NTNU
Norwegian University of
Science and Technology

Contamination in an Arctic Environment: Abiotic and Biotic Impacts of Local Pollution

Gina Mariell Beitveit

Master of Science	
Submission date:	May 2016
Supervisor:	Bjørn Munro Jenssen, IBI
Co-supervisor:	Frode Fossøy, IBI Tomasz Maciej Ciesielski, IBI Bård Gunnar Stokke, IBI

Norwegian University of Science and Technology
Department of Biology

Acknowledgements

The present master thesis has been carried out at the Department of Biology at the Norwegian University of Science and Technology (NTNU, Trondheim), as a final part of a Master's degree in NTNU's teaching programme, with specialization in biology and chemistry. The costs of fieldwork and analyses have been covered by the *VINTERSPURV* project, which constitutes a part of a long-term snow bunting project that first started in Adventdalen in 1998. The *VINTERSPURV* project is supported by Svalbard environmental protection fund, and addresses climate, migration and toxicology.

I would like to express my gratitude to my supervisors Bjørn Munro Jenssen, Tomasz Maciej Ciesielski, Frode Fossøy and Bård Gunnar Stokke. They have guided me steadily through fieldwork, chemical analyses, statistics and constructive feedback in the writing process, and have always met me with great interest and a smile. A special thank you to Frode who has helped me through the hard times with the statistics, and to Tomasz who carried me across the rivers at Svalbard!

I also have to thank Kristian Hassel at the NTNU University Museum, who helped me with the species determination of mosses, and Syverin Lierhagen at the Department of Chemistry NTNU, who conducted the HR-ICP-MS. Thank you.

I would like to acknowledge the importance of my family, especially Monica Beitveit, Roger Bugge and Gunn Beitveit, and their lifelong support. I would also like to express my gratitude to my friends. Among them, Linda Dalen Nordnes, you have my deepest gratitude for academic and loving support. To all fellow students and friends at LUR, Gløshaugen and Moholt: thank you for 5 remarkable years!

Gløshaugen, May 2016
Gina Mariell Beitveit

Abstract

The Svalbard ecosystem is characterized by relatively low species diversity. A population collapse might consequently be detrimental to the overall ecological balance. Thus, an assessment of changes in and conditions of the environment are of importance. Nevertheless, there is a scarcity of studies investigating the impact of local pollution on the Arctic environment. Important sources of emission might include the coal industry, which has been prominent on Svalbard for more than 100 years. A coal power plant is situated in Longyearbyen, and Store Norske Spitsbergen Kulkompani AS is still operating on a coal mine (Gruve 7) in Adventdalen, just outside Longyearbyen. Abandoned coal mines (e.g. Gruve 6) are also present in Adventdalen as protected cultural remains. The aim of the present investigation was to evaluate whether Longyearbyen coal power plant and Gruve 6 have a significant impact on the chemical element distribution in soil and terrestrial biota in Adventdalen. An a priori expectation existed based on literature from Geological survey of Norway, where the coal power plant and Gruve 6 were expected to have an impact on chemical element distribution of Al, As, B, Be, Cd, Co, Cr, Fe, Hg, La, Mn, Mo, Ni, Pb, S, Sb, Se, Sm, Th, U, V, Y, Yb and Zn.

Soil, mosses, insects/spiders and feathers from snow bunting nestlings (*Plectrophenax nivalis*) were sampled from 18 stations located along a transect extending from Longyearbyen coal power plant to Gruve 6. Subsequently, analyses of these 24 elements were carried out by HR-ICP-MS. The results indicate that there were a strong positive relationship ($p < 0.002$) between distance from the coal power plant and concentration of Cd in insects/spiders and Mo in soil. The positive correlations implies that Gruve 6 and/or Gruve 7 constitute main point sources of Cd and Mo emission to the transect. However, due to differences in sample material, e.g. differences in species composition, it might be problematic to compare the stations. Moreover, due to multiple pollution sources and differences in topography it might be difficult to detect the isolated impact of the coal power plant and Gruve 6 on the transect. Local natural sources, in addition to local anthropogenic sources such as cruise ships, snowmobiles, air and road traffic, landfill, cableway station, the historically German weather station (*Bansø*) and cabins, might have had an impact on the chemical element distribution at the different stations.

