in Lapland. Often, the widely differing circumstances of northern ecosystems make them very sensitive. If damage occurs in the wild, recovery is usually slow, or does not happen at all. The environment of Lapland also suffers at times from long-range transported heavy metals and organic environmental toxins. These are hardly produced in the area; they are mainly transported by air currents to Lapland, where they accumulate in northern food chains and finally reach humans through natural foods. Heavy metals and environmental toxins are already a health risk in some places, especially for people using a traditional diet. Preventing the movement of environmental toxins, and reducing their concentrations in northern ecosystems, will increasingly require international action.

In addition to long-range deposition, Lapland is also somewhat affected by emissions from within the region or from emission sources in its immediate vicinity. The growing use of natural resources, and related industries and traffic, increases overall environmental stress. The greatest source of stress is from the north, and especially the mining and metal industries of the Kola Peninsula. The risk of environmental contamination can best be reduced by using technologies and practices well suited to local circumstances. This has already been done in the Kola Peninsula region.

Lichens that grow on the ground or on trees differ from plants because they are formed from symbiosis between green algae and fungi. Lichen is now regarded as being more like a sponge than a plant. Lichens take water and nutrients directly from the air and grow from the tip. They grow very slowly, often only 2-3 mm per year. They are also sensitive to air pollution, and react to impurities e.g. in appearance, concentration, external damage, and biochemical or physical changes. In their growth spots, lichens collect from the air even substances that appear in small concentrations, such as heavy metals (including selenium). Like mosses, they can be used in measuring pollution and as so-called bioindicators in animals eating a natural diet (Tikkanen 1995). Mosses can also accumulate heavy metals, and as lichen eating decreases their incidence in the reindeer diet increases.

Heavy metals are metals with a density greater than 5 g/cm^3. They are elements that do not disappear from the natural cycle but may change their form. They occur naturally in rocks and soils, plants, and animals as minerals, ions dissolved in water, salts, or gases. They can bind to organic or inorganic molecules or adhere to particles floating in the air. Organic heavy metal compounds are fat-soluble and can accumulate in the fatty tissue of animals. From an environmental viewpoint, the most troublesome are cadmium, lead, and mercury. Copper, zinc, and iron are required as trace elements in living organisms. They can act as catalysts, enzymes, and building materials, and participate in photosynthesis and nitrogen fixation. However, excessive amounts of copper, nickel, and arsenic are poisonous.

Heavy metals are released into the atmosphere and water as a result of human activities, mainly fossil-fuel combustion, non-ferrous metal production, and waste incineration. To some extent, they are also released in volcanic eruptions. Heavy metal concentrations in the atmosphere are affected, among other things, by the season, distance from the source of emissions, wind direction, and local topography. In urban settings, heavy metals usually come from nearby areas. Concentrations in rural areas are smaller and often come from a distance, sometimes from the area's factories and mines. With increasing wind speeds, concentrations decrease but the materials spread faster and farther. Heavy metals are removed from the air through wet deposition, in snow and rain, or through dry deposition. Large amounts of heavy metals are also released through weathering. Heavy metals attached to soil particles or bottom sediment can return to circulation when conditions change. Acidification and peat land drainage also increase the release and circulation of heavy metals. In Finland, the total emissions of heavy metals decreased greatly in the 1990s. Emissions of lead and zinc decreased by about 90%, and chromium and vanadium by half. By 2002, lead emissions had decreased about 8-fold, and cadmium emissions more than 4-fold, but mercury emissions remained at almost the same level. The concentration of cadmium and other harmful metals in lake sediment decreased at the turn of the century by 20-40% (Mannio 2001).

Cadmium (Cd) is the most mobile heavy metal, and it accumulates more on land than in water courses. Soil contamination is often a serious risk in industrial areas. Cadmium is still used, for instance, in nickel-cadmium batteries, for the surface treatment of steel, in colour pigments, and in PVC plastics. As late as 1995, 50,000 kilograms of cadmium were used in batteries, the highest amount in the Nordic countries. In Finland, cadmium still enters the environment primarily from batteries and car wrecks. It also escapes from metal mining and manufacture, and phosphate fertilizers. In general, acidification increases the release of cadmium. From a food production viewpoint, it is significant if cadmium enters the fields directly with livestock manure, synthetic fertilizers, sewage sludge, and other organic waste. The cadmium levels in Finnish phosphorus fertilizers are the lowest in the world, since the raw materials are quite clean. Cadmium moving from fields to crops, animals, and humans creates only a small risk in northern Finland. In southern Finland, there is almost twice as much cadmium in the fields.

