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Cadmium, lead, arsenic and nickel in wild edible mushrooms

Riina Pelkonen, Georg Alfthan and Olli Järvinen

Finnish Environment Institute

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PREFACE

In Finland wild-growing products such as mushrooms and berries grow in abundance in forests and are traditionally used as a source of food by the Finns. Although the majority of edible mushrooms growing in Finnish forests are not consumed, picking mushrooms is a common activity for a large part of the population. Fungi are widely recognised to have a good nutritional value and in the recent years younger generations in particular seem to have taken a culinary interest in mushrooms.

As mushrooms may be freely picked and consumed there is no monitoring system to control the amounts of trace elements that enter the human body from the consumption of fungi. In Finland the levels of trace elements in fungi have not been extensively researched apart from the studies carried out in the turn of the 1970s and 1980s (Hinneri 1975, Laaksovirta & Alakuijala 1978, Laaksovirta & Lodenius 1979, Kuusi et al. 1981, Lodenius et al. 1981a, Nuorteva et al. 1986). However, it is evident that considerable variation in trace element concentrations has occurred in the environment, both temporally and geographically. Therefore it is considered vital to gather more information on the consumption of mushrooms and its negative as well as positive effects on human health. The aim of this research is to contribute by updating and increasing the data on cadmium, lead, arsenic and nickel concentrations of wild fungi in Finland. The study also aims to investigate the patterns of variation in time, due to traffic pollution and between ecological groups.

For the public authorities the results of this research may be useful for setting new guidelines for and giving recommendations concerning wild edible mushrooms. What is more, the study will hopefully provide helpful information on mushrooms for consumers, that is which species may be favoured and which are advisable to be avoided.

Riina Pelkonen has conducted the research as a BSc degree project for the Geography Department of Queen Mary, University of London. She has carried out the laboratory analysis of samples, completed the background research as well as written the study paper. Georg Alfthan (National Public Health Institute, Finland) has collected the samples and identified the species as well as performed the drying, homogenisation and preservation of the samples. He also has revised and commented on this paper together with Olli Järvinen (Finnish Environment Institute), who has supervised the laboratory work and provided guidance during the analysis process. Many thanks are due to Dr Kate Heppell (Geography Department of Queen Mary, University of London) for providing valuable suggestions and constructive criticism during the progress of the study.

CONTENTS

1 Introduction

1.1

Key to abbreviations

Key to abbreviations used in the study

AAS	atomic absorption spectroscopy
As	arsenic
Cd	cadmium
Cu	copper
d.w.	dry weight
EU	European Union
f.w.	fresh weight
FAO	Food & Agriculture Organization of the United Nations
Fe	iron
H_2SO_4	sulphuric acid
$HClO_4$	perchloric acid
Hg	mercury
HNO_3	nitric acid
ICP-MS	inductively coupled plasma mass spectrometry
JECFA	Joint FAO/WHO Expert Committee on Food Additives
Mg	magnesium
Mn	manganese
Ni	nickel
Pb	lead
PTDI	provisional tolerable daily intake
PTWI	provisional tolerable weekly intake
Se	selenium
sp.	species
WHO	World Health Organization
Zn	zinc

1.2

Research objectives

Trace elements such as cadmium, lead, arsenic and nickel are known to have severe toxicological effects on human health even at very low concentrations of a few micrograms per kg (EELA 2000, National Food Agency 2002a). The fruit bodies, commonly known as mushrooms, of many fungi species have been found to accumulate these trace elements much more effectively than cereals or other foodstuff growing in similar conditions (Nuorteva et al. 1986, Svoboda et al. 2000). However, significant variation has been observed in trace element concentrations within the fungi group. In order to evaluate the possible health risks involved in the consumption of generally edible mushrooms these differences need to be examined.

Due to the particularly low safety factor involved (WHO 1992 & 1995) and their relatively high frequency in the environment, cadmium, lead and arsenic are among the most important elements to review in terms of food contamination (McLaughlin et al. 1999). Health concerns about food safety have led to extensive research on their concentrations in commercial food products. The effects of nickel in food are less conclusively investigated but some recent evidence has indicated that nickel-containing food may be an aggravating factor for allergic contact dermatitis (Veien 1997, Ring et al. 2001). In particular, heavy metals cadmium and lead are recognised to cause toxicological as well as carcinogenic or mutagenic effects resulting from a low level but chronic exposure (Council of Europe 2001).

The most studied trace elements in terms of both their environmental behaviour and accumulation in fungi are cadmium and lead (see Appendices 1 & 2) and high concentrations of Cd and Pb in mushrooms have been found at both polluted (Laaksovirta & Alakuijala 1978, Kuusi et al. 1981, Kalač et al. 1991, Kalač et al. 1996) and unpolluted locations (Movitz 1980, Michelot et al. 1999). The ability of fungi to accumulate arsenic (Byrne & Ravnik 1976, Andersen et al. 1982) and nickel (Andersen et al. 1982, Jorhem & Sundström 1995, Michelot et al. 1998) has been indicated by a few studies in other European areas but they have rarely been included in previous Finnish surveys (see Appendices 3 & 4). This study aims to update the data on cadmium and lead concentrations in Finnish edible fungi as well as provide new information on the less extensively studied but potentially harmful elements, arsenic and nickel.

Collecting wild mushrooms for eating purposes is a popular activity among a considerable part of the Finnish population. Mushrooms are virtually a free source of nutrition and their collection is easy due to the abundance of suitable forest areas and the 'everyman's right' allowing wild products such as mushrooms and berries to be picked practically everywhere in the country without the landowner's permission. Consequently, approximately 90 % of the total amount of mushrooms collected annually in Finland are picked and consumed by private households without intervening commercial retailers (Ministry of Agriculture and Forestry 2002a). The annual total of 2 – 10 million kg of mushrooms collected by private households equals, however, merely 1 % of the average total crop of mushrooms in Finnish forests. It is estimated that 46 % of the population aged between 25 – 65 years pick mushrooms regularly. The average annual consumption of wild mushrooms ranges from 0.5 to 2 kg per person (Ministry of Agriculture and Forestry 2002a) – there is, however, considerable variation within the Finnish population and the consumption by many individuals can be assumed to greatly exceed these averages.

The mushroom species chosen for this research project (see Table 1) are all edible and among the most commonly collected and consumed wild fungi species in Finland. Apart from *Agaricus abruptibulbus* and *Macrolepiota procera*, the studied mushrooms are listed as commercial mushroom species (see Appendix 5), that is species accepted for sale as food products (Ministry of Agriculture and Forestry 2002b). Although both *A. abruptibulbus* (Meisch et al. 1977, Andersen et al. 1982, Vetter 1993) and *M. procera* (Byrne & Ravnik 1976, Jorhem & Sundström 1995) have previously been found to contain high concentrations of some toxic trace elements they are still referred to as good edible species in most contemporary mushroom field guides. Besides, no official recommendations have been made concerning the consumption of *A. abruptibulbus* and *M. procera* in Finland. It may be assumed that, as relatively abundant species, *A. abruptibulbus* and *M. procera* are commonly picked and eaten in Finnish households and it is therefore important to include them in this research.

Table 1. The number of samples examined for each mushroom species.

Species	Number of samples
Agaricus abruptibulbus	28
Albatrellus ovinus	12
Boletus sp. *(B.edulis, B.pinophilus)*	21
Cantharellus cibarius	17
Cantharellus tubaeformis	17
Craterellus cornucopioides	8
Gyromitra esculenta	5
Hydnum sp. *(H.repandum, H.rufescens)*	23
Lactarius sp.*(L.deliciosus, L.deterrimus, L.rufus, L.torminosus, L.trivialis)*	21
Leccinum sp. *(L.aurantiacum, L.versipelle)*	25
Macrolepiota procera	4
Suillus variegatus	10
Total	191

Research on the accumulation of trace elements in fungi has often been focused on investigating merely the element concentrations leaving the implications for health as a lesser consideration. While the harmful effects of some poisonous mushroom species are fairly well recognised among the general public, the ability of fungi to accumulate high concentrations of trace elements is relatively unknown. Therefore it is likely that, unlike incidents of acute mycotoxin poisonings, possible long-term toxicological impacts are often not recognised as the consequence of a chronic trace element accumulation in the body.

The objectives of this study are:

- To determine the average trace element concentrations in wild mushrooms.
  The general average concentrations of Cd, Pb, As and Ni are determined for the most commonly consumed Finnish mushroom species. The possible relationships between the elements within all mushrooms as well as for each species are investigated.
- To evaluate toxicological risks posed by trace element concentrations in mushrooms.
  The trace element contents of mushrooms are evaluated in terms of their potential to pose a health risk to consumers. The established element concentrations are compared to the current legal standards operative in the European Union concerning trace elements in food. The possible health effects are assessed in the light of the weekly intake limits of Cd, Pb, As and Ni set by the WHO/FAO (Council of Europe 2001).

- To assess factors affecting the variation in the trace element concentrations. The variation patterns resulting from (a) traffic pollution, (b) differences between ecological groups and (c) different parts of fungi are reviewed in order to establish recommendations for consumption.

2 Literature Review

2.1

Trace elements in the environment

Small amounts of Cd, Pb, As and Ni occur naturally in the environment as minerals in lithospheric parent rock material or soils (see Table 2 for element concentrations in stream sediments in Finland). However, excessive levels of these trace elements are mostly due to various anthropogenic activities such as industry, urban development or agriculture (WHO 1991, 1992 & 1995). Trace elements may enter the natural environment as atmospheric emissions, as water discharge, or in sewage sludge or waste material dumped on land. Diffuse atmospheric contamination may be transported long distances (Rühling 1994) until it is deposited as dust or through precipitation into water bodies or onto soils. The trace elements in soil originate mainly from anthropogenic pollution but to a lesser extent also from the weathering of parent rock material (WHO 1991, 1992 & 1995). Some additional factors such as acidification (Rühling 1994, Voegelin 2003) may increase the rate at which elements are released to the environment.

Table 2. Concentrations of Cd, Pb, As and Ni in stream sediments in Finland.

Cd mg kg^{-1}	Pb mg kg^{-1}	As mg kg^{-1}	Ni mg kg^{-1}
0.08–1.0	3.4–22	0.8–15	6–40

Source: Lahermo et al. (1996)

Cadmium minerals are relatively rare in the natural environment and mostly occur due to human activities (WHO 1992). The predominant anthropogenic sources of cadmium are the sewage and atmospheric emissions from zinc and lead mining, and metal industry (CEPA 1994a). It is also released in fossil fuel combustion, waste incineration and the use of fertilisers (WHO 1992, Lahermo et al. 1996). Due to the previous usage of non-domestic Cd-containing fertilisers cadmium may still be enriched in the soil of some agricultural land areas (Lahermo et al. 1996). In addition, the implementation of EU directives (Council Directive 76/116/EEC; European Council 2002) led to the introduction of non-domestic fertilisers in Finland in the late 1990s. This can be assumed to have increased the soil metal concentrations as fertilisers with generally higher element concentrations may be applied to agricultural land.

Composted sludge from sewage treatment plants can also be added to soil used for lawns or fields in urban areas (National Food Agency 2002a). In 1981 the Cd content of sewage sludge applied on fields in the Helsinki area was 10 – 22 ppm (Myrkkyasiain neuvottelukunta 1982). This soil can have a very high Cd content and therefore mushrooms growing in parks or similar areas may potentially contain considerable amounts of cadmium. The concentrations of Cd, Pb and Ni currently allowed on agricultural land containing sewage sludge can be seen in Appendix 6 (Ministry of the Environment 1994).

Cadmium contents in the environment may also be elevated due to the use of cadmium-containing tyres in vehicles (Mukherjee 1989). Particles that are worn-off from tyres are carried with runoff from roads (The Environment Agency 2002) and thus have a potential to affect the Cd concentrations of fungi growing near road traffic.

Small amounts of lead occur everywhere in the environment due to natural sources such as geological weathering and volcanic emissions (WHO 1995). In comparison to other metals, the concentrations of lead have experienced the greatest increase due to the impact of anthropogenic activities (Lahermo et al. 1996). Airborne Pb is released from coal and oil burning and industrial activities such as metal smelting and manufacture of lead-acid batteries (Gerba 1996). In the past decades the predominant source of atmospheric lead in urban areas in particular has been vehicle emissions (Gerba 1996). In Finland lead-containing petrol has been replaced by unleaded petrol in virtually all vehicles since 1985 (National Food Agency 2002a). As a consequence, the amount of atmospheric lead has experienced a steady decrease since the early 1990s (Lahermo et al. 1996, National Food Agency 2002a&b). Other sources of Pb include fertilisers (Mukherjee 1994), sewage and other waste material (Lahermo et al. 1996).

The majority of arsenic present in the natural environment originates from arsenic-containing minerals occurring naturally in soils and parent rock material (Gerba 1996). The anthropogenic sources of arsenic include the manufacture of copper, nickel and lead mining and smelters, metal industry emissions, wood industry, paints and landfill sites (CEPA 1993, Gerba 1996, Hassinen 2002) as well as the production of some herbicides and insecticides (McLaughlin et al. 1999).

Volcanic eruptions naturally release small amounts of nickel to the atmosphere. Anthropogenic emissions result principally from activities such as metal processing, mining or fossil fuel combustion (WHO 1991). The environmental levels of nickel have been on the increase due to the recent growth of nickel use in modern technology and industries (Denkhaus and Salnikow 2002).

As no comprehensive data was available for the soil content of the studied elements, element concentrations in stream sediments, which reflect the levels in soil, were used to examine the environmental element levels. The concentrations of Cd, Pb, As and Ni in stream sediments in Finland are illustrated in Figures 1 – 4. The maps show a prevailing north-south gradient in element levels with the highest concentrations generally being found in the southern parts of the country. This is largely due to long-range atmospheric transport from the more industrialised and densely populated regions of Central and Eastern Europe, particularly in the case of cadmium and lead (Rühling 1994). Some local emission sources around urban centres or industrial emission sources are, however, superimposed on the general deposition pattern.