Sammendrag

Økosystemet på Svalbard er karakterisert av et relativt lavt artsmangfold. En populasjonskollaps kan følgelig være skadelig for den overordnede økologiske balansen. Vurdering av endringer og forhold i miljøet vil dermed være av høyst viktighet. Likevel er det få studier som undersøker innvirkningen av lokal forurensning på det arktiske miljøet. Viktige kilder for utslipp kan inkludere kullindustrien, som har vært fremtredende på Svalbard i mer enn 100 år. Et kullkraftverk er per dags dato lokalisert i Longyearbyen, og Store Norske Spitsbergen Kulkompani AS driver fortsatt kullgruvedrift ved en av kullgruvene (Gruve 7) i Adventdalen, like utenfor Longyearbyen. Forlatte kullgruver (for eksempel Gruve 6) er også tilstede i Adventdalen som beskyttede kulturminner. Målet med den foreliggende undersøkelsen var å evaluere om Longyearbyen kullkraftverk og Gruve 6 har en signifikant innvirkning på distribusjonen av kjemiske elementer i jord og terrestrisk biota i Adventdalen. En forventning var på forhånd gjort basert på litteratur fra Norges geologiske undersøkelse, hvor kullkraftverket og Gruve 6 var forventet å ha en innvirkning på distribusjon av Al, As, B, Be, Cd, Co, Cr, Fe, Hg, La, Mn, Mo, Ni, Pb, S, Sb, Se, Sm, Th, U, V, Y, Yb og Zn.

Jord, mose, insekter/edderkopper og fjær fra snøspurvunger (*Plectrophenax nivalis*) ble samlet inn fra 18 stasjoner lokalisert langs et transekt som strekte seg fra Longyearbyen kullkraftverk til Gruve 6. Deretter ble analyse av de 24 elementene gjennomført ved bruk av HR-ICP-MS. Resultatene indikerer at det var et sterkt positivt forhold ($p < 0.002$) mellom distanse fra kullkraftverket og konsentrasjon av Cd i insekt/edderkopper og Mo i jord. De positive korrelasjonene antyder at Gruve 6 og/eller Gruve 7 utgjør hovedkilder for frigjøring av Cd og Mo til transektet. På grunn av forskjeller i prøvemateriale, slik som forskjeller i artssammensetning, kan det derimot være problematisk å sammenligne stasjonene. Videre kan flere forurensningskilder og forskjeller i topografi gjøre det vanskelig å detektere den isolerte innvirkningen av kullkraftverket og Gruve 6 på transektet. Lokale naturlige kilder, i tillegg til lokale antropogene kilder som cruiseskip, snøscootere, luft- og veitrafikk, avfallsdeponiet, Vinkelstasjonen, den historiske tyske værstasjonen (*Bansø*) og hytter, kan ha hatt en innvirkning på distribusjon av de kjemiske elementene ved de ulike stasjonene.

Table of Contents

1 Background and Theory

1.1 Pollution

Pollution is defined as the addition of a substance to the environment, at a rate that leads to a higher than natural concentration of the substance. The increase in concentration may result in adverse individual, populational and ecological effects (Newman, 2010; Ottesen et al., 2010). Many different chemicals are regarded as pollutants, including metals, organometallic compounds, radioactive isotopes, and organic pollutants such as hydrocarbons, polychlorinated biphenyls (PCBs) and insecticides. Not all pollutants are synthetically produced, and some, such as metals, are natural substances. However, metals are continuously being enriched in the environment and made bioavailable through human activities (Walker et al., 2006).