Although cadmium emissions have declined slightly in recent years, concentrations in organisms have increased. Cadmium and mercury also have a high tendency to accumulate in flue gases. This and their toxicity make them the most important heavy metal problems in waste incineration. Cadmium remains in the atmosphere for about seven days. A significant part of the cadmium deposition in Lapland comes from Central Europe. Cadmium generally accumulates in the kidneys of animals, and it has a long half-life in the body of 19-38 years. Cadmium also interferes with the body's enzyme activity and is toxic.

As early as the 1990s, we began to see a decrease in cadmium emissions, especially in Lapland (Melanen et al. 1999). For example, the amount in mosses decreased by 35% (Rühling et al. 1996). By that time there was already some cadmium in wild berries, with an average of 0.010 mg/kg dry weight in cowberries and 0.024 mg in bilberries. There was rather more cadmium in mushrooms (Laine et al. 1993, Lodenius 1993). In 1992 there was an average of 0.08 mg/kg of cadmium in reindeer lichen in the reindeer herding area and also in the forest reindeer area of Salamajärvi National Park. In the western part of the Kola Peninsula there was already an average of 2.2 mg/kg dry weight of cadmium and in the eastern part, 3.6 mg/kg (Nieminen & Lodenius 2000).

Even in the late 1970s the concentration of cadmium in reindeer meat was 0.01 mg/kg fresh weight, but that was only 10% of the concentration in horse meat (Salmi & Hirn 1981). Ten years later, the cadmium concentration in reindeer lichen in Lapland averaged only 0.18 mg/kg dry weight. Cadmium levels in reindeer calf and adult doe roasts were very low around the reindeer herding area. Liver and kidney cadmium concentrations were significantly higher and a little higher still in the southern than in the northern parts of the reindeer herding area (Nieminen et al. 1988, Nieminen, 1989). During the period 1990-99, cadmium levels in the meat of reindeer, moose, and mountain hare were low, close to the limit of quantification (0.001 mg/kg) and did not exceed the recommended limit (0.1 mg/kg fresh weight) (Niemi et al. 1993, Rintala et al. 1995, Venäläinen et al. 1996, Venäläinen 2007).

In the late 1970's, the cadmium concentration in reindeer liver averaged 0.19 mg/kg and in kidneys 0.88 mg/kg fresh weight (Salmi & Hirn 1981). For example, for seven Norwegian regions the cadmium concentration in reindeer liver was 0.26-1.32 mg/kg, and for eight different regions the concentration in moose liver was 0.11-0.73 mg/kg fresh weight. During the period 1980-99, the liver and kidneys of many woody plant eating moose in Finland showed significantly increased cadmium levels that already exceeded the recommended levels (0.2 and 0.5 mg/kg fresh weight). The liver and kidneys of moose more than one year old are no longer recommended for human consumption. In Sweden in 1980, for example, the cadmium concentration in adult moose liver averaged 0.58 mg/kg, and in kidneys 3.5 mg/kg fresh weight. Also in southern Norway in the 1980's, cadmium levels in the liver of wild deer averaged 0.6 and in kidneys 3.3 mg/kg fresh weight (Frøslie et al. 1986). The cadmium concentration in Finnish reindeer liver has fallen further and is now below the recommended limit in Scandinavia (0.5 mg/kg fresh weight). Cadmium levels in the liver and kidneys of mountain hare and further south also brown hare, with their arboreal diets, are too high for food use (Venäläinen 2007).

Lead (Pb) occurs in more than 200 minerals, but its biological function is not yet known. Emissions to air are for the most part from industry (not the ferrous metal industry), and transport. In Finland, lead emissions from transport ended in 1993. However, lead reaches Finland from Russia, where leaded petrol is still used. Lead can be transported over long distances in the air. A significant portion of lead comes from Europe. Lead remains in the atmosphere for 7-30 days before deposition. Lead also enters the environment from lead acid batteries, paints, and lead shot. Birds can even become paralyzed from eating lead shot. In Finland, the use of lead shot for waterfowl hunting is now prohibited. Lead adheres effectively to humus and is not mobile in soil. Lead concentrations in humus soil remain over long periods, although the burden of lead is now declining. The low solubility of lead compounds reduces lead movement and concentrations in aquatic environments. Lead accumulates in bodies of water via river silts, but it quickly settles, for example as lead carbonate ($PbCO_3$). In fish, lead and cadmium levels in muscle are generally very low, since these and other heavy metals accumulate only in the liver and kidneys (cadmium), gills (aluminium and iron), and bone (lead).