2.2 Studies on mushrooms

The majority of edible Finnish mushroom species belong to the class *Basidiomycotina* (Korhonen 1992). The mushrooms studied in this project are all *Basidiomycetes* apart from *Gyromitra esculenta*, which is an *Ascomycete* species. The structures appearing above ground, known as fruit bodies or mushrooms, act as the reproductive organs of the fungi. The fruit bodies generally develop to their mature stage in 11 to 25 hours

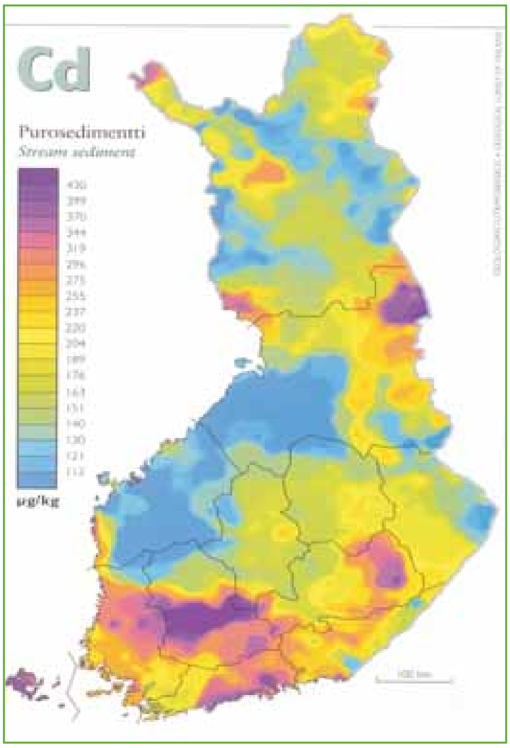


Figure 1. Cd concentrations in stream sediments in Finland. From: Lahermo et al. (1996).

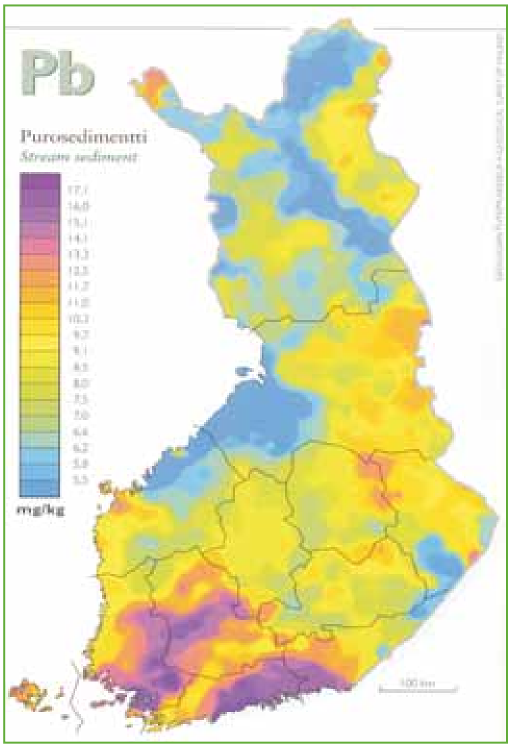


Figure 2. Pb concentrations in stream sediments in Finland. From: Lahermo et al. (1996).

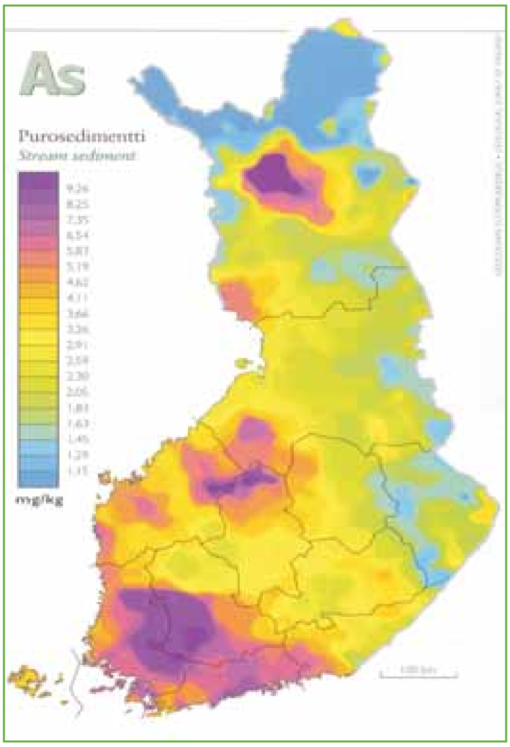


Figure 3. As concentrations in stream sediments in Finland. From: Lahermo et al. (1996).

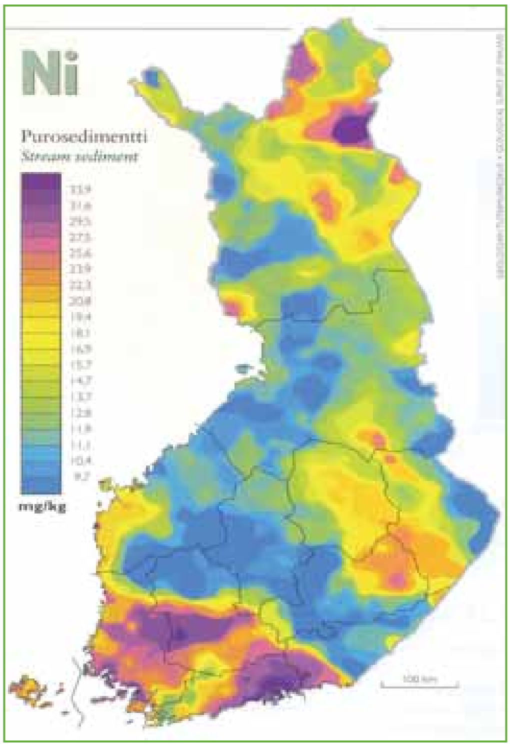


Figure 4. Ni concentrations in stream sediments in Finland. From: Lahermo et al. (1996).

(Elliott 1994) and have a total life span of approximately 10 – 14 days (Svoboda et al. 2000). The largest part of the fungi organism is the subsurface mycelium, which may spread over areas of several square metres (Byrne & Ravnik 1976). The high growth rate and compressed nature of the mycellia enable fungi to extract elements from the soil very efficiently (Byrne & Ravnik 1976). A broad mycelium cover allows for the fungi to accumulate elements even from soil that has relatively low concentrations of the particular elements (Eurola et al. 1996).

Mushrooms have a relatively high nutritional status: the protein content of certain mushroom species is known to be higher than in vegetables apart from spinach and soybean (Alexopoulos et al. 1996). They are also a good source of valuable vitamins, such as vitamin D (Mattila et al. 2000), and several essential minerals (Souci et al. 1981, Alexopoulos et al. 1996).

Cadmium, lead, arsenic and nickel concentrations for fungi in previous studies may be seen in Appendices 1 – 4. In Finland and other Nordic countries the element contents of mushrooms were more actively studied from the late 1970s to early 1980s in both urban (Laaksovirta & Alakuijala 1978, Laaksovirta & Lodenius 1979, Kuusi et al. 1981, Lodenius et al. 1981a) and rural environments (Hinneri 1975, Movitz 1980, Andersen et al. 1982, Nuorteva et al. 1986). The most investigated elements in Finnish mushrooms have been cadmium, lead and mercury whereas arsenic and nickel (Varo et al. 1980) have received very limited attention. This research aims to broaden the knowledge of Cd and Pb concentrations for the most commonly consumed species as well as to examine the less frequently studied arsenic and nickel contents.

Many of other European studies were carried out prior to mid 1980s (Stivje & Roschnik 1974, Seeger et al. 1976, Stivje & Besson 1976, Tyler 1980, Tyler 1982, Bargagli & Baldi 1984). Like the Finnish studies, most European fungi research has been carried out on heavy metals along with nutritionally essential elements such as Cu, Zn and Mg. Recent research has largely been concentrated on areas of Southern and Eastern Europe (Svoboda et al. 2000, Demirbaş 2001a&b, Svoboda et al. 2002) and often with different species and different environmental conditions to Finland.

The impact of human activities on fungi trace element contents has been established by various studies. In Southern Finland the distributions of background atmospheric concentrations for Cd, Pb, As and Ni are rather uniform as the air-transferred trace elements from mainly Central and Eastern Europe are deposited in a relatively even manner throughout the region (Rühling 1994). Hence the variation in the environmental trace element contents seems to be predominantly controlled by more local factors.

In general, the major local sources of trace element contaminants to the environment are industrial activities and traffic emissions. Many European studies have focused on the impact of specific industrial contaminant sources such as metal smelters (Kalač et al. 1991, Kalač et al. 1996, Svoboda et al. 2000) or mining areas (Bargagli & Baldi 1984). Some Finnish studies have been carried out particularly on the area surrounding the Harjavalta metal smelter (Eurola et al. 1996). These industrial point sources are, however, usually relatively well known among the general public and therefore the collection of fungi or berries is likely to be avoided in their immediate proximity. No significant point sources, such as metal smelters, refineries or landfill sites, of Cd, Pb, As and Ni are located in the proximity of the sampling sites of this study (Reinikainen 1993, Hassinen 2002). Therefore the specific pollutant sources to consider are primarily traffic emissions.

Traffic pollution is reported to have a considerable effect on the concentrations of Pb in areas where leaded petrol is widely used (Laaksovirta & Alakuijala 1978, Kuusi et al. 1981, Tüzen et al. 1998). The Cd concentrations of decomposer species in particular have been found to correlate positively with vehicle emission levels (Laaksovirta & Alakuijala 1978, Kuusi et al. 1981). Traffic emissions seem to have a less significant effect on the levels of As and Ni in mushrooms but only limited research has, however, been carried out on the subject.

Eurola et al. (1996) have provided the most recent and comprehensive study in the research area by investigating the levels of Cd, Pb, Hg, Cu, Zn and Mn in wild mushrooms. The research included six of the species examined here and covered mainly samples from relatively remote uncontaminated sites. Possible elevation in mushroom element levels at sites close to traffic pollution sources was not considered in the study and measured element concentrations were generally of a relatively low magnitude. Apart from the elevated lead levels observed in the more urbanised regions in Southern Finland, Eurola et al. (1996) found no significant differences in the Cd and Pb concentrations between geographical regions in Finland.

2.3

Accumulation of trace elements in fungi

Cadmium and lead are both non-essential elements for plants and fungi and are found to affect the physiological and biochemical functions in plants. Arsenic is generally also considered to be a non-essential mineral (Gerba 1996) though some studies have indicated that inorganic arsenic may have a nutritional essentiality for plant growth (McLaughlin et al. 1999) and for some animals (Klaassen 1996). Nickel has a nutritional importance to plants but becomes toxic at high, usually above 50 mg kg^{-1} d.w., concentration levels (WHO 1991).

In previous studies fungi have been shown to accumulate certain trace elements at much higher concentrations than plants or other organisms. Especially the Cd, Pb and As levels are generally higher than those of green plants (see Appendix 7 for element concentrations in similar foodstuff). The extensive mycelium enables the fungi to effectively extract trace elements from the substrate (Huhtinen 1981). Besides, fungi tend to accumulate trace elements more selectively than plants, in which the concentrations are typically more closely correlated with the element contents of the soil (Tyler 1980).

In general, trace elements can be accumulated to the fruit bodies directly from the air as atmospheric deposition or through the mycelium that takes up trace elements from soil moisture or soil along with other, essential micro-elements such as zinc and copper (Jennings & Lysek 1996). For trace elements such as Cd, As and Ni the principal route of element uptake seems to be via the mycelium (Gast et al. 1988, Michelot et al. 1998). The importance of these mechanisms in lead accumulation is, however, more debated. Lead is seen to be mainly absorbed from the air: Tüzen et al. (1998) claim that rinsing wild mushrooms with water can decrease the lead content of mushrooms by 68 % on average. This indicates that a considerable portion of Pb in fungi is deposited from the atmosphere. Furthermore, Laaksovirta & Alakuijala (1978) state that direct deposition seems to have an apparent effect in regions where the atmospheric concentrations of lead are particularly high.

However, Jorhem & Sundström (1995) and Svoboda et al. (2000) argue that the life span of fruit bodies, which is typically up to two weeks, is usually too short for considerable element accumulation. Laaksovirta & Alakuijala (1978) point out that the young specimens growing beneath the surface are found to contain lead contents similar to those of the mature species and that the accumulation of lead tends to be greater in the decomposer group than in the mycorrhizal fungi. These factors indicate that Pb uptake is governed by other than atmospheric concentrations. This research contributes to the discussion by studying the effect of vehicle emissions as well as different growth stages and genetic characteristics of mushrooms on the accumulation of Pb and other trace elements.

Certain species have been found to contain high concentrations of elements even at locations where no significance pollution sources are present. For instance, Michelot et al. (1999) found concentrations of Cd, Pb and Hg in primary forests of Latin America to be of the same order of magnitude as those observed in highly polluted regions in Central Europe. Demirbaş (2001b) observed very little variation between element concentrations for the samples of the same species growing in locations with different soil or substrate type thus concluding that the trace element concentrations in fungi are far more dependent on the species ability to uptake elements from the soil than from the element composition of the substrate.

The relative insignificance of soil characteristics is supported by the evidence of Tyler (1980) who found very different contents of trace elements for different species collected at the same site. Several analyses on relationships between soil and fungi concentrations have indicated the relative insignificance of edaphic factors to the trace element concentrations of fungus fruit bodies. For instance, *Agaricales* are found to bioaccumulate Hg, Pb and Cd to much higher concentrations than the levels present in soil (Stivje & Besson 1976, Lodenius 1982).

In addition to species-specific factors, ecological characteristics of fungi are known to have a significant role in their ability to accumulate trace elements (Laaksovirta & Lodenius 1979, Kuusi et al. 1981, Michelot et al. 1998). The common Finnish edible mushroom species generally fall into two ecological groups, mycorrhizal and lawn decomposers. Mycorrhizal fungi can have symbiotic relationships and take nutrients at a greater depth than the decomposers, which typically get their essential nutrients from the top soil that is the most affected by atmospheric contaminant deposition (Laaksovirta & Alakuijala 1978). Of the two functional groups, the decomposers have frequently been found to contain higher contents of trace elements than the mycorrhizal species (Laaksovirta & Alakuijala 1978, Laaksovirta & Lodenius 1979, Kuusi et al. 1981, Melgar et al. 1998).