1.2 Pollution on Svalbard

According to a review conducted by the Norwegian Polar Institute (Jaworowski, 1989), there are four main sources of pollutants in the Arctic environment. 1) Local natural sources include sources such as bedrock, soils and sea spray. Analyses imply that soil-derived dust might account for <10 % of the mercury (Hg) and selenium (Se), 20-30 % of the copper (Cu), molybdenum (Mo), nickel (Ni), lead (Pb), antimony (Sb) and zinc (Zn), and >50 % of the chromium (Cr), manganese (Mn) and vanadium (V) emitted annually to the atmosphere by natural sources. Sea spray, however, seem to account for less than 10 % of the atmospheric cycle of trace metals (Nriagu, 1989). 2) Remote natural sources comprise sources such as volcanic emission and forest fires. Volcanic emission contribute to a significant enrichment of sulfur (sulfur dioxide, hydrogen sulfide, carbonyl sulfide, carbon disulfide) in the atmosphere (Ottesen et al., 2010; Textor et al., 2004). It has also been suggested that volcanic activity contributes to the atmospheric cycle of heavy metals, where it is estimated to account for 20-40 % of the arsenic (As), Cr, Cu, Ni, Pb and Sb and 40-50 % of the cadmium (Cd) and Hg emitted annually from natural sources (Nriagu, 1989). Of particular concern however, is the anthropogenic emission, including local and remote sources. 3) Coal mining has been prominent on Svalbard for more than 100 years. Consequently the coal industry comprises an important part of local anthropogenic sources on Svalbard. Waste might also contribute to the total concentration of pollutants in the ambient environment (Ottesen et al., 2010). In the time period 2008-2010, 1 054 tons of waste was deposited on the landfill close to Gruve 6 (Mine 6) in Adventdalen, Longyearbyen (Lyche & Nedland, 2012). Pollutants might consequently leach out of discarded products into the environment. Moreover, cruise ships, snowmobiles, air and road traffic release heavy metals (Cd, Mn, Ni, Pb, Sb, V, Zn) and aluminum (Al) into the environment. Research conducted at the Zeppelin Observatory in Ny Ålesund implies that cruise ship emission is significantly affecting the concentration of related pollutants in the atmosphere (Eckhardt et al., 2013). 4) The fourth source of pollution in the Arctic – remote anthropogenic sources – is related to long distance transport of pollutants through the atmosphere and ocean currents. Heavy metals such as Hg, Pb, Cu, Zn and Ni, sulphates and sulphur dioxides, radionuclides, organohalogenated contaminants and organic gases are transported by air. Many of these pollutants originate from mid-latitudes as a result of industrial combustion and application (Jaworowski, 1989; Pacyna et al., 1985; Simões & Zagorodnov, 2001). Metals are transported in gas form (e.g. Hg), or condensed at particulate matter prior to transportation (AMAP, 1997; Jaworowski, 1989). Analysis conducted at the Zeppelin Observatory show that air masses originating in northern Europe contains the highest concentrations of Pb (Paatero et al., 2003). Asia additionally contributes to high anthropogenic emissions of trace metals (Pacyna & Pacyna, 2001). The relative importance of long-range atmospheric transport to the Arctic is however varying among elements. Transport of pollutants to the Arctic is determined by emission source, chemical property of the pollutant and environmental factors, such as pH, precipitation and temperature. Chemical properties include properties such as speciation, molecular stability and vapor pressure. Mercury, for instance, has a relatively high molecular stability and vapor pressure, resulting in a long atmospheric residence time (1 year) and a tendency to volatilize at lower latitudes. Mercury is consequently especially susceptible to global distribution through long-range atmospheric transport (Anderson & Hillwalker, 2008; Casarett & Doull, 2013).

It is difficult to defining the relative contribution of the four sources to the total level of pollution in the Arctic. A growing concern for long-range atmospheric pollutants has led to implementation of a global monitoring network, where the Zeppelin Observatory in Ny-Ålesund is aimed to function as a long-term platform for measurements. The Zeppelin Observatory is minimally affected by local pollution, and have consequently attained the status as a reference station for remote sources of pollution (Norwegian Polar Institute, Undated). Comprehensive studies on the environmental impact of local sources are however less prominent. Nevertheless, studies from other areas indicate that local anthropogenic point sources, such as coal industry, might contribute significantly to the total level of pollution in environmental compartments (Askaer et al., 2008; Bhuiyan et al., 2010; Zhao et al., 2008).