Lead can cause both acute poisoning and neurological symptoms. Cadmium and mercury are less toxic, but their high concentrations can cause problems. Lead accumulates in animal liver, kidneys, bones and teeth. Its biological half-life is long, 5-20 years. Inorganic lead remains in the body for life. In Finland, extensive use of fish increases lead, since about 20% of daily lead intake comes from fish.

In 1983, lichen samples from various parts of the reindeer herding area showed average lead content of 13 mg/kg dry weight. Lead concentrations in reindeer meat were low in the late 1980s, especially in the northern part of the reindeer herding area. The lead concentration in adult does was slightly higher than in calves. The lead concentration in reindeer liver was significantly higher than in flesh, with the highest concentrations measured in the southern part of the reindeer herding area (Nieminen et al. 1988, Nieminen 1989). For example, in seven regions of Norway in the late 1970s, the lead concentration in reindeer liver averaged 0.19-1.08 mg/kg and in moose liver just 0.05-0.21 mg/kg fresh weight. In Sweden in 1980, the lead concentration in adult moose liver averaged 0.08 mg/kg, and in kidneys 0.09 mg/kg fresh weight.

In 1992, the lead concentration in reindeer lichen in the reindeer herding area averaged 2.8 mg/kg, and in the forest reindeer area of Salamajärvi National Park 3 mg/kg dry weight. In the western part of the Kola Peninsula, the lead concentration in reindeer lichen was 2.2, but in the eastern part 3.6 mg/kg fresh weight (Nieminen & Lodenius 2000). Moss research also showed that by 1995 long-range deposition of lead emissions had decreased in Finland by about 40% (Rühling & Steinnes 1998), and that concentrations decreased towards the north. The lead content of reindeer and moose meat, as well as concentrations of chromium, nickel, and copper, were then at a low level (Rintala et al. 1995). Emissions of pollutants from the Kola Peninsula spread with the winds mainly to the east and to the north-eastern parts of the region.

As early as the late 1990s, the lead concentration in Finnish reindeer was low, close to the limit of quantification (0.01 mg/kg fresh weight) (Venäläinen et al. 1999). The lead concentration in reindeer and moose liver and kidneys has also now fallen below 0.05 mg/kg fresh weight. Lead concentrations, however, are higher in reindeer than in domesticated animals (Hirvi & Venäläinen 2000, Venäläinen 2007).

Mercury (Hg) is the only liquid metal found under normal conditions. From an environmental viewpoint, it is very problematic because it easily forms a variety of compounds and moves from one element to another. It also readily vaporizes and can thus drift for long distances in the air. Natural emissions of mercury can be large. Man-made mercury problems are particularly harmful because they are often concentrated in populated areas. Mercury escapes into the environment mostly from industry, and from wood and chlorine factories. Mercury has been used as a slimicide in timber-processing and as a grain seed dressing (banned in Finland in 1992). Other emission sources include fossil fuels, especially coal and waste combustion, emissions from dental clinics, household batteries, and thermometers. In developing countries, mercury is still used in the separation of gold.

Finland's biggest mercury emissions are from zinc plants and energy production. In Finland, industrial mercury emissions to the air are about five times greater than the amount of mercury evaporating naturally from soil and bodies of water. In the early 1990s, it was estimated that mercury deposition to Finland from the atmosphere nearly equals Finnish emissions. Today, East German emissions have almost ended, and Finland's emissions are low.

Mercury is highly toxic as a liquid and mercury fumes are hazardous when inhaled. In nature, mostly as a result of microbial action, mercury also forms toxic organic methyl mercury (CH_3Hg), which is persistent and accumulates especially in the food chains of aquatic ecosystems. Mercury is released from the soil into food chains, for example during the construction of reservoirs and in ditching. The bottom-dwelling animals, water plants, and fish in acidic lakes tend to contain more heavy metals because acidity prevents the metals from dissolving. In such waters, the lead concentration in fish bones has been measured as up to one hundred times that found in natural lakes. The biological function of mercury is largely unknown, but in plants it can disturb root growth and photosynthesis. Fat-soluble methyl mercury readily crosses the placenta in animals, and in humans it accumulates easily in hair. The half-life of mercury gas is 40-70 days, and of methyl mercury 70 days.