Different parts of the fruit body are known to have very distinct abilities to accumulate trace elements. Several elements such as Cd (Seeger et al. 1976), Hg (Seeger et al. 1976, Alfthan unpubl.) and Se (Alfthan unpubl.) are found to be more abundant in the cap than in the stalk. The highest concentrations are, however, determined for the spore-forming part of specimens, the sporophore (Meisch et al. 1977, Melgar et al. 1998, Alfthan unpubl.).

The differences between the trace element concentrations of cap and stalk may have to do with the distribution of other essential elements in the fruit body. For example, Fe, Mg and Zn have been found to be more abundant in the cap than in the stalk of some species (Ohtonen 1982). This suggests that heavy metals and other trace elements are accumulated in a similar manner to essential elements and may replace essential elements in mushroom uptake. Accordingly, elevated trace element accumulation levels could occur even when the environmental levels of the essential elements are low.

2.4

Trace elements and health

Cadmium is considered as one of the most harmful environmental toxins. It has a long biological half-time of up to several decades (WHO 1992). Cd is a non-essential element for most organisms and at high levels it has been proven to be toxic, mutagenic and carcinogenic to humans and animals (WHO 1992, CEPA 1994a). In human body Cd is accumulated over a lifetime and is mainly enriched in kidneys and liver (WHO 1992) thus damaging their normal functioning (WHO 1992, National Food Agency 2002b). Acute Cd poisoning can impair the gastrointestinal system but more severe impacts are caused in kidneys by chronic intoxication (Gerba 1996).

Together with drinking water and dust, food supplies represent the principal source of lead to humans (WHO 1995, National Food Agency 2002b). Pb is primarily absorbed from the gastrointestinal tract; children absorb ingested Pb even more efficiently than adults. The toxicity of Pb is based on its ability to bind and interfere with the functions of biologically important molecules (Council of Europe 2001). Pb can be enriched in liver and kidneys as well as in bones and teeth. Excess Pb intake may cause damage to the gastrointestinal, neuromuscular or blood-forming systems (WHO 1995). Experiments on animals have shown lead to cause kidney problems as well as carcinogenic effects. In children, whose blood-brain barrier is still undeveloped, an excessive lead exposure may affect the central nervous system and eventually have adverse impacts on mental development. The most severe health effect is, however, lead encephalopathy, a condition gradually deteriorating the brain. It can occur in adults but is nowadays more common in children and often has adverse neurological if not lethal consequences (Gerba 1996).

Ingestion in food represents the principal route of arsenic to human body (CEPA 1993). Unlike for instance Cd, As has not been found to be enriched in the food chain and most of As is usually excreted from the body. Chronic As poisoning can lead to severe kidney or liver injury, or damage the brain and central nervous system (Gerba 1996). As has also been classified as a human carcinogen (CEPA 1993).

Small amounts of nickel are needed in human metabolisms as well as for the functioning of many important enzymes but at high concentrations Ni becomes toxic (WHO 1991, Lahermo et al. 1996). The main intake route for Ni is gastrointestinal absorption (CEPA 1994b). At a particular risk to Ni exposure are individuals with nickel allergic contact dermatitis. They have been found to be more susceptible to high Ni content in drinking water and similar effects are suggested to result from nickel-containing foodstuff aggravating existing skin eczema (WHO 1991, Veien 1997). At least some forms of Ni are considered to highly increase the risk of cancer (WHO 1991).

This study focuses on investigating the levels of trace elements in wild fungi samples and factors that may potentially affect them. Particular attention is given to factors such as differences in concentrations between species and distance from roads, which may be controlled by choosing specimens carefully. General large-scale factors such as geographical variation within the country and levels of background atmospheric deposition are not considered in detail.

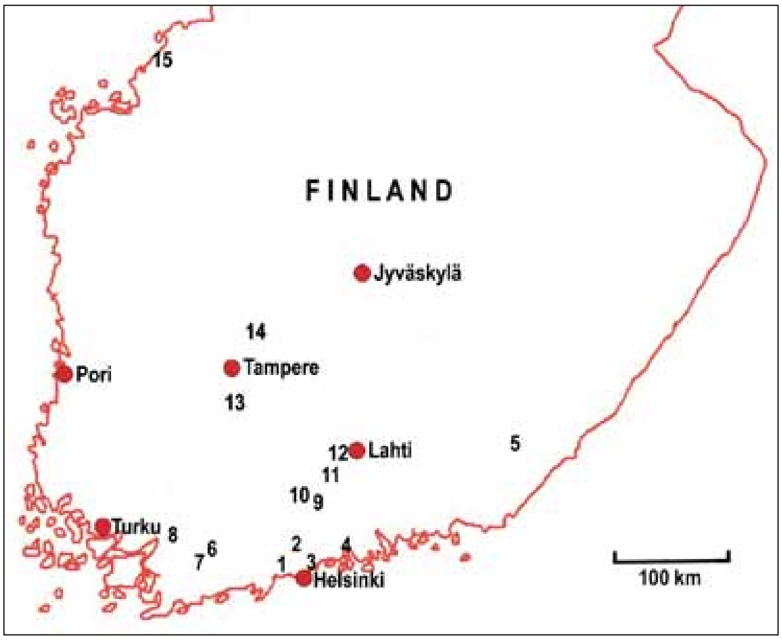
3 Methodology

3.1
Sampling and sample regime

The samples examined in this research were chosen from a larger set of mushroom samples collected by Georg Alfthan (National Public Health Institute, Finland). G. Alfthan has performed the identification of the species, drying and homogenisation of the mushrooms, as well as preserved the samples.

The 191 fungi samples included in this study were collected from various locations in Southern Finland between the years 1977 and 1999. The 36 collection sites, which are situated within the 15 areas seen in Figure 5, were chosen randomly depending on where suitable mushrooms were observed. The sites cover forest and park areas as well as some road sites in both rural and urban areas. The research aimed to define the general trace element content of edible mushrooms that people would privately pick and consume. Thus the sampling sites were principally chosen to represent ordinary collection sites and exclude locations in a close vicinity of any large metal-emitting industries or other such specific polluters. The number of samples from each location and for each species was dependent on the availability of mushrooms in a particular year.

The majority of Finnish mushroom species principally grow in forested areas (Korhonen 1992). However, *Boletus* species in particular commonly grow on park lawns and *Agaricus abruptibulbus, Gyromitra esculenta* and *Macrolepiota procera* are also frequently found at more open sites.



1 Espoo
2 Vantaa
3 Helsinki
4 Sipoo
5 Pertunmaa
6 Sammatti
7 Karjalohja
8 Salo
9 Hikiä
10 Riihimäki
11 Kärkölä
12 Lahti
13 Lempäälä
14 Juupajoki
15 Pietarsaari

Figure 5. Map showing the collection areas of mushroom samples.

Mushrooms generally appear in late summer or early autumn. However, the fruit-bodies of different species are found at very different times and in variable abundances each year. The variation in the start and length of the harvesting period as well as regional differences in abundance depend greatly on the environmental conditions, such as temperature, amount of light and precipitation, of a particular year.

The characteristics of wild mushrooms to appear very randomly in terms of location, abundance and time pose limitations to research regimes. It is often very uncertain whether an adequate amount of suitable samples may be found, especially if more specific analyses, such as differences between samples of different growth stages, from different substrate types, or from differently contaminated areas, are required.

The focus of this research project was on the investigation of the average trace element levels in wild fungi. Therefore specific environmental parameters, such as local levels of atmospheric deposition or soil concentrations, that are rarely relevant or available for mushroom pickers to guide them in their choice of specimens, were not an interest of this survey. Instead, some research was done on the influence of other factors, such as nearby traffic and accumulation in different parts of mushrooms, which can be used to make recommendations for choosing and consuming mushrooms safely. As the total sample set included specimens collected during a relatively long period of time as well as from locations with variable levels of environmental contamination, studying these parameters also served for the purpose of establishing whether the specimens of each species could, in fact, be considered as a single assemblage when analysing a dataset. Further recommendations for research on these specific parameters are discussed later in chapter 7.

3.2
Sample preparation

The samples, including the cap, sporophore and stalk, were mainly mature specimens though some individuals at other growth stages were also included. To maintain a good level of accuracy, species with less than two individuals were discarded from the analysis.

Following the collection, the mushroom samples were cleaned carefully using a knife. The sliced fruit bodies were air-dried on filter paper or in a hanging mesh and then further dried at 90 ^{o}C for 30 minutes. The dried samples were homogenised in an agate mortar and stored at room temperature in glass vials or plastic bags.

The concentrations of some elements may be affected by a long storage period. The dried and homogenised fungi samples were stored in glass or plastic containers at normal room temperature, which is an appropriate technique for non-volatile elements such as Cd, Pb, As and Ni. Changes in trace element concentrations from sample storage were therefore not considered significant.

Sample contamination was minimised by using an agate mortar in the homogenising procedure and by following the cleaning procedure practices applied at the Finnish Environment Institute Laboratory for non-disposable containers coming in contact with the samples. Concentrations of trace elements may be easily affected by contamination from vessels used in the analysis. Levels of lead, which is ubiquitous in the environment (WHO 1995), in particular may therefore be distorted, especially since the ICP-MS has such low detection limits (see Table 6). In this study the reference material samples (see Appendix 8) had, however, generally consistent levels of the studied elements and therefore the cleaning regime of sample vessels was considered effective to maintain a good level of accuracy.

3.3
Analysis techniques

The acid digestion and ICP-MS analysis were performed at the Finnish Environment Institute Laboratory in Helsinki. In order to examine the amount of fungi sample required for accurate results, an in-house reference sample mixture containing several mushroom samples of different species from locations similar to the studied samples was examined using duplicate samples weighed at 50, 100, 150 and 200 mg. The results are shown in Table 3. As the variance of the measured concentrations for each element was low (0.001 – 0.005) with a highly significant probability ($p = 9.76 \times 10^{-31}$), it was concluded that samples weighed between 50 and 100 mg were adequate to provide accurate results of the element concentrations.

Table 3. Concentrations of Cd, Pb, As and Ni in in-house reference sample mixture (dry weight).

Sample weight		Cd ($\mu g\ g^{-1}$)	Pb ($\mu g\ g^{-1}$)	As ($\mu g\ g^{-1}$)	Ni ($\mu g\ g^{-1}$)
50 mg	i	1.53	1.28	2.18	5.37
50 mg	ii	1.63	1.26	2.24	5.00
100 mg	i	1.58	1.17	2.07	5.23
100 mg	ii	1.62	1.12	2.20	5.02
150 mg	i	1.50	1.09	2.04	4.94
150 mg	ii	1.60	1.21	2.24	5.22
200 mg	i	1.59	1.07	2.19	5.16
200 mg	ii	1.52	3.54*	2.09	5.16

*Outlier value excluded from variance calculations

Seven fungi samples were processed at a time with one blank and one standard reference material (Certified Reference Material *Cantharellus tubaeformis*, Swedish National Food Administration, Sweden; see Appendix 8 for element concentrations of the reference material samples) sample (see Table 4). Precision (CV %) between the batches for the reference material samples was 5.5 for Cd, 8.3 for Pb, 14.6 for As and 14.2 for Ni. The accuracy expressed as bias was 1.6 % for Cd, 1.5 % for Pb and 16.9 % for Ni. For As no certified value was given.

Table 4. The sample batch order used in the analysis of fungi samples.

1)	Blank
2)	Standard Reference Material (*Cantharellus tubaeformis*)
3)	Sample 1 (i)
4)	Sample 1 (ii)
5)	Sample 2
6)	Sample 3
7)	Sample 4
8)	Sample 5
9)	Sample 6
10)	Sample 7

One duplicate fungi sample was prepared for each digestion batch and the average value used as the established concentration. 50 – 100 mg of each homogenised sample was weighed and dissolved in 5 ml of 65 % nitric acid (Romil-SpA™ Super Purity Acid) by using an MLS-1200 MEGA microwave unit. The containers used in the microwave unit were 120 ml Teflon® PFA digestion vessels.

After the microwave-assisted acid digestion the sample–acid solutions were left to cool for approximately 50 minutes and then diluted to 25 ml with deionised water. These were further diluted into a 1/10 solution.

The analysis of the trace element concentrations in the samples was conducted using a computer-controlled Perkin-Elmer Sciex ELAN 6000 inductively coupled plasma mass spectrometry, ICP-MS. The operating conditions for the ICP-MS are shown in Table 5.

Table 5. ICP-MS operating conditions.

Parameter	Setting
Plasma power (W)	1 100
Nebuliser Ar flow (l/min)	0.87–0.90
Coolant Ar (l/min)	15
Auxiliary Ar (l/min)	~1.2
Argon supply (psi)	58
Main water temperature (°C)	17.0–18.0
Interface water temperature (°C)	36.0–37.0
Lens voltage (V)	10
Analog stage voltage (V)	2 300
Pulse stage voltage (V)	1 550

A blank sample was first run on the ICP-MS and its measured concentration levels for each element were then reduced from all following calibration, control and sample solutions. The ICP-MS was calibrated using a 1/50 solution of (Claritas PPT) Multi-element Solution SPEX-CLMS Certiprep 2. The results of these multi-element standards of 1, 10 and 100 µg/l were used to construct linear calibration curves from which the element composition of the samples can be inferred.

The intensity of SPEX 2 was also measured as the first, every 10th and the last sample during each ICP-MS analysis run. A second set of standards was obtained by using Standard Reference Material NIST 1640 (Trace elements in Natural Water) as an extra control standard in the ICP-MS process. The values of these control standards were used for monitoring the accuracy of the analysis results.