1.3 Coal

Coal has been formed from decayed and compacted plant material, and contains 50 % by weight or 70 % by volume or more carbonaceous material. The carbonaceous material additionally consists of hydrogen (H), oxygen (O), nitrogen (N) and sulfur (S). Apart from organic compounds, coal contains inorganic components – minerals – where metals are incorporated (Speight, 2013). The exact composition of coal is however dependent on the geological time it was formed. Coal produced in the Carboniferous period (360–290 million years ago) for instance, is located deeper and has been exposed to higher heat and pressure than coal from the Tertiary period (66-2.6 million years ago). The result is a higher carbon and energy content and a lower O, H and moisture content for the coal originating in the Carboniferous period. The N and S content in coal will also typically vary for different coal ages (Higman & van der Burgt, 2008; Speight, 2013; WCA, Undated).

1.3.1 Coal industry, Longyearbyen

Exploitation of natural resources through coal mining has existed since the late 1890's. Commercial interest was mainly due to the demand of coal in domestic heating and its use in European industries. The mining on Svalbard have been based on a Tertiary coal layer (Askaer et al., 2008), and the coal exploited is so called high volatile bituminous coal (Ćmiel & Fabiańska, 2004) – a dark-brown-to-black organic sedimentary rock that is easy to transport and store due to its relatively high heat value and low moisture content (Kopp, 2009). The mining was first started by Norwegian companies, followed by a transfer of the claims to British and American businessmen. It was the American capitalists Frederick Ayer and John Munroe Longyear who established the now administrative capital of Svalbard – Longyear City – at the same time as they founded the *Arctic Coal Company* in 1906. Longyear City and the rights to coal deposits was subsequently taken over by a private owned company named *Store Norske Spitsbergen Kulkompani AS* (SNSK) in 1916, which have been state-owned by the Norwegian government since 1976 (Hisdal, 1998).

Apart from some remaining mines, the mining activity has ceased. At present there are three active coal mines at Svalbard, located on the largest island, Spitsbergen (Figure 1). SNSK is working the deposit at Svea Nord and Gruve 7, whereas the Russian *Trust Arktikugol* is operating a coal mine at Barentsburg. Until now, Svea Nord has constituted SNSK's main coal mining operation, but a 3-year break from April 2016 is currently planned (SNSK, Undated-d; Winther, 2014). Gruve 7 is located in Adventdalen, whereupon 150.000 tons of coal is extracted annually (SNSK, Undated-b). The mining activity at Gruve 7 provides coal to coal-fired power plants in Europe and the foundry industry in Germany, in addition to Longyearbyen coal power plant, which generates electricity and heating for the local community. Furthermore, abandoned coal mines are also present in Adventdalen. Gruve 6 is located between Todalen and Bolterdalen (Figure 2), where operations were active in the time period 1967-1981. Though the coal mine has been abandoned, the mining constructions are still present as protected cultural remains. Protected remains additionally include the cableways and cable trestles, which were previously used as a coal transportation system from the mines to the harbor (Figure 2) (Avango et al., 2014; Piepjohn et al., 2012; SNSK, Undated-c). Nevertheless, study of the environmental impact of abandoned coal mines might be transferable to the environmental impact of the active coal mines situated on Svalbard today.

Figure 1. The active coal mines at Svalbard: Svea Nord, Gruve 7 and Barentsburg. Svea Nord and Gruve 7 are located 60 km and 15 km from Longyearbyen, respectively (generated from TopoSvalbard, Norwegian Polar Institute, http://toposvalbard.npolar.no/. Retrieved April 11, 2016. Scale undetermined).

1.3.1.1 Coal mining

Mining, loading and transport of coal cause increased emissions of dust to the environment (SNSK, Undated-a). In addition, disposal of mine waste rocks above ground have been a common practice in the operation of coal mining. Pollutants might leach into soil and groundwater, and be subject to airborne and waterborne transport. Residues might also be transported via soil and sediment-born particles. It has however been thought that the permafrost are slowing migration of pollutants (Askaer et al., 2008). Pollutants derived from mine waste rocks might additionally influence bioavailability of other pollutants by affecting environmental parameters (e.g. pH). At the mine tailings, the sulphide minerals (ferrous sulfate/pyrite, aluminium sulfate, manganese sulfate) oxidize in contact with air, resulting in production of sulphuric acid, which decreases the pH. This results in leaching of metals, such as