In Finland, on average about 60% of mercury comes from fish and fish products. Slow-growing predatory fish, such as pike, perch, pike perch, and burbot, tend to ingest heavy concentrations of mercury. Pike is at the end of the aquatic food chain, and large amounts of mercury accumulate in its system. The level of mercury pollution in fish is often measured from kilo-sized pike. In the 1970's, mercury led to restrictions on the use of fish from reservoirs in Lapland. In the early 1980s, mercury concentrations in burbot and pike from the Lokka reservoir were 0.5-0.7 mg/kg fresh weight (Lodenius et al. 1983). In 1981, the National Board of Health decided that if the mercury concentration in pike was 0.5-1 mg/kg, a limit of half a kilo should be placed on weekly consumption. In 2001, 7.5% of pike fell into this range. In 2000-01, the mercury concentration in pike in the lakes of Lapland and in the Tornionjoki River was 0.19-0.45 mg/kg (Mannio et al. 2002). At that time there was most mercury in the pike of Lake Kemijärvi and least in those of Lake Inari. Mercury concentrations in Lapland pike, however, were lower than those in Finnish Lakeland, with an average mercury content of 0.52 mg/kg (Verta et al. 2002). Mercury concentrations in whitefish and Arctic char were also low in Lapland, at just 0.06-0.1 mg/kg. Inari vendace had an average mercury concentration of 0.16 mg/kg fresh weight (Mannio et al. 2002). Mercury concentrations in sea fish have been generally low.

In southern and central Finland, the concentration of mercury in pike is now

2-3 times higher than the assumed natural level. Deposition from the air has increased the mercury concentration in fish in completely unspoiled lakes. In Finland, the maximum allowable mercury concentration in fish offered for sale is now 1 mg, and in many other countries only 0.5 mg/kg fresh weight. The Finnish Food Safety Authority recommends that, outside Lapland, pike should be eaten only once or twice monthly. The mercury concentration in reindeer meat has also been low in Lapland, at only 13 µg/kg fresh weight. For example, in seven different regions of Norway, the mercury concentration in reindeer in the 1970s averaged 16-192 ppb.

Nickel (Ni), copper (Cu), cobalt (Co) and arsenic (As) continue to spread to Lapland, mainly through emissions from metal smelters and arsenical coal-fired power stations in the Kola Peninsula. Nickel can cause lung and nasal cancer, and high doses of arsenic can also lead to lung cancer, skin and mucosal lesions, and neurological symptoms. In Finland, almost 50% of arsenic comes from fish products. Copper is an essential trace element, but in high concentrations it is highly toxic, for example to the juvenile stages of shellfish. Heavy metal emissions in the Inari-Paatsjoki river area come mainly from the Petšenganikel production units at Nikel and Zapolyarny on the Kola Peninsula. Production there releases mainly nickel and copper into the environment, but also cobalt and arsenic. These heavy metals settle into lakes and streams, and onto trees, other vegetation, and the ground surface around the smelters. Some metals are transported in the atmosphere farther away from the emission areas. Prevailing wind conditions mean that areas to the north and northeast of the factories suffer most from emissions. Heavy metals have accumulated there for more than 70 years in vegetation and sediments.

The damage to terrestrial ecosystems in the vicinity of the smelters is very serious, but the effect weakens gradually with distance. The amount of emissions can be seen clearly from nickel and copper concentrations in bilberry, birch leaves, and pine needles, and even more strongly in mosses and lichens. Emissions are most harmful to the environment in the spring and summer. Increased levels of nickel and copper are detrimental because they can easily accumulate in food chains. Long-lived mosses and lichens take most of their nutrients from rain and melt water, so heavy metals accumulate in them very effectively. They move from vegetation first to herbivores and then to predators. In the end, the entire food chain may be contaminated with toxic metals. In some areas, high concentrations of heavy metals have been measured in fish and birds.

In old spruce forests, the amount of beard lichen decreased by 50-76%, possibly from the impact of pollutants, in 1976-88 at Pomokaira (Sodankylä) and Taivalkoski. However, reindeer also played a part. In the 1990s, heavy metals from the Kola Peninsula had a particular impact on reindeer pastures in eastern Inari and near the eastern border in North Salla. There were elevated levels of nickel and copper in the area's pine needles and mosses (Tikkanen, 1995). However, in 1992 heavy metal concentrations in reindeer lichen were low in the Finnish reindeer herding area. Reindeer lichen had higher concentrations of magnesium, iron, and aluminium in the western part of the Kola Peninsula, and very high concentrations in the eastern part of the peninsula (Nieminen & Lodenius 2000). Even then, the winds in the Kola Peninsula blew mainly towards the northeast and east. Reindeer had also eaten the covering of lichen that protected the land in eastern Lapland, and the microbiological activity in the soil was impaired. This affected the area's nutrient conditions the frost resistance of tree roots, and forest death. Emissions from the Kola Peninsula have halved in 30 years. Further from Nikel, lichen have already recovered. Over the last ten years, lichens and mosses have also increased in the western part of the Kola Peninsula. Heavy metal concentrations in mosses have generally fallen, although in recent years they have slightly risen along with growth in production from the factories. However, pollutants have not had a clear effect on reindeer lichen in Finland or on beard lichen within reach of reindeer. The reindeer have been eating lichens.