100 µl of Rhodium (Rh) were added to each 10 ml blank, SPEX2, NIST 1640 and sample solution as an internal standard making the Rh concentration of each solution 10 µg per litre. The internal standard is used to correct for the variations in the ICP-MS instrument response as the analysis proceeds as well as in the calculation of the trace element concentrations for the samples. The detection limits of the ICP-MS for the four elements are shown in Table 6.

Table 6. ICP-MS detection limits for Cd, Pb, As and Ni.

	Detection Limit for ICP-MS** (µg l^{-1})
Cd	0.03
Pb	0.03
As	0.06
Ni	0.04

**Perkin-Elmer Sciex ELAN 6000

3.4

Dry and fresh weight

The moisture content of fresh mushrooms generally varies between 90 – 95 %. For determining the amount of trace elements in fresh fungi the average dry material contents established in the study by Eurola et al. (1996) were used for *Albatrellus ovinus, Boletus* species, *Cantharellus cibarius, C. tubaeformis, Craterellus cornucopioides* and *Hydnum* species. Values measured by Souci et al. (1981) were used for *Leccinum* species. For *Lactarius* species the average of *L. deterrimus* (Souci et al. 1981), *L. rufus* and *L. trivialis* (Eurola et al. 1996) was used. The dry material contents for each species are displayed in Appendix 9.

3.5

Statistical analyses

Appendix 10 presents the average, standard deviation, coefficient of variation, median, range and count values for the element concentrations of each fungi species. Analysis of variance (single factor ANOVA) test was performed to statistically examine whether individual factors cause significant variation within fungi element concentrations.

Regression analysis was carried out to see if there are significant general relationships in the accumulation of the studied elements in fungi. Correlation coefficients between the element pairs were also calculated for each mushroom species in order to determine whether there are mutual patterns in the uptake of elements by different species. Establishing possible positive or negative correlations between elements is particularly important in terms of health concerns as the concentration measured for one element may act as an indicator of the likely level of another element in a given species. This is useful for issuing recommendations for the consumption of mushrooms when the concentrations of only a limited number of elements are available.

The data set was found to be log-normally distributed and therefore the concentration values were log-transformed for ANOVA and regression analyses. The level of significance used in ANOVA and regression analyses was 95 %.

4 Results and Discussion

Table 7. The median concentrations of Cd, Pb, As and Ni for each mushroom species (dry weight).

Latin	Finnish	Swedish	English	Number of samples	Cd mg kg^{-1}	Pb mg kg^{-1}	As mg kg^{-1}	Ni mg kg^{-1}
Agaricus abruptibulbus	Kuusen herkkusieni	Knölfotad snöbolls-champinjon	Champignon	28	29.70	6.05	5.11	1.22
Albatrellus ovinus	Lampaan-kääpä	Fårticka	Sheep polypore	12	0.48	0.54	0.18	9.08
Boletus species	Herkkutatit	Stensoppar	Cep, Boletes	21	4.51	0.56	0.44	1.50
Cantharellus cibarius	Kanttarelli	Kantarell	Chanterelle	17	0.44	1.71	0.16	2.08
Cantharellus tubaeformis	Suppilo-vahvero	Tratt-kantarell	Trumpet Chanterelle	17	0.48	1.83	0.14	0.87
Craterellus cornucopioides	Musta torvisieni	Svart trumpetsvamp	Horn of Plenty	8	0.93	2.24	0.24	0.79
Gyromitra esculenta	Korvasieni	Stenmurkla	False Morel	5	2.74	0.92	0.16	0.63
Hydnum species	Orakkaat	Tagg-svampar	Hedgehog fungus	23	0.22	0.83	0.61	0.50
Lactarius species	Rouskut	Riskor	Milkcaps	21	0.60	1.23	0.75	0.94
Leccinum species	Punikkitatit	Tegel- & aspsoppar	Orange Birch Bolete	25	0.77	0.36	0.40	0.41
Macrolepiota procera	Ukonsieni	Stolt fjällskivling	Parasol Mushroom	4	0.59	2.15	1.13	1.21
Suillus variegatus	Kangastatti	Sandsopp	Velvet Bolete	10	1.46	1.11	1.54	1.17
Median for all 12 species				191	0.80	1.22	0.42	1.04

Source of trivial names in Swedish: Korhonen (1992) & Phillips (1992)

Source of trivial names in English: British Mycological Society (2005)

The median concentrations of cadmium, lead, arsenic and nickel for each mushroom species are presented in Table 7. Other statistical values for each species may be seen in Appendix 10.

4.1

Cadmium

The range of cadmium concentrations in the mushrooms was very large. The median concentration for all samples was 0.80 mg kg-1 d.w. (see Table 7) but it was slightly raised by the extremely high Cd contents of *Agaricus abruptibulbus* (29.70 mg kg^{-1} d.w.) – with *A. abruptibulbus* excluded, the median value for 11 species was 0.67 mg kg^{-1} d.w. Slightly elevated levels were observed for *Boletus* species (4.51 mg kg^{-1} d.w.), *Gyromitra esculenta* (2.74 mg kg^{-1} d.w.) and *Suillus variegatus* (1.46 mg kg^{-1} d.w.). For all other species the Cd contents were below 1 mg kg^{-1} d.w. the lowest concentration being 0.22 mg kg^{-1} d.w. in *Hydnum* species.

4.2

Lead

A. abruptibulbus had the highest lead concentration with 6.05 mg kg^{-1} d.w. For the other species the concentrations ranged from 0.36 to 1.83 mg kg^{-1} d.w. with rather high levels found in *Craterellus cornucopioides* and *Macrolepiota procera*. *Leccinum* species, *Albatrellus ovinus* and *Boletus* species had the lowest Pb concentrations. The median for all fungi species was 1.22 mg kg^{-1} d.w. and 1.02 mg kg^{-1} d.w. without *A. abruptibulbus*.

4.3

Arsenic

A. abruptibulbus had the highest arsenic level of 5.11 mg kg^{-1} d.w. while the other species' concentrations fell within the range of 0.14 – 1.54 mg kg^{-1} d.w. *M. procera* and *S. variegatus* had somewhat higher than average As levels whereas the lowest concentrations were observed in *A. ovinus*, *G. esculenta*, *C. cibarius* and *C. tubaeformis*. The median including all 12 species was 0.42 mg kg^{-1} d.w. and 0.35 mg kg^{-1} d.w. when *A. abruptibulbus* was excluded.

4.4

Nickel

In general, nickel levels in wild fungi varied between 0.41 and 2.08 mg kg^{-1} d.w. apart from the rather high Ni concentration of 9.08 mg kg^{-1} d.w. found in *Albatrellus ovinus.* Slightly raised levels were measured for *S. variegatus, M. procera, A. abruptibulbus* and *Boletus* species while the other species had concentrations of less than 1 mg kg^{-1} d.w. The median for all species was 1.04 mg kg^{-1} d.w. and 0.99 mg kg^{-1} d.w. without *A. ovinus*.

4.5
Comparison of results with previous studies

Very high cadmium concentrations of up to 45 mg kg^{-1} d.w. have frequently been found especially in *Agaricales* (Stivje & Besson 1976, Meisch et al. 1977, Tyler 1980, Kuusi et al. 1981, Lodenius et al. 1981b, Andersen et al. 1982, Vetter 1993). Cadmium accumulation in *Macrolepiota procera* and *Boletus edulis* has been reported by Byrne & Ravnik (1976) while Andersen et al. (1982) and Lodenius et al. (1981b) found raised Cd levels in other *Boletus* species. High Cd levels have also been found for *Suillus variegatus* (Michelot et al. 1998) and *Lactarius* species (Byrne & Ravnik 1976). The Cd levels of the studied species generally fall within the range of 0.21 – 32.4 mg kg^{-1} d.w. established for Finnish mushrooms in preceding studies (see Appendix 1). The contents of *A. abruptibulbus* and *Gyromitra esculenta* are somewhat higher whereas *Leccinum* species and *M. lepiota* are lower than in previous Finnish research but these concentrations are still well within the range of the levels found for fungi elsewhere in Europe.

Lead is considered to be generally less bioconcentrated in fungi than cadmium. However, Michelot et al. (1998) found lead to be accumulated particularly in *B. edulis, Craterellus cornucopioides, Leccinum aurantiacum* and *Suillus variegatus* with concentrations between 20.75 and 33.80 mg kg^{-1} d.w. High lead accumulation has been shown for *Macrolepiota procera* in the vicinity of metal smelters (Kalač et al. 1996, Svoboda et al. 2000) as well as in rural areas (Jorhem & Sundström 1995). Also *Agaricales* (Stivje & Besson 1976, Kuusi et al. 1981, Lodenius et al. 1981b), *Cantharellus tubaeformis* (Lodenius et al. 1981b) and *Lactarius rufus* (Varo et al. 1980) have been reported to contain elevated lead levels.

Lead concentrations for *C. cornucopioides, G. esculenta* and *M. procera* are higher than has previously been measured in Finland (see Appendix 2). The Pb levels are, however, principally lower than in specimens from many Central European locations, particularly in samples from Denmark (Andersen et al. 1982), France (Michelot et al. 1998) and Germany (Seeger et al. 1976).

The bioaccumulation of arsenic in genera *Agaricus* and *Macrolepiota* has also been shown by Vetter (1993). The As concentration for *C. cibarius* is notably higher and for *C. tubaeformis* lower than the levels of 0.01 – 1.9 mg kg^{-1} d.w. shown in earlier research (Varo et al. 1980, Andersen et al. 1982). The As content of *B. edulis* and *L. rufus* also is higher than is reported in previous Finnish studies. These comparisons are, however, based on very limited information as arsenic levels for the studied species have been established only by very few previous studies (see Appendix 3).

High nickel concentrations of 5.08 – 8.51 mg kg^{-1} d.w. have been observed for *B. edulis, C. cornucopioides, L. aurantiacum* and *S. variegatus* in France (Michelot et al. 1998) (see Appendix 4). Jorhem & Sundström (1995) found the average nickel content of Swedish *A. ovinus* samples to be 7.2 mg kg^{-1} d.w. with some individual samples reaching a concentration of up to 13 mg kg^{-1} d.w. No information was available on Ni levels for *A. ovinus* in Finland. Very low Ni contents have been reported for several other species in Finland by Varo et al. (1980).

4.6
Correlations between elements

Table 8. Correlation coefficients for all fungi species (n=191)

	Cd	Pb	As	Ni
Cd				
Pb	0.328*			
As	0.527*	0.398*		
Ni	0.159*	0.133	-0.086	

* p<0.05

The correlation coefficients for each element pair for all edible mushroom samples may be seen in Table 8 and for each species in Table 9. A significant positive correlation ($p < 0.05$) was observed for four element pairs among all samples: Cd–Pb, Cd–As, Cd–Ni and Pb–As. There was a significant positive correlation between cadmium and lead in *Boletus* species and *Cantharellus cibarius*. Cadmium had a significant correlation with arsenic in *C. cibarius* and with nickel in *Boletus* and *Hydnum* species. Lead and arsenic were correlated in *Cantharellus tubaeformis* and *Suillus variegatus* while lead and nickel concentrations correlated in *Boletus* species, *C. tubaeformis* and *Leccinum* species. A significant negative correlation was observed between lead and arsenic in *Craterellus cornucopioides* as well as between arsenic and nickel in *Agaricus abruptibulbus*.

Table 9. The correlation coefficients for trace element pairs for each mushroom species.

Agaricus abruptibulbus						*Gyromitra esculenta*				
	Cd	Pb	As	Ni			Cd	Pb	As	Ni
Cd	-					Cd	-			
Pb	-0.013	-				Pb	0.759	-		
As	0.113	-0.069	-			As	-0.065	0.507	-	
Ni	-0.085	0.242	-0.699*	-		Ni	0.655	0.635	0.425	-
Albatrellus ovinus						*Hydnum* species				
	Cd	Pb	As	Ni			Cd	Pb	As	Ni
Cd	-					Cd	-			
Pb	-0.364	-				Pb	-0.362	-		
As	0.092	0.234	-			As	-0.069	0.351	-	
Ni	0.571	-0.536	-0.046	-		Ni	0.479*	-0.056	0.047	-
Boletus species						*Lactarius* species				
	Cd	Pb	As	Ni			Cd	Pb	As	Ni
Cd	-					Cd	-			
Pb	0.519*	-				Pb	0.103	-		
As	0.326	0.245	-			As	0.115	-0.403	-	
Ni	0.475*	0.535*	0.326	-		Ni	-0.353	-0.077	-0.058	-

Cantharellus cibarius						*Leccinum* species				
	Cd	Pb	As	Ni			Cd	Pb	As	Ni
Cd	-					Cd	-			
Pb	0.529*	-				Pb	0.204	-		
As	0.629*	0.477	-			As	-0.084	0.155	-	
Ni	0.259	0.314	0.219	-		Ni	0.345	0.472*	0.095	-
Cantharellus tubaeformis						*Macrolepiota procera*				
	Cd	Pb	As	Ni			Cd	Pb	As	Ni
Cd	-					Cd	-			
Pb	-0.008	-				Pb	0.914	-		
As	0.139	0.550*	-			As	0.167	0.423	-	
Ni	0.029	0.705*	0.370	-		Ni	0.112	-0.087	-0.929	-
Craterellus cornucopioides						*Suillus variegatus*				
	Cd	Pb	As	Ni			Cd	Pb	As	Ni
Cd	-					Cd	-			
Pb	-0.155	-				Pb	0.130	-		
As	-0.120	-0.774*	-			As	0.599	0.682*	-	
Ni	-0.373	0.196	-0.397	-		Ni	0.458	0.374	0.225	-

* p<0.05

4.7
Legislative standards

The intake limits set by JECFA and WHO may be seen in Table 10. According to the EU Scientific Committee for Food Adult Weight parameter (DOH 2002), 60 kg was used for intake calculations as the weight of an average consumer.

Table 10. JECFA provisional tolerable weekly intake (PTWI) values for Cd, Pb, As and Ni.