In Norwegian Finnmark, lichen pastures have decreased by as much as 70-80% in the last 30-40 years. This has been caused by the excessive number of reindeer, rather than pollutants (Johansen & Karlsen 2002). In recent years, the condition of lichen pasture has improved in some areas. Lichen coverage has improved in recent years on the Kola Peninsula and on the Finnish border in eastern Lapland. The effects of pollutants are only visible closer to the Nikel factories (Myking et al. 2009). The Tornio factories have been the largest single source of chromium emissions in Finland. The most significant emissions have come from the steel foundry and chrome iron factory. Nowadays even these chromium emissions are only one-tenth of emissions in the 1980's (AMAP II 2002).

Selenium (Se) is a sulphur-like silver-grey element, which is rare in the soil of Finland. A deficiency of selenium in animals can lead to muscular dystrophy and heart muscle deterioration. Selenium enters the atmosphere mainly from volcanic eruptions. Burning coal and oil also increase the amount of selenium in the atmosphere. Selenium accumulates efficiently in lichens and also in reindeer through rain and long-range deposition. Selenium is an essential part of the glutathione peroxidase enzyme, which is highly active in reindeer in the autumn (Nieminen & Szilagyi 1988). The most important task of this enzyme is to break down fatty acid peroxides in the body. Selenium protects the body from so-called free radical and peroxide damage, together with vitamin E.

In Lapland, reindeer lichen is rich in selenium, at 0.1-0.5 mg/kg dry weight. There is also selenium in mushrooms (Nieminen 1989 Heiskari & Nieminen 1989). In Finland, reindeer meat has high concentrations of selenium, especially in the northern part of the reindeer herding area. They are 5-10 times higher than in the meat of domesticated animals. In reindeer, selenium concentrations are slightly higher in adult does than in calves. Selenium concentrations in reindeer liver and kidneys are very high (Nieminen 1994).

Organic environmental toxins

Persistent organic pollutants (POPs) remain in the environment for a long time without breaking down. They appear in various foods as polychlorinated dibenzo paradioxines (75 compounds), dibenzofurans (PCDD/F) and polychlorinated biphenyls (PCBs) (135 compounds altogether). PCBs have been widely used as flame retardants and transformer oils, and in the plastics industry. The most toxic are the so-called dioxin-like PCB compounds (17 compounds). Spreading mainly as long-range transboundary air pollution, PCBs now occur everywhere. They easily accumulate through fish to birds and mammals, including humans, at the top of the food chain. Dioxins and furans are not produced in industry, but in Finland they are produced from the chlorophenoles used in sawmills. Large amounts are also produced from the incineration of waste, and they are then carried around the world by air currents. They break down slowly in natural conditions and accumulate easily in body fats, which are especially needed for survival in cold environments. Large amounts are found in Baltic fatty fish, such as herring and salmon, less in freshwater fish. In Finland, 60-80% of dioxin is found in fish. Most dioxin is in older fish, and dioxin levels in the Baltic Sea have barely fallen. It is best to avoid heavy and one-sided consumption of Baltic herring, and fatty Atlantic salmon and sea trout. Some of the dioxins and PCBs that accumulate in sea food can only be removed by skinning fish before use.

In the 1990's the amount of DDT in salmon in the Tenojoki River was only 1/7, and of PCB 1/5 of those in Baltic salmon (AMAP 1997). Measured concentrations of DDT and PCB in pike from Lake Kemijärvi and Lake Inari (0.5-2.5 µg/kg fresh weight) were at the same level as inland lakes farther south (Nakari et al. 2002). Concentrations in Baltic whitefish from the Tornionjoki River were significantly higher owing to the effect of the Baltic Sea (5-20 µg/kg, Korhonen 2000). Concentrations in Baltic herring and salmon from the Baltic averaged 5-8 ng/kg (Kiviranta et al. 2000). Some dioxins and furans (PCDD/F) have been found in vendace from Lake Inari and in Arctic char from Lapland, but only 0.05-0.1 ng/kg fresh weight (Vartiainen et al. 1996). Also, Tenojoki River salmon have clearly lower levels of dioxin than Baltic salmon (Figure 3).

In Lapland in the early 1990s DDT and PCB concentrations in reindeer kidneys were low, at about the same level as was normal in cattle. The total concentration of PCBs in fat content was 75 µg and of hexachlorobenzene (HCB) 6-84

Fig. 3. In Lapland, there are more than 130,000 local recreational fishermen and 260,000 from outside, and the annual fish catch is about 3.5 million kg. Mercury, dioxin, and caesium 137 concentrations are very low in fish. Photo Mauri Nieminen.

μg/kg fresh weight (Berg, 1994). In 2000, the concentration of HCB in reindeer was 5-22 μg/kg. In recent years, slightly elevated concentrations of dioxins and PCBs have been found in reindeer calves (Ruokojärvi et al. 2007). The toxic equivalent (TEQ) of dioxin and PCBs in reindeer calf meat has averaged 3.2 pg/g of fat, which is more than in moose calfs (1.9 pg/g). Reindeer calfs are exposed to dioxins in their mother's milk. Concentrations in reindeer does and moose cows were nonetheless at the same level (2.3 pg/g) (Shoemaker et al. 2009). The total concentration of dioxins and PCBs in moose meat averages 2 pg TEQ/g of fat. Dioxins are quite similar in reindeer and moose meat and in reindeer liver and milk (Suutari et al. 2012). The EU has not set a limit on dioxin or PCB levels in reindeer or moose. In Finland, for example, the use of seal fat in food is not allowed, and about 100g of seal meat can be eaten only once or twice a month.

Radioactivity in lichen, reindeer, moose, and fish

Radioactivity in food in Lapland derives mainly from natural radionuclides, especially potassium 40. Radioactive materials also remain in the environment from nuclear tests conducted in the 1950s and 60s, from the Chernobyl incident in 1986, and from the Japanese nuclear accident at Fukushima in March 2011. Small amounts of these have also contaminated foodstuffs. Of deposited radioactive substances, the most important are short-lived iodine-131, and long-lived strontium-90 and caesium-137 (half-lives of 28-30 years). In Finland, concentrations of radioactive materials in food must not exceed 600 Bq/kg fresh weight.

The transition of caesium-137 from the soils to mushrooms and forest berries, and through food plants to game has been almost constant in Finland and Lapland since 1986. Its concentration falls by 2.3% per year, mainly through radioactive decay. The concentration of caesium-137 had decreased by over 30% by the turn of the century (Saxén et al. 2003). The intake of radionuclides by deer and other game depends mainly on food and varies greatly from season to season. For example, in the autumn mushrooms can increase the concentration of caesium-137 in reindeer and moose meat. The concentration in the meat of moose calfs has been 1.2-1.5-fold compared to that of mature animals. However, in 2000 the activity concentration of caesium-137 in moose meat was less than in reindeer, under 100 Bq/kg fresh weight.

The reduction of caesium-137 in mushrooms has been slow; in Lapland, for example, the effective half-life in boletus and milk cap was 8-10 years, and in *Russula decolorans* up to 18 years (Saxén et al. 2003). In the early 1990s caesium-137 concentrations in the most common mushrooms still averaged 90-230 Bq/kg fresh weight. In Lapland in 2000, the caesium-137 concentration in boletus was 15-150, in Russula 50-90, and in milk cap only about 100 Bq/kg. In Norway and Sweden, in a good mushroom autumn, caesium-137 concentrations rise in the meat of moose, wild deer, reindeer, and sheep. In Finland, the concentration in the meat of mountain hare can be up to three times higher than in moose from the same area. Concentrations of caesium-137 are significantly lower in waterfowl, phasianidae, and brown hare.

In the reindeer herding area, caesium-137 can be very harmful owing to the lichen-reindeer-herder food chain, which is characteristic of the area and effectively concentrates radiocaesium. Lapland also includes a number of factors that have much greater and longer-term effects than in the south owing to the influence of radioactive fallout. The subarctic northern environment is rugged and oligotrophic. This contributes to the movement of radioactive substances into terrestrial and aquatic food chains. In dry peaty forests and lichen pastures, the organic humus layer is thin, often only 1-2 cm. There are also many low-potassium swamps, sometimes covering more than 60% of the area (Nieminen 2008). When organisms have too little of the potassium they need, they easily take persistent and radioactive caesium instead.