	Cd mg kg^{-1}	Pb mg kg^{-1}	As mg kg^{-1}	Ni mg kg^{-1}
PTWI per kg body weight	0.007	0.025	0.015	0.035**
PTWI per adult (of 60 kg)	0.42	1.50	0.90	2.10

**Calculated from WHO Tolerable Daily Intake (TDI) for nickel = 0.005 mg kg^{-1} body weight
Sources: Council of Europe (2001) & DOH (2002)

The EU has set a maximum permitted level (mg kg^{-1} wet weight) for cadmium and lead in cultivated mushrooms but no legislative standards are as yet set for arsenic and nickel in similar food products by the EU (European Commission 2001). The limit for Cd, 0.2 mg kg^{-1} wet weight, was exceeded not only by the median of *Agaricus abruptibulbus* but also by *Boletus* species and *Gyromitra esculenta* (see Table 11 for fresh fungi median values). In addition, some individual specimens of *Lecci-*

num species, *Macrolepiota procera* and *Suillus variegatus* were found to exceed the EU level. The highest contents of up to 13.10 mg kg^{-1} f.w. were measured for specimens of *A. abruptibulbus* while the Cd concentrations for samples of all other species were below 1 mg kg^{-1} f.w.

Table 11. The median concentrations of Cd, Pb, As and Ni in fresh fungi material.

	Cd mg kg^{-1} fresh weight	Pb mg kg^{-1} fresh weight	As mg kg^{-1} fresh weight	Ni mg kg^{-1} fresh weight
Agaricus abruptibulbus	2.970	0.605	0.511	0.122
Albatrellus ovinus	0.040	0.045	0.015	0.771
Boletus species	0.451	0.056	0.044	0.150
Cantharellus cibarius	0.040	0.154	0.014	0.187
Cantharellus tubaeformis	0.031	0.119	0.009	0.057
Craterellus cornucopioides	0.087	0.210	0.022	0.074
Gyromitra esculenta	0.274	0.092	0.016	0.063
Hydnum species	0.015	0.057	0.042	0.035
Lactarius species	0.051	0.104	0.063	0.079
Leccinum species	0.059	0.028	0.031	0.032
Macrolepiota procera	0.059	0.215	0.113	0.121
Suillus variegatus	0.146	0.111	0.154	0.117
EU maximum permitted level	0.2	0.3		

The EU maximum permitted level for lead in cultivated mushrooms is 0.3 mg kg^{-1} wet weight (European Commission 2001). The median concentration of *Agaricus abruptibulbus* only was higher than this limit (see Table 11). Most of the individual samples with high lead contents were specimens of *A. abruptibulbus* but some samples of *Boletus* species, *Cantharellus cibarius, Craterellus cornucopioides, Lactarius* species, *Leccinum* species and *Macrolepiota procera* also had Pb concentrations exceeding the EU maximum permitted level. Extremely high lead levels were observed for several samples of *A. abruptibulbus* with up to 5.51 mg kg^{-1} f.w., and for one *M. procera* specimen with 3.38 mg kg^{-1} f.w. In general, specimens with the highest concentrations were growing at sites along main roads or in urban centres with high traffic contamination levels. The highest Pb concentrations were largely measured for samples collected within the period of 1977 –1983 but also for a few specimens from 1992 –1999.

4.8

Possible toxicological risks

The effects of elevated trace element concentrations are usually accumulative and the implications for health can be seen on a long-term basis. Nevertheless, Michelot et al. (1998) suggested that the high accumulation of some metals in fungi may explain abnormal incidents of poisoning caused by species classified as edible. Nickel is of particular interest as there are indications that an oral intake of 2.5 mg of Ni may cause a flare of dermatitis in individuals who already suffer from skin nickel dermatitis (Veien 1997). Single peak doses of Ni are suggested to have more significance in the production of vesicular hand eczema flares than the mean daily intake.

Table 12. Amount of fresh fungi that may be consumed according to JECFA (FAO/WHO) limits.

	Cd kg/week	Pb kg/week	As kg/week	Ni kg/week
Agaricus abruptibulbus	0.14	2.48	1.76	17.21
Albatrellus ovinus	10.40	32.99	60.50	2.72
Boletus species	0.93	26.79	20.45	14.00
Cantharellus cibarius	10.61	9.75	62.50	11.22
Cantharellus tubaeformis	13.46	12.61	98.90	37.14
Craterellus cornucopioides	4.83	7.14	40.74	28.28
Gyromitra esculenta	1.53	16.30	56.25	33.33
Hydnum species	27.67	26.19	21.38	60.87
Lactarius species	8.30	14.46	14.23	26.49
Leccinum species	7.08	54.11	29.22	66.52
Macrolepiota procera	7.18	6.99	7.96	17.43
Suillus variegatus	2.88	13.51	5.84	18.03

4.8.1

Cadmium

Agaricus abruptibulbus, Boletus species and *Gyromitra esculenta* seemed to have the greatest tendency to accumulate cadmium. A person who is 60 kg in weight could safely intake 0.42 mg of Cd per week (see Table 12) without exceeding the provisionally tolerable weekly intake (PTWI) of 0.007 mg kg^{-1} set by JECFA. Accordingly, 1.53 kg of fresh *G. esculenta* fungi could be consumed per week while the tolerable amount of fresh *A. abruptibulbus* would be merely 0.14 kg. No data on the average daily amount of mushrooms eaten per individual in Finland were available. However, it is estimated here that the consumption of mushrooms may be approximately 100 g of fresh fungi per meal per person. Thus two meals of *A. abruptibulbus* per week are enough to exceed the recommended limits for cadmium intake.

4.8.2

Lead

The concentrations of lead varied from 0.36 mg kg^{-1} d.w. for *Leccinum* species to 6.05 mg kg^{-1} d.w. for *Agaricus abruptibulbus*. A person weighing 60 kg could have 2.48 kg of fresh *A. abruptibulbus* and even 54.11 kg of *Leccinum* species without exceeding the JECFA PTWI of 0.025 mg kg^{-1} body weight.

The maximum tolerable daily intake amount for children weighing 20 kg is 0.007 mg $kg^{-1}$of Pb (National Food Agency 2002a). As the weekly intake should not exceed 0.49 mg kg^{-1}, a safe amount of *Agaricus abruptibulbus* is only 0.08 g for children.

4.8.3

Arsenic

The greatest content of arsenic, 0.51 mg kg^{-1} f.w., was found in fresh *Agaricus abruptibulbus*. The concentrations in other species were generally less than 0.1 mg kg^{-1} f.w. apart from the slightly elevated levels of *Suillus variegatus* and *Macrolepiota procera*. JECFA has established a PTWI of 0.015 mg kg^{-1} body weight allowing 0.9 mg of arsenic to be consumed weekly by a person of 60 kg in weight. As 1.76 kg of fresh *A. abruptibulbus* could be eaten per week without exceeding the PTWI value, no significant risk of excess arsenic intake is seen to arise from the consumption of the studied mushroom species.

4.8.4

Nickel

The nickel contents of fresh fungi were mostly between 0.032 and 0.187 mg kg^{-1} f.w. aside from *Albatrellus ovinus*, which had an exceptionally high Ni concentration of 0.771 mg kg^{-1} f.w. JECFA has not established a limit for nickel but the value for tolerable daily intake for nickel set by WHO (WHO 1991) is 0.005 mg kg^{-1} body weight. For a person weighing 60 kg this would mean an amount of 2.1 mg of nickel per week. On the basis of the nickel content *Hydnum* species, for instance, could thereby be consumed up to about 60.87 kg fresh fungi per week and *Leccinum* species even up to 66.52 kg fresh fungi per week. However, in the case of *A. ovinus* the amount recommended would only be approximately 2.72 kg f.w. per week or 0.39 kg fresh fungi per day.

3.24 kg of fresh *A. ovinus* is required to obtain the above-mentioned 2.5 mg oral dose of Ni. Thus there seems to be no significant risk of a single peak dose to individuals suffering from nickel allergy.

It has to be taken into consideration that values calculated in this manner assume there to be no other sources of the elements in diet. As the total intake levels for trace elements can vary considerably according to dietary preferences, the guideline levels calculated here for safe fungi consumption are, in fact, somewhat higher than the amounts of mushrooms advisable to eat. Moreover, the PTWI and PTDI values for foodstuff do not include the additional intake from other common sources such as drinking water or cigarettes.

It should also be noted that according to JECFA the safety margin between the exposure in the normal diet and the level causing adverse health effects may be relatively small (Council of Europe 2001). This is true with cadmium in particular, as the Cd exposure from diet alone is very close to the established PTWI level for a considerable part of the population (Council of Europe 2001).

4.9
Causes of variation in element concentrations

4.9.1
Traffic

The reach of traffic pollutants is dependent on the amount of the pollution and climatic conditions as well as on local factors such as surface relief, vegetation or built structures (Nurmi 1982). Rural regions have generally lower pollution levels than urban areas but large amounts of particulate pollutants are also present in more remote areas along large roads and particularly in intersection areas. According to Nurmi (1982), the Pb content of forest vegetation growing 40 – 50 m away from a road is usually decreased to about half of the level measured for the vegetation on the immediate road side. At locations with more sparse vegetation the concentrations may remain high even at a distance of 100 m.

The effect of traffic was investigated by splitting the sampling sites into two categories: polluted and unpolluted. The polluted sites included the sites in the most densely populated region in the capital area and around another town, Riihimäki, as well as sites at a distance of 50 m or less from streets with moderate or heavy traffic or less than 100 m away from motorways or other major roads in other areas of the country. Unpolluted sites were located in relatively remote, mainly forested regions of Southern Finland with no significant roads in their proximity.

ANOVA analysis was performed to test whether there is a significant difference between the samples from polluted and unpolluted locations. Only the Pb concentrations of *Agaricus abruptibulbus* ($p = 0.023$) and the Cd contents of *Lactarius* species ($p = 0.032$) showed a statistically significant difference between the polluted and unpolluted sites.

The effect of traffic on lead levels of fungi has been observed by Kuusi et al. (1981) and Lodenius et al. (1981b). Laaksovirta & Alakuijala (1978) found a significant positive correlation between both cadmium and lead contents and traffic flow in the Helsinki area. In addition, they noted that Cd and Pb concentrations increased with traffic density. The correlation was, however, calculated for all samples representing different species and therefore no single species can be used for comparison.

4.9.2
Temporal variation

Temporal differences were investigated between mushroom samples collected during the years 1977 – 1983 and 1992 – 1999. Table 13 shows the concentrations of cadmium, lead, nickel and arsenic for the seven species with two or more specimens in each temporal group. Due to the previously mentioned decline in traffic-originated atmospheric lead levels since the early 1990s, higher Pb values were expected for the period of 1977 – 1983. The samples collected in 1977 – 1983 had slightly higher lead concentrations in all species with statistically significant ($p < 0.05$) difference between the two time periods seen in *Albatrellus ovinus* ($p = 0.0025$), *Boletus* species ($p = 0.0004$), *Cantharellus tubaeformis* ($p = 0.0008$) and *Lactarius* species ($p = 0.0030$). A significant difference was found also for cadmium concentrations in *Agaricus abruptibulbus* ($p = 0.0088$) and *Leccinum* species ($p = 0.0483$). It should be noted that even though *A. abruptibulbus* had a very high Cd content of 35.80 mg kg^{-1} d.w. in the earlier samples the Cd levels for the more recent samples were also considerably high, that is 12 mg kg^{-1} d.w. No significant temporal variation was observed for As and Ni levels in the samples.

Table 13. The median Cd, Pb, As and Ni concentrations for mushrooms collected in 1977 – 1983 and 1992 – 1999 (dry weight).

Years		Cd mg kg^{-1}	Pb mg kg^{-1}	As mg kg^{-1}	Ni mg kg^{-1}
1977-1983	*Agaricus abruptibulbus*	35.80*	7.77	3.99	1.20
1992-1999	*Agaricus abruptibulbus*	12.00*	3.40	8.12	1.39
1977-1983	*Albatrellus ovinus*	0.40	0.73*	0.24	9.28
1992-1999	*Albatrellus ovinus*	0.62	0.19*	0.14	8.06
1977-1983	*Boletus* species	4.59	0.63*	0.45	1.59
1992-1999	*Boletus* species	2.37	0.20*	0.43	1.31
1977-1983	*Cantharellus tubaeformis*	0.48	1.90*	0.15	0.97
1992-1999	*Cantharellus tubaeformis*	0.35	0.63*	0.12	0.67
1977-1983	*Hydnum* species	0.26	0.99	0.50	0.49
1992-1999	*Hydnum* species	0.09	0.73	0.89	0.50
1977-1983	*Lactarius* species	0.60	1.30*	0.75	0.97
1992-1999	*Lactarius* species	0.75	0.35*	0.72	0.88
1977-1983	*Leccinum* species	0.82*	0.44	0.36	0.37
1992-1999	*Leccinum* species	0.55*	0.24	0.40	0.45

* = Statistically significant difference between the temporal groups of a species ($p < 0.05$)

Changes in element contents due to temporal variation have rarely been studied for wild mushrooms in Finland but a decrease in lead levels has been observed for Finnish fruit and vegetables with a reduction of approximately 25 % between the 1970s and 1990s (Mustaniemi et al. 1994). The reduced Pb levels in fungi are therefore likely to be a consequence of the substantial decrease in the amount of lead from traffic emissions.

The temporal variation in cadmium contents of fungi agreed with concentrations found in vegetables, which have generally experienced some or no reduction in Finland during the same time period (Mustaniemi & Hallikainen 1994). Movitz (1980) found that Cd concentrations in some *Agaricus* species collected between 1890 and 1926 were similar to the levels measured for samples from 1979. This indicates that background concentrations of Cd, which are largely governed by the intensity of industrial and other human activities present, have a relatively minor effect on the element levels accumulated in fungi. Furthermore, Mustaniemi & Hallikainen (1994) point out that some reductions in element concentrations, particularly in the case of Cd, are associated not only with changes in environmental concentrations but also with the improved accuracy of modern measurement techniques and lower detection limits.