The concentration of caesium-137 in reindeer meat in the winter of 1965 was almost 3,000 Bq/kg fresh weight. In southern Finland the concentration in bovine meat was only 50 Bq/kg. The difference was mainly due to the reindeer's winter diet of lichen, including beard lichen. Summer food also had an effect. In summer, the concentration of caesium-137 in reindeer food is only about 1/5 of what it is in winter. The concentration of caesium-137 in the reindeer herders of Inari in the mid 1960's also averaged as much as 45,000 Bq/man. Just before the Chernobyl accident, concentrations had decreased to less than 5,000 Bq/man. After the accident, they averaged 10,000, but in the late 1990s only about 3,000 Bq/man. In the reindeer herding area, the concentration of caesium-137 decreased with an effective half-life of around six years (Saxén et al. 2003).

In the spring of 1986, before the nuclear accident at Chernobyl, the caesium-137 from nuclear tests remaining in reindeer meat amounted to only 300 Bq/kg fresh weight, or one tenth of the highest concentrations in the 1960s. In winter 1986 the average activity concentration of caesium-137 in reindeer meat was about 700 Bq/kg (Nieminen 1987). In the early 2000s, however, the concentration had fallen to less than 200, and has now dropped to less than 100 Bq/kg. The radioactive fallout from Chernobyl was much smaller than from nuclear tests, and in Finland it was directly proportional to the condition of lichen pastures and the lichen eaten by reindeer. After the accident, for example, reindeer in the reindeer herding cooperatives of Paistunturi and Kemi-Sompio showed caesium-137 concentrations averaging about 1,100 Bq/kg, while the figure in Ivalo was only 600 Bq/kg. The concentration at Kemi-Sompio was only about 300 Bq/kg in the early 2000s, but with worn lichen pastures and feeding, reindeer at Ivalo and Paistunturi showed concentrations of only about 150 Bq/kg (Saxén et al. 2003). In the winter of 2001, forest reindeer at Kuhmo still had a caesium-137 concentration of 1,000 Bq/kg and the figure at Suomenselkä was 3,000 Bq/kg. This was due to much better lichen pastures than in the reindeer herding area. In the autumn of 2011, caesium-134 and caesium-137 from Fukushima accounted for less than 1 Bq/kg in Finnish mushrooms as well as reindeer and moose meat. The same mushroom samples showed 25-3,000 Bq/kg from Chernobyl caesium-137 while reindeer and moose meat contained only 17-95 Bq/kg fresh weight (STUK 2012).

Compared to the terrestrial environment, caesium-137 leaves water quickly; it binds to solids and settles into bottom sediments. From there, it continues to move into bottom fauna and aquatic plants. Caesium-137 passes into the edible parts of fish, but strontium-90 only into the bones. In oligotrophic lakes, more caesium-137 tends to move into fish. In the multi-stage food chain of predatory fish, such as pike, burbot, pikeperch, and perch, caesium-137 concentrations were at their peak a couple of years after the Chernobyl accident. For example, the caesium-137 content of Finnish pike in 1988 was almost 4,000 Bq/kg fresh weight. In the worst affected areas of Central Finland, the reduction of caesium-137 levels in fish to pre-accident levels might take more than 20 years.

In many parts of northern and eastern Finland, caesium-137 concentrations in fish declined in ten years to pre-Chernobyl levels of 10-80 Bq/kg. Elsewhere in Finland, concentrations of caesium-137 in the early 2000s were still at 100-700 Bq/kg, but on average only about 100 Bq/kg for inland fish. Salmon in the Tenojoki River, and in the Tulomajoki River of the Kola Peninsula, had a caesium-137 content of less than 0.3 Bq/kg. The concentration of caesium-137 in salmon rising from the Baltic Sea to the Kemijoki, Simojoki, and Tornionjoki rivers has been 30 to 60 Bq/kg. The highest caesium-137 concentrations from salmon in the Baltic Sea were still around 300 Bq/kg in 1990 but had fallen to 70 Bq/kg fresh weight in 2000 (Saxén et al. 2003). In Finland, concentrations of radioactive substances in food are currently low, and there are no usage restrictions.

Summary

The Arctic region and Lapland have been and remain mainly among the Earth's cleanest and most unspoiled areas. However, significant changes affecting these areas, such as increased human activity, reindeer overgrazing, and long-range transported pollutants, make it necessary to pay more attention to environmental protection and also to the living conditions of residents and the survival of indigenous peoples. Lapland interacts in many ways with other regions of the Earth and its protection benefits others, at least indirectly, especially in southern areas. Finland should better follow the principle of sustainable development in Lapland and in the reindeer herding area.