4.9.3

Ecological groups

The studied decomposer species, that is *Agaricus abruptibulbus, Gyromitra esculenta* and *Macrolepiota procera*, had markedly higher contents of cadmium, lead and arsenic than the larger group of mycorrhizal species (see Table 14). However, the very high levels of the large *A. abruptibulbus* assemblage distorted the average values for the decomposers: without *A. abruptibulbus* (see Table 14) only the cadmium concentration for the decomposers was considerably greater than that for the mycorrhizal group. There was a highly significant difference ($p < 0.001$) between the Cd, Pb and Ni levels of the mycorrhizal and decomposer groups. No significant differences were found between the trace element concentrations of the two groups when *A. abruptibulbus* was excluded.

Table 14. The median Cd, Pb, As & Ni concentrations for decomposer and mycorrhizal fungi groups (dry weight).

	Cd mg kg^{-1}	Pb mg kg^{-1}	As mg kg^{-1}	Ni mg kg^{-1}
Decomposer sp. (3 species)	16.00*	4.11*	3.26	1.10*
Mycorrhizal sp. (9 species)	0.65*	1.03*	0.36	1.03*
Decomposer sp. (excluding *Agaricus abruptibulbus*)	2.23	0.98	0.74	0.24

* = Highly significant difference between the fungi groups ($p < 0.001$)

These results are similar to the ones by Lodenius et al. (1981a), who measured notably higher concentrations of Cd and Pb in decomposer species. Significantly higher lead contents for decomposers were also found by Laaksovirta & Alakuijala (1978) and Kuusi et al. (1981). In contrast, Gast et al. (1988) and Demirbaş (2001b) found no difference between the mycorrhizal and decomposer groups. However, both of the latter studies were performed merely on six species as well as by using species different to this research and therefore cannot be directly applied to Finnish mushrooms.

4.9.4

Different parts

Some documentation has been carried out on the accumulation of trace elements in the different parts of mushroom fruiting bodies. Stivje & Roschnik (1974) found that the concentrations of methyl mercury are higher in the cap than in the stalk. Ohtonen (1982) noted higher levels of Mg and Cu in caps of *L. rufus* and *S. variegatus* but higher Mn levels in stalks.

As a part of this study, the cap and stalk of one specimen of *Macrolepiota procera*, a decomposer species, were analysed to give a rough indication of the element distribution in the fruit body. The values for cadmium, lead and arsenic (see Table 15a) were higher for the cap whereas the nickel content is greater in the stalk. On the whole, the variation in trace element levels between the two parts seemed, however, relatively small. This supports the results by Falandysz & Chwir (1997), who found a higher Hg content in the caps than stalks of *Macrolepiota procera*.

Table 15a. The Cd, Pb, As & Ni concentrations for different parts of *Macrolepiota procera* (dry weight).

Macrolepiota procera	Cd mg kg^{-1}	Pb mg kg^{-1}	As mg kg^{-1}	Ni mg kg^{-1}
Cap	0.87	2.33	0.51	1.39
Stalk	0.24	0.98	0.35	2.21

Table 15b. The Cd, Pb, As & Ni concentrations for different parts of *Boletus edulis* (dry weight).

Boletus edulis	Cd mg kg^{-1}	Pb mg kg^{-1}	As mg kg^{-1}	Ni mg kg^{-1}
Cap	1.94	0.69	0.17	1.20
Stalk	1.85	0.42	0.19	1.08
Sporophore	9.95	0.56	0.33	1.97

The trace element content of the different parts was also determined for one specimen representing the mycorrhizal group, *Boletus edulis*. Concentration of Cd in particular was higher in the cap than in the stalk (see Table 15b). Pb, Ni, and As had moderately higher levels in the cap. Nevertheless, greater differences could be observed when the sporophore was analysed separately. The amount of cadmium was noticeably higher in the sporophore (9.95 mg kg^{-1} dry weight) than in the rest of the cap (1.94 mg kg^{-1} d.w.) or stalk (1.85 mg kg^{-1} d.w.). Nickel and arsenic were also slightly more abundant in the sporophore (1.97 and 0.33 mg kg^{-1} d.w., respectively) compared to the rest of the cap (1.20, 0.17 mg kg^{-1} d.w.) and stalk (1.08, 0.19 mg kg^{-1} d.w.). This corroborates the findings of Meisch et al. (1977), Melgar et al. (1998) and Alfthan (unpubl.).

In general, the sporophore seemed to accumulate the greatest amount of trace elements while no significant difference was detected in the concentrations for the rest of the cap and stalk. The only exception was made by lead: Pb concentration in *B. edulis* was virtually uniform for the sporophore (0.56 mg kg^{-1} d.w.), cap (0.69 mg kg^{-1} d.w.) and stalk (0.42 mg kg^{-1} d.w.). However, these results were based on a single sample and therefore only act as indicators of the differences between the fruit body parts. In order to perform statistical analyses and draw conclusions about the general trace element levels in wild fungi a much larger sample set must be investigated.

4.9.5

Other factors

Other factors suggested having an influence on the mushroom element concentrations include the growth stage and protein content of the fruit body as well as the soil pH level. The growth stage of the fruit body has been found to affect the trace element concentrations found in the edible parts of mushrooms. The results of Stivje & Roschnik (1974) and Leh (1975) show higher concentrations for mature sporocarps whereas Seeger et al. (1976) measured greater amounts of elements in the juvenile sporocarps of *Agaricus* species and *Boletus edulis*.

Ohtonen (1982), however, observed higher concentrations of Mg, Cu and Zn in the smallest *Suillus variegatus* specimens but no obvious differences was seen for *Lactarius rufus*. This is suggested to result from the higher growth rate of *Suillus variegatus*.

Protein content is suggested to be a potential factor affecting the element content of mushrooms. Stivje & Besson (1976) found Hg and Se concentrations to be correlated with the sulfhydryl protein groups in six edible fungi species including *B. edulis, C. cibarius* and *M. procera*. This could explain some of the variation within different species as they are reported to contain very differing amounts of protein (Souci et al. 1981).

Most Finnish forest areas have an acidic soil type. In general, the mobility of metals increases as the pH level decreases. Nuorteva et al. (1986) found cadmium in particular to be activated by acidic conditions whereas Movitz (1980) saw no differences in the Cd content of *Agaricus* species growing on chalk land and acidic soil. Gast et al. (1988) state the trace element levels in fungi to be generally rather unaffected by the pH level of the substrate. They concluded that these results can, however, be due to the generally low pH values in all examined soils. Nevertheless, acidification processes occurring in the soil may eventually lead to the release of metals that have previously been accumulated in the soil (WHO 1991, Rühling 1994, Voegelin et al. 2003).

Other factors may, however, counteract the effect of acidification. For example, pesticides containing phosphates are found to bind lead to the soil and thus reduce the amount of lead available for plant uptake (Lahermo et al. 1996). Acid precipitation and particularly pollutants such as sulphur dioxide may also decrease the extent of mycelium and reduce its growth (Holopainen 2002), which in turn can reduce the ability of fungi to accumulate trace elements.

5 Conclusions

Table 16. The maximum amount of fresh fungi recommended for consumption according to JECFA (FAO/WHO) limits.

	kg/week	Limiting element
Agaricus abruptibulbus	0.14	Cd
Boletus species	0.93	Cd
Gyromitra esculenta	1.53	Cd
Albatrellus ovinus	2.72	Ni
Suillus variegatus	2.88	Cd
Craterellus cornucopioides	4.83	Cd
Macrolepiota procera	6.99	Pb
Leccinum species	7.08	Cd
Lactarius species	8.30	Cd
Cantharellus cibarius	9.75	Pb
Cantharellus tubaeformis	12.61	Pb
Hydnum species	21.38	As

Table 16 presents a summary of the maximum weekly amounts of fresh mushrooms that are recommended for consumption according to the PTWI and PTDI limits by JECFA (Council of Europe 2001). The recommended levels are mainly limited by Cd, which is considered to be the only studied element that may potentially cause a health risk. This is due to the fact that it is seen rather unlikely for any individual to consume more than 0.2 kg of mushrooms daily or more than 1.4 kg weekly.

In general, the trace element contents of fungi in Southern Finland were relatively low. However, the consumption of *Agaricus abruptibulbus*, which had significantly high concentrations of cadmium, lead and arsenic, should be avoided. Lodenius et al. (1981b) also noted that even though other edible *Agaricus* species may have lower trace element concentrations, it is advisable to limit the consumption of wild *Agaricales* due to the difficulty of identifying the different species.

High concentrations of Cd were also found in *Boletus* species, particularly in its spore-forming part, and *Gyromitra esculenta*. They are therefore recommended only for occasional consumption. Furthermore, decomposing species tended to generally accumulate elements more than mycorrhizal species. Thus it may be advisable to mainly consume mycorrhizal species, which in fact constitute the majority of edible mushrooms in Finland.

Surprisingly high levels of nickel were found in *Albatrellus ovinus* and more research is required especially on the health impacts related to nickel contact dermatitis. There seems to be no immediate risk of Ni poisoning but it is not advisable to consume excessive amounts of *A. ovinus*, particularly not by individuals with nickel allergy.

A rather limited data is currently available on the concentrations of arsenic and nickel in fungi and therefore only very limited comparisons could be made with other locations. What is more, the surprisingly high nickel contents for *Albatrellus ovinus* imply that it is essential to expand monitoring programmes to other less frequently studied elements.

For this research no distinction was made between the different chemical forms of elements in fungi but only the total amount of each element was determined. The uptake of different forms and complexes of trace elements in mushrooms should, however, be considered in more detail as the impacts on health can vary depending on the chemical form of the trace element ingested. Further investigations should also be focused on the possible accumulative and synergistic toxicological effects of multiple trace elements in fungi.

When evaluating the toxicity of an element and the risks posed by exceeding a particular exposure level, it is necessary to take notice of the factors influencing the actual effects of a toxic element. For instance, the absorption of zinc and copper is reduced by cadmium (Klaassen 1996). Furthermore, cadmium interferes with enzyme reactions by disturbing the role of zinc in essential body mechanisms (Lahermo et al. 1996). High levels of zinc in nutrition are thought to provide protection from the effects of cadmium (Lahermo et al. 1996). Moreover, cadmium bioavailability in food has been found to be associated adversely with iron nutrition in human feeding studies and also affected by the presence of elements such as zinc, potassium and calcium as well as phytate, fiber and other food constituents (McLaughlin et al. 1999).

Element concentrations in the environment have largely been shown to have less importance in the mushroom trace element contents than genetic factors. However, Stivje & Besson (1976) note that the enrichment correlation factor between the fungus and the substrate may show some distortion due to the pieces of mycelium often present in soil samples.

A more accurate investigation is required on the specific parameters, such as differences between the parts of the fruit body or distance from traffic, that may help consumers at choosing mushrooms. A future study should include a larger set of samples for several species that are recorded as representatives of juvenile and mature states, as well as more samples of which the cap, stalk and spores are analysed separately. It would be also interesting to further explore the possible changes resulting from an increasing distance from traffic within the same area. In addition, a more profound examination of variations due to genetic characteristics requires a great number of multiple samples from several different types of sites. It should be noted that due to above-mentioned difficulty of actually finding samples with only one differing predominant parameter, the task of eliminating the effect of surrounding environmental conditions on such detailed studies could, however, prove to be extremely demanding.

This research has been successful as it has met the objectives to increase the knowledge on Cd and Pb levels in several edible fungi species and to establish concentrations for As and Ni, which have not been broadly investigated in previous research on mushrooms. The study also assessed possible toxicological risks involved in the consumption of wild fungi in Finland and examined potential factors influencing the accumulation of the studied trace elements in mushrooms. Overall, the research has provided recommendations for consumers on choosing and consuming wild mushrooms safely.

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Appendix 1. Cadmium concentrations for mushrooms in some previous studies.

Species	Origin	No of samples	Cd mg kg^{-1} dry weight	Range mg kg^{-1}	Reference
Agaricus abruptibulbus	Denmark	1	37		Andersen et al. 1982
	Hungary		45		Vetter 1993
	Germany	13	26.43	0.33-77.9	Meisch et al. 1977
Agaricus species	Finland	53	12	0.4-100	Lodenius et al. 1981b
	Finland	16	32	<0.2-130	Lodenius et al. 1981b (Mikkeli)
	Finland	2	16.8	0.6-33.0	Kuusi et al. 1981
	Sweden	4	0.1*	0.03-0.18*	Jorhem & Sundström 1995
	Yugoslavia	1	1.38		Byrne & Ravnik 1976
Albatrellus ovinus	Finland	4	0.8	0.5-1.9	Kuusi et al. 1981
	Sweden	6	0.74*	0.14-1.5*	Jorhem & Sundström 1995
Boletus edulis	Finland	6	1.3	0.4-0.29	Kuusi et al. 1981
	Finland	6	2.9	<0.2-5.7	Lodenius et al. 1981b
	Finland	2	1.95	0.9-3.0	Varo et al. 1980
	Sweden	5	2.1*	1.1-4.1*	Jorhem & Sundström 1995
	The Czech Republic	20	2.3		Kalač et al. 1991
	The Czech Republic	5	15		Kalač et al. 1991 (Pb smelter area)
	Slovakia	5	6.58		Kalač et al. 1996 (Cu smelter area)
	Yugoslavia	3	2.26	1.55-3.5	Byrne & Ravnik 1976
	France	2	1.55	1.39-1.7	Michelot et al. 1998
Boletus species	Finland	62	1.62	0.30-6.73	Eurola et al. 1996
	Finland	17	1.3	0.4-2.9	Kuusi et al. 1981
	Finland	7	5.3	0.3-25	Lodenius et al. 1981b
	Denmark	3	6.2	2.4-12	Andersen et al. 1982
	Turkey		1.03		Tüzen et al. 1998
Cantharellus cibarius	Finland	64	0.29	0.07-1.15	Eurola et al. 1996
	Finland	5	0.24	0.2-0.3	Varo et al. 1980
	Finland	4	0.5	0.2-0.9	Kuusi et al. 1981
	Finland	4	1	0.4-2.0	Lodenius et al. 1981b
	Sweden	6	0.90*	0.4-2.57*	Jorhem & Sundström 1995
	Yugoslavia	1	0.62		Byrne & Ravnik 1976
Cantharellus tubaeformis	Finland	34	0.51	0.08-2.50	Eurola et al. 1996
	Finland	1	1.2		Kuusi et al. 1981
	Finland	1	0.7		Lodenius et al. 1981b
	Sweden	5	1.5*	0.54-3.1*	Jorhem & Sundström 1995
	Denmark	1	0.5		Andersen et al. 1982