As a result of reindeer grazing, mountain areas, large protected areas, national parks, nature reserves, and wilderness areas are badly worn, in some places even more than in outside areas. Reindeer grazing has been the biggest factor in changing vegetation and has caused erosion in some areas. The current condition of winter pastures and the continual change for the worse show that maintaining the current number of reindeer is no longer possible with natural winter food. As a result of climate change, increased snow and ice cover will make the food intake of reindeer on worn pastures increasingly difficult. Reindeer and moose meat are not organic products. Reindeer husbandry based on feeding and heavy technology now has a heavy environmental impact and carbon footprint. The carbon footprint is greatly increased by fertilizers, feed production and purchased feed, as well as many vehicles and much other machinery.

In addition to long-range deposition, Lapland is still somewhat affected by emissions from within the region or from emission sources in its immediate vicinity. The growing use of natural resources and related industries and traffic, increase overall environmental impact. The simple lichen-reindeer-man food chain is very sensitive to pollutants and environmental toxins. Multi-tiered aquatic ecosystems can be a problem for fish. Especially in Lapland, the concentrations of heavy metals (cadmium, lead, and mercury) have been greatly reduced. Cadmium levels in reindeer, moose, and mountain hare meat are low and close to the limit of quantification (0.001 mg/kg fresh weight). They do not exceed the recommended limit (0.1 mg / kg). The cadmium concentration in reindeer liver has also fallen further and is now below the recommended limit (0.5 mg/kg). Cadmium concentrations in the liver and kidneys of adult moose, which eat lots of woody plants, have risen significantly and exceed the recommended maximum limits. Cadmium levels in the liver and kidneys of mountain hare, and farther south brown hare, are also too high for food use. The lead concentration in reindeer meat is low, and the lead concentration in reindeer and moose liver and kidneys has decreased and is below 0.05 mg/kg fresh weight. In Lapland, reindeer lichens and mushrooms are rich in selenium. Selenium concentrations are also high in reindeer meat, especially in the northern part of the reindeer herding area, and they are 5-10 times higher than is normal in domesticated animals.

Slow-growing predatory fish, such as pike, perch, pike perch, and burbot, tend to ingest large amounts of mercury. The mercury concentration in pike from the lakes of Lapland and the Tornionjoki River is less than 0.5 mg/kg fresh weight. Mercury appears most in pike from Lake Kemijärvi, and least from Lake Inari. In Lapland, mercury concentrations in pike are lower than in Finnish Lakeland. Mercury levels in whitefish and Arctic char are also low, and the concentration in vendace from Lake Inari has averaged only 0.16 mg/kg. In the 1990's, the DDT concentration of salmon in the Tenojoki River was 1/7, and the PCB concentration 1/5 of those in Baltic salmon. Concentrations in the Baltic whitefish of the Tornionjoki River were higher owing to the effect of the Baltic Sea. Organic environmental toxins, such as dioxins and furans, are very common in oily Baltic herring and salmon, but appear less in freshwater fish. Concentrations are also limited in the vendace of Lake Inari and the Arctic char of Lapland. Tenojoki River salmon have clearly lower levels of dioxin than Baltic salmon. The use of seal fat in food is not recommended in Finland, and about 100g of seal meat may be eaten only once or twice a month. Dioxin and PCB concentrations are low in reindeer and moose meat, with an average toxic equivalent (TEQ) of 2 pg/g fat.

By the early 2000s, the caesium-137 content of reindeer meat in Lapland was less than 200 and is now less than 100 Bq/kg fresh weight. On better lichen pasture in Kuhmo, the concentration of caesium-137 in forest reindeer was still 1,000 Bq/kg, and in Suomenselkä up to 3,000 Bq/kg. The concentration of caesium-137 in moose meat is now lower than in reindeer. Salmon in the Tenojoki River, and in the Tulomajoki River of the Kola Peninsula, has a caesium-137 concentration of less than 0.3 Bq/kg. The concentration of caesium-137 in salmon rising from the Baltic Sea to the Kemijoki, Simojoki, and Tornionjoki rivers has been 30 to 60 Bq/kg. The largest caesium-137 concentrations in Baltic Sea salmon (about 300 Bq/kg) was measured in 1990. Ten years later, the concentration was only 70 Bq/kg fresh weight. In general, the purest reindeer, game, and fish are found in Lapland today.

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Lapland and its unique nature are widely known. The clean environment of Lapland – or its image – are used in many ways for the needs of diverse stakeholders, including economic life: tourism, agriculture and food industry. However, knowledge about the state of Lapland´s environment can be based on images rather than facts as the availability of research-based, popular information has been limited. From scientific point of view, the charm of Lapland´s nature is based on soil, water and air and their interactions with diverse biota, including humans. This publication is the result of co-operation between Research Society of Lapland, LAPPI LUO ("Lappi Creates") – working programme and several research scientists. The publication is for all who are interested in the state of Lapland´s environment.

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