Species	Origin	No of samples	Cd mg kg-1 dry weight	Range mg kg-1	Reference
Craterellus cornucopioides	Finland	26	0.43	0.12-1.01	Eurola et al. 1996
	Sweden	4	2.2*	0.5-4.3*	Jorhem & Sundström 1995
	Denmark	3	0.3	0.2-0.5	Andersen et al. 1982
	France	1	2.06		Michelot et al. 1998
Gyromitra esculenta	Finland	2	0.21		Varo et al. 1980
Hydnum repandum	Finland	3	0.3	0.2-0.6	Kuusi et al. 1981
	Finland	1	<0.2		Lodenius et al. 1981b
	Sweden	5	0.44*	0.08-0.86*	Jorhem & Sundström 1995
	Denmark	1	0.2		Andersen et al. 1982
	Turkey		3.42		Tüzen et al. 1998
Lactarius deliciosus	Yugoslavia	4	2.94	0.88-4.6	Byrne & Ravnik 1976
	Slovakia	3	1.27		Kalač et al. 1996 (Hg smelter area)
Lactarius deterrimus	Sweden	5	0.73*	0.18-1.8*	Jorhem & Sundström 1995
Lactarius rufus	Finland	5	0.54	0.4-0.9	Varo et al. 1980
Lactarius torminosus	Finland	5	0.22	0.2-0.3	Varo et al. 1980
	Yugoslavia	1	1.3		Byrne & Ravnik 1976
Lactarius trivialis	Finland	71	0.26	0.05-1.15	Eurola et al. 1996
	Finland	6	0.233	0.1-0.4	Varo et al. 1980
Lactarius species	Finland	11	0.8	0.3-0.15	Kuusi et al. 1981
	Finland	11	1	0.5-1.5	Lodenius et al. 1981b
	Turkey		1.16		Tüzen et al. 1998
	Yugoslavia	3	5.73	0.59-10.3	Byrne & Ravnik 1976
Leccinum aurantiacum	France	1	2.36		Michelot et al. 1998
	Hungary		0.35		Byrne & Ravnik 1976
Leccinum species	Finland	72	1.57	0.08-6.17	Eurola et al. 1996
	Turkey		0.66		Tüzen et al. 1998
Macrolepiota procera	Finland	2	1.2	1.1-1.3	Kuusi et al. 1981
	Sweden	3	1.46*	1.15-1.92*	Jorhem & Sundström 1995
	Yugoslavia	3	7.11 (cap only)	5.72-11	Byrne & Ravnik 1976
	Slovakia	10	5.92		Kalač et al. 1996 (Cu smelter area)
	Slovakia	3	2.14		Kalač et al. 1996 (Hg smelter area)
	United Kingdom	2	0.16*	0.06-0.26*	Thomas 1992
Suillus variegatus	France	1	8.95		Michelot et al. 1998

* = converted to dry weight using the value of 10 % dry material

Appendix 2. Lead concentrations for mushrooms in some previous studies.

Species	Origin	No of samples	Pb mg kg^{-1} dry weight	Range mg kg^{-1}	Reference
Agaricus abruptibulbus	Denmark	1	4.4		Andersen et al. 1982
Agaricus species	Finland	53	9.2	<0.5-30	Lodenius et al. 1981b
	Finland	14	5.1	1.2-10	Lodenius et al. 1981b (Mikkeli)
	Finland	2	13	8.0-18.0	Kuusi et al. 1981
	Sweden	4	0.11*	<0.06-0.19*	Jorhem & Sundström 1995
	United Kingdom	1	3.2 *		Thomas 1992
Albatrellus ovinus	Finland	4	<0.5		Kuusi et al. 1981
	Sweden	6	0.25*	0.1-0.44*	Jorhem & Sundström 1995
Boletus edulis	Finland	6	0.9	<0.5-2.0	Kuusi et al. 1981
	Finland	6	0.9	<0.5-2.5	Lodenius et al. 1981b
	Finland	2	0.3	0.2-0.4	Varo et al. 1980
	Sweden	5	0.27*	0.05-0.86*	Jorhem & Sundström 1995
	The Czech Republic	20	1.2		Kalač et al. 1991
	Slovakia	5	3.03		Kalač et al. 1996 (Cu smelter area)
	France	2	20.75	20.3-21.2	Michelot et al. 1998
Boletus species	Finland	63	0.24	0.04-0.87	Eurola et al. 1996
	Finland	17	0.9	<0.5-4.3	Kuusi et al. 1981
	Finland	7	1.1	<0.5-3.3	Lodenius et al. 1981b
	Denmark	3	1.1	0.6-2.2	Andersen et al. 1982
	Germany	44	8.35		Seeger et al. 1976
	Turkey		0.965		Tüzen et al. 1998
Cantharellus cibarius	Finland	64	0.26	0.07-0.78	Eurola et al. 1996
	Finland	5	1.1	0.6-2.0	Varo et al. 1980
	Finland	4	0.7	<0.5-1.0	Kuusi et al. 1981
	Finland	4	1.7	0.6-3.2	Lodenius et al. 1981b
	Sweden	6	0.84*	0.14-3.3*	Jorhem & Sundström 1995
Cantharellus tubaeformis	Finland	34	0.68	0.21-2.12	Eurola et al. 1996
	Finland	1	1.4		Kuusi et al. 1981
	Finland	1	8.9		Lodenius et al. 1981b
	Sweden	5	0.9*	0.57-1.4*	Jorhem & Sundström 1995
	Denmark	1	9.8		Andersen et al. 1982
Cantharellus species	Germany	11	7.18		Seeger et al. 1976
	Germany	5	5.2	2.9-9.4	Leh 1975

Species	Origin	No of samples	Pb mg kg^{-1} dry weight	Range mg kg^{-1}	Reference
Craterellus cornucopioides	Finland	26	0.6	0.18-1.44	Eurola et al. 1996
	Sweden	4	3.8*	1.1-8.8*	Jorhem & Sundström 1995
	Denmark	3	7.7	4.3-15	Andersen et al. 1982
	France	1	30.7		Michelot et al. 1998
Gyromitra esculenta	Finland	2	0.07		Varo et al. 1980
Hydnum repandum	Finland	3	0.9	0.7-1.2	Kuusi et al. 1981
	Finland	1	0.5		Lodenius et al. 1981b
	Sweden	5	0.5*	0.3-0.66*	Jorhem & Sundström 1995
	Denmark	1	1.3		Andersen et al. 1982
	Turkey		2.45		Tüzen et al. 1998
Hydnum species	Germany	6	11.04		Seeger et al. 1976
Lactarius deterrimus	Sweden	5	0.33*	0.18-0.6*	Jorhem & Sundström 1995
Lactarius rufus	Finland	5	13.6	1.0-40.0	Varo et al. 1980
Lactarius torminosus	Finland	5	1.6	1.0-3.0	Varo et al. 1980
Lactarius trivialis	Finland	70	0.33	0.09-1.00	Eurola et al. 1996
	Finland	6	0.92	0.5-2.0	Varo et al. 1980
Lactarius species	Finland	11	1.8	<0.5-8.5	Kuusi et al. 1981
	Finland	11	3.3	<0.5-8.9	Lodenius et al. 1981b
	Turkey		3.21		Tüzen et al. 1998
Leccinum aurantiacum	France		33.8		Michelot et al. 1998
Leccinum species	Finland	71	0.28	0.04-1.27	Eurola et al. 1996
	Turkey		0.437		Tüzen et al. 1998
Macrolepiota procera	Finland	2	0.7	0.6-0.8	Kuusi et al. 1981
	Sweden	3	7.4*	2.9-11*	Jorhem & Sundström 1995
	Slovakia	10	26.4		Kalač et al. 1996 (Cu smelter area)
	Slovakia	3	2.84		Kalač et al. 1996 (Hg smelter area)
	United Kingdom	2	0.14 *	0.06-0.22*	Thomas 1992
Suillus variegatus	France	1	27.7		Michelot et al. 1998

* = converted to dry weight using the value of 10 % dry material

Appendix 3. Arsenic concentrations for mushrooms in some previous studies.

Species	Origin	No of samples	As mg kg^{-1} dry weight	Range mg kg^{-1}	Reference
Agaricus abruptibulbus	Denmark	1	3.1		Andersen et al. 1982
Agaricus species	Yugoslavia	1	0.35		Byrne & Ravnik 1976
Boletus edulis	Finland	2	0.01		Varo et al. 1980
	Yugoslavia	3	0.65	0.42-1.04	Byrne & Ravnik 1976
Boletus species	Denmark	3	0.8	0.6-1.0	Andersen et al. 1982
Cantharellus cibarius	Finland	5	0.01		Varo et al. 1980
	Yugoslavia	1	0.16		Byrne & Ravnik 1976
Cantharellus tubaeformis	Denmark	1	1.9		Andersen et al. 1982
Craterellus cornucopioides	Denmark	3	0.9	0.4-1.5	Andersen et al. 1982
Hydnum repandum	Denmark	1	0.3		Andersen et al. 1982
Lactarius deliciosus	Yugoslavia	4	1.02	0.19-1.63	Byrne & Ravnik 1976
Lactarius rufus	Finland	5	0.01		Varo et al. 1980
Lactarius torminosus	Finland	5	0.02	0.02-0.03	Varo et al. 1980
	Yugoslavia	1	0.45		Byrne & Ravnik 1976
Lactarius trivialis	Finland	6	0.09	0.07-0.10	Varo et al. 1980
Lactarius species	Yugoslavia	3	0.98	0.14-2.6	Byrne & Ravnik 1976
Macrolepiota procera	Yugoslavia	3	2.2 (cap only)	1.17-3.9	Byrne & Ravnik 1976

Appendix 4. Nickel concentrations for mushrooms in some previous studies

Species	Origin	No of samples	Ni mg kg^{-1} dry weight	Range mg kg^{-1}	Reference
Agaricus species	Sweden	4	0.2*	0.14-0.32*	Jorhem & Sundström 1995
Albatrellus ovinus	Sweden	6	7.2*	3.5-13*	Jorhem & Sundström 1995
Boletus edulis	Finland	2	0.1		Varo et al. 1980
	Sweden	5	1.2*	0.9-1.5*	Jorhem & Sundström 1995
	Denmark	3	2.6	2.5-2.7	Andersen et al. 1982
	France	2	5.08	4.8-5.35	Michelot et al. 1998
Cantharellus cibarius	Finland	5	0.1	0.05-0.1	Varo et al. 1980
	Sweden	6	1.4*	0.56-4*	Jorhem & Sundström 1995
Cantharellus tubaeformis	Sweden	5	0.44*	0.26-0.64*	Jorhem & Sundström 1995
	Denmark	1	2.2		Andersen et al. 1982
Craterellus cornucopioides	Sweden	4	0.61*	0.38-0.75*	Jorhem & Sundström 1995
	Denmark	3	3.6	1.0-8.5	Andersen et al. 1982
	France	1	6.96		Michelot et al. 1998
Gyromitra esculenta	Finland	2	0.1		Varo et al. 1980
Hydnum repandum	Sweden	5	0.53*	0.22-1.6*	Jorhem & Sundström 1995
	Denmark	1	2.4		Andersen et al. 1982
Lactarius deterrimus	Sweden	5	0.62*	0.28-0.8*	Jorhem & Sundström 1995
Lactarius rufus	Finland	5	0.05	0.04-0.1	Varo et al. 1980
Lactarius torminosus	Finland	5	0.1	0.05-0.1	Varo et al. 1980
Lactarius trivialis	Finland	6	0.1	0.05-0.1	Varo et al. 1980
Leccinum aurantiacum	France	1	8.51		Michelot et al. 1998
Macrolepiota procera	Sweden	3	0.26*	0.24-0.3*	Jorhem & Sundström 1995
Suillus variegatus	France	1	7.98		Michelot et al. 1998

* = converted to dry weight using the value of 10 % dry material

Appendix 5. Mushrooms listed as commercially sold species in Finland.

Albatrellus ovinus
Armillaria mellea group
Boletus edulis
Boletus pinophilus
Boletus reticulatus
Cantharellus lutescens
Cantharellus cibarius
Cantharellus tubaeformis
Craterellus cornucopioides
Gyromitra esculenta
Hydnum repandum
Hydnum rufescens
Hygrophorus camarophyllus
Lactarius deliciosus
Lactarius deterrimus
Lactarius rufus
Lactarius torminosus
Lactarius trivialis
Lactarius utilis
Leccinum aurantiacum
Leccinum versipelle
Leccinum vulpinum
Morchella species
Rozites caperatus
Russula claroflava
Russula decolorans
Russula obscura
Russula paludosa
Suillus luteus
Suillus variegatus

Source: Ministry of Agriculture and Forestry (2002b)

Appendix 6. The maximum permitted concentrations of Cd, Pb and Ni in agricultural soils containing sewage sludge.

	mg kg^{-1} dry weight
Cd	0.5
Pb	60
Ni	60

Source: Ministry of the Environment (1994)

Appendix 7. Concentrations of Cd, Pb, As and Ni in some food products in Finland (dry weight).

	Cd mg kg^{-1}	Pb mg kg^{-1}	As mg kg^{-1}	Ni mg kg^{-1}
Mushrooms	0.56	3.31	0.30	0.80
Leafy vegetables	0.44	0.71	0.07	3.30
Fruity vegetables	0.12	0.14	0.14	1.60
Root vegetables	0.16	0.15	0.16	0.60
Fruits	0.01	0.59	0.11	0.50
Berries	0.05	0.46	0.05	0.40

Source: Varo et al. (1980)

Appendix 8. The Average, Coefficient of Variation (%), Certified Values and Bias (%) for Reference Material (Cantharellus tubaeformis) samples.

Number of Batches = 30

	Cd mg kg^{-1}	Pb mg kg^{-1}	As mg kg^{-1}	Ni mg kg^{-1}
Average	0.44 ±0.02	1.45 ±0.12	0.067 ±0.01	0.046 ±0.06
CV %	5.5	0.83	14.6	14.2
Certified Value	0.437	1.43	-	0.381
Bias (%)	+1.6	+1.5	-	+16.9

Appendix 9. The dry material contents of the fungi species as % of fresh fungi weight.

*	10.0	*Agaricus abruptibulbus*
	8.5	*Albatrellus ovinus*
	10.0	*Boletus* species *(B. edulis, B. pinophilus)*
	9.0	*Cantharellus cibarius*
	6.5	*Cantharellus tubaeformis*
	9.4	*Craterellus cornucopioides*
*	10.0	*Gyromitra esculenta*
	6.9	*Hydnum* species *(H. repandum, H. rufescens)*
**	8.4	*Lactarius* species *(L. deliciosus, L. deterrimus, L. rufus, L. torminosus, L. trivialis)*
	7.7	*Leccinum* species *(L. aurantiacum, L. versipelle)*
*	10.0	*Macrolepiota procera*
*	10.0	*Suillus variegatus*

* = general reference value of 10% dry material used
** = average of *L.deterrimus, L.rufus* & *L.trivialis*
Sources: Eurola et al. (1996), Souci et al. (1981)

Appendix 10. The statistical values for each mushroom species (dry weight).

A = Average	MIN = Minimum
SD = Standard deviation	MAX = Maximum
CV = Coefficient of variation	R = range value
Med = Median	n = number of samples

		Cd mg kg^{-1}	Pb mg kg^{-1}	As mg kg^{-1}	Ni mg kg^{-1}
All 12 species	A	6.54	2.61	1.44	1.72
	SD	18.23	5.61	2.77	2.25
	CV	2.79	2.14	1.92	1.30
	Med	0.80	1.22	0.42	1.04
	MIN	0.05	0.09	0.06	0.19
	MAX	131.00	55.10	18.80	12.50
	R	130.95	55.01	18.74	12.31
	n	191	191	191	191
Agaricus abruptibulbus	A	36.58	9.33	6.32	1.65
	SD	34.99	11.01	4.69	1.13
	CV	0.96	1.18	0.74	0.69
	Med	29.70	6.05	5.11	1.22
	MIN	0.68	0.34	1.00	0.50
	MAX	131.00	55.10	18.80	4.61
	R	130.32	54.76	17.80	4.11
	n	28	28	28	28
Albatrellus ovinus	A	0.60	0.60	0.20	8.35
	SD	0.42	0.51	0.10	3.57
	CV	0.69	0.85	0.51	0.43
	Med	0.48	0.54	0.18	9.08
	MIN	0.15	0.13	0.06	0.51
	MAX	1.51	2.02	0.38	12.50
	R	1.36	1.89	0.32	11.99
	n	12	12	12	12
Boletus species	A	4.27	0.81	0.45	1.66
	SD	2.11	0.86	0.23	0.65
	CV	0.49	1.07	0.50	0.39
	Med	4.51	0.56	0.44	1.50
	MIN	1.21	0.10	0.17	1.04
	MAX	9.95	4.08	1.03	3.53
	R	8.74	3.98	0.86	2.49
	n	21	21	21	21

		Cd mg kg⁻¹	Pb mg kg⁻¹	As mg kg⁻¹	Ni mg kg⁻¹
Cantharellus cibarius	A	0.58	2.21	0.22	2.14
	SD	0.31	1.42	0.13	0.69
	CV	0.53	0.64	0.59	0.32
	Med	0.44	1.71	0.16	2.08
	MIN	0.19	0.74	0.11	0.91
	MAX	1.25	5.37	0.53	3.27
	R	1.06	4.63	0.42	2.36
	n	17	17	17	17
Cantharellus tubaeformis	A	0.61	2.02	0.15	1.04
	SD	0.44	0.95	0.05	0.53
	CV	0.71	0.47	0.34	0.52
	Med	0.48	1.83	0.14	0.87
	MIN	0.20	0.62	0.08	0.46
	MAX	1.87	3.97	0.28	2.52
	R	1.67	3.35	0.20	2.06
	n	17	17	17	17
Craterellus cornucopioides	A	0.80	2.23	0.48	1.02
	SD	0.46	0.65	0.49	0.58
	CV	0.57	0.29	1.02	0.57
	Med	0.93	2.24	0.24	0.79
	MIN	0.20	1.37	0.14	0.61
	MAX	1.50	3.34	1.45	2.36
	R	1.30	1.97	1.31	1.75
	n	8	8	8	8
Gyromitra esculenta	A	2.80	0.85	0.17	0.64
	SD	0.86	0.29	0.04	0.23
	CV	0.31	0.34	0.26	0.37
	Med	2.74	0.92	0.16	0.63
	MIN	1.75	0.44	0.13	0.41
	MAX	4.12	1.22	0.24	0.98
	R	2.37	0.78	0.11	0.57
	n	5	5	5	5
Hydnum species	A	0.36	1.01	0.86	1.07
	SD	0.49	0.49	0.71	2.32
	CV	1.37	0.49	0.82	2.18
	Med	0.22	0.83	0.61	0.50
	MIN	0.05	0.33	0.10	0.22
	MAX	2.40	2.41	2.61	11.60
	R	2.35	2.08	2.51	11.38
	n	23	23	23	23

		Cd mg kg^{-1}	Pb mg kg^{-1}	As mg kg^{-1}	Ni mg kg^{-1}
Lactarius species	A	0.64	1.42	0.88	1.24
	SD	0.38	0.88	0.58	1.24
	CV	0.60	0.62	0.66	1.00
	Med	0.60	1.23	0.75	0.94
	MIN	0.15	0.20	0.16	0.42
	MAX	1.67	3.72	2.51	6.47
	R	1.52	3.52	2.35	6.05
	n	21	21	21	21
Leccinum species	A	1.84	0.72	0.40	0.51
	SD	2.33	1.05	0.20	0.32
	CV	1.27	1.46	0.50	0.63
	Med	0.77	0.36	0.40	0.41
	MIN	0.12	0.09	0.12	0.19
	MAX	8.40	4.57	0.92	1.61
	R	8.28	4.48	0.80	1.42
	n	25	25	25	25
Macrolepiota procera	A	0.91	9.77	1.55	1.23
	SD	0.92	16.03	1.50	0.80
	CV	1.02	1.64	0.97	0.66
	Med	0.59	2.15	1.13	1.21
	MIN	0.24	0.98	0.35	0.28
	MAX	2.23	33.80	3.60	2.21
	R	1.99	32.82	3.25	1.93
	n	4	4	4	4
Suillus variegatus	A	1.62	1.02	2.13	1.39
	SD	0.92	0.48	1.29	0.80
	CV	0.57	0.47	0.60	0.58
	Med	1.46	1.11	1.54	1.17
	MIN	0.64	0.23	0.73	0.44
	MAX	3.84	1.98	4.75	3.29
	R	3.2	1.75	4.02	2.85
	n	10	10	10	10

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	Riina Pelkonen, Georg Alfthan and Olli Järvinen	
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Publication series and number	The Finnish Environment 17/2006	
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Abstract	The aim of the study was to study the geographical and temporal variation of Cd, Pb, As and Ni in wild edible mushrooms and to evaluate possible toxicological risks resulting from their consumption. The research focused on 12 mushroom species commonly collected in Finland. The samples were collected at common collection sites in Southern Finland between the years 1977 and 1999 and analysed using ICP-MS. The median dry weight concentrations ranged between 0.22–29.70 mg kg^{-1} d.w. for Cd, 0.36–6.05 mg kg^{-1} d.w. for Pb, 0.14–5.11 mg kg^{-1} d.w. for As and 0.41–9.08 mg kg^{-1} d.w. for Ni. The highest concentrations of Cd, Pb and As were found in *Agaricus abruptibulbus* and the highest level of Ni in *Albatrellus ovinus*. The Pb concentrations in *A. abruptibulbus* and Cd levels in *Lactarius* species were found to be significantly higher at polluted than at unpolluted sites. The Pb contents of *A. ovinus, Boletus* species, *Cantharellus tubaeformis* and *Lactarius* species as well as Cd levels of *A. abruptibulbus* and *Leccinum* species were significantly higher for samples collected in 1977–1983 than for ones collected in 1992–1999. Decomposer species had generally higher concentrations of Cd, Pb and As than mycorrhizal fungi. Apart from the high element concentrations of *A. abruptibulbus*, the consumption of mushrooms was generally not considered to pose a toxicological risk in the light of the safety limits set by WHO. However, the Cd and Pb contents in *A. abruptibulbus* and Cd levels of *Gyromitra esculenta* and *Boletus* species exceeded the EU maximum permitted concentrations for cultivated mushrooms.

Keywords	arsenic, cadmium, lead, nickel, fungi, mushrooms			
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Tiivistelmä	Tutkimuksen tavoitteena oli tutkia syötävien metsäsienten Cd-, Pb-, As- ja Ni-pitoisuuksien alueellista ja ajallista vaihtelua sekä selvittää, aiheutuuko niiden nauttimisesta mahdollista terveysriskiä. Tutkimus käsitti 12 yleistä sienilajia, jotka kerättiin yleisiltä poimintapaikoilta vuosien 1977 ja 1999 välisenä aikana. Metallipitoisuudet määritettiin ICP-MS –menetelmällä. Metallipitoisuuksien (kuivapainosta) mediaaniarvojen vaihteluvälit olivat kadmiumilla 0,22–29,70 mg/kg, lyijyllä 0,36–6,05 mg/kg, arseenilla 0,14–5,11 mg/kg ja nikkelillä 0,41–9,08 mg/kg. Suurimmat Cd-, Pb- ja As-pitoisuudet olivat *Agaricus abruptibulbus* –lajilla ja korkein Ni-pitoisuus *Albatrellus ovinus* –lajilla. Saastuneilla poimintapaikoilla *A. abruptibulbus* –lajin lyijypitoisuudet sekä *Lactarius*-lajin kadmiumpitoisuudet olivat merkittävästi ei-saastuneiden alueiden pitoisuuksia korkeampia. 1977-1983 kerätyt *A. ovinus-, Boletus*-lajin, *Cantharellus tubaeformis*- ja *Lactarius*-lajin näytteet olivat lyijypitoisuudeltaan merkittävästi suurempia kuin välillä 1992-1999 kerätyt. Kadmiumpitoisuus puolestaan oli korkeampi 1977-1983 kerätyissä *A. abruptibulbus*- ja *Leccinum*-sienissä. Lahottajasienet sisälsivät yleisesti suurempia Cd-, Pb- ja As-pitoisuuksia kuin mykoritsasieniin kuuluvat lajit. WHO:n asettamien sietorajojen valossa sienten kulutuksen ei yleisesti katsottu aiheuttavan toksikologista riskiä, lukuun ottamatta *A. abruptibulbus*-lajista löydettyjä suuria pitoisuuksia. On kuitenkin huomionarvoista, että *A. abruptibulbus*-lajin Cd- ja Pb-pitoisuudet sekä *Gyromitra esculenta*- ja *Boletus*-lajin Cd-pitoisuudet ylittivät EU:n viljellyille sienille asettamat korkeimpien sallittujen pitoisuuksien rajat.			
Asiasanat	arseeni, kadmium, lyijy, nikkeli, sienet			
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Sammandrag	Studiens mål var att undersöka den geografiska och tidsbundna variationen i ätliga svampars Cd-, Pb-, As- och Ni-halt i Finland samt värdera dessa metallers toxikologiska risk för svamp som föda. Studien omfattade 12 vanliga svamparter vilka hade samlats mellan 1977 och 1999 på olika orter i södra Finland. Metallhalterna analyserades med ICP-MS. Medianhalten av Cd i alla svampproven varierade mellan 0,22–29,70 mg/kg, Pb mellan 0,36–6,05 mg/kg, As mellan 0,14–5,11 mg/kg och Ni mellan 0,41–9,08 mg/kg torrvikt. De högsta Cd-, Pb- och As-halterna förekom i *Agaricus abruptibulbus* och de högsta Ni-halterna i *Albatrellus ovinus*. Pb-halterna i *A. abruptibulbus* och Cd-halterna i svampar av *Lactarius* species var signifikant högre i förorenade jämfört med oförorenade områden. Pb-halterna i *A. ovinus, Boletus species, Cantharellus tubaeformis* och *Lactarius* species och Cd-halterna i *A. abruptibulbus* och *Leccinum* species var signifikant högre i prov samlade åren 1977-1983 jämfört med åren 1992-1999. I genomsnitt var Cd-, Pb- och As-halterna högre i nedbrytarspecies jämfört med mykorritsa svampar. Med undantag av de höga metallhalterna i *A. abruptibulbus*, föranleder konsumtion av dessa svampar ingen toxikologisk risk i förhållande till säkerhetsgränser tillsatta av WHO. Å andra sidan överskrider Cd- och Pb-halterna i *A. abruptibulbus* och Cd-halterna i *Gyromitra esculenta* och *Boletus* species EU:s gränsvärden för odlade svampar.			
Nyckelord	arsen, bly, kadmium, nickel, svampar			
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In Finland wild-growing products such as mushrooms grow in abundance in forests and are traditionally used as a source of food. Fungi are widely recognised to have a good nutritional value but they also may be a source of toxic trace elements. As mushrooms may be freely picked and consumed there is no monitoring system to control the amounts of trace elements that enter the human body from the consumption of fungi.

The aim of this research was to contribute by updating and increasing the data on cadmium, lead, arsenic and nickel concentrations of wild fungi in Finland. The study also aimed to investigate the patterns of variation in time, due to traffic pollution and between ecological groups and the study provides helpful information on mushrooms for consumers, that is, which species may be favoured and which are advisable to be avoided.

CADMIUM, LEAD, ARSENIC AND NICKEL IN WILD EDIBLE MUSHROOMS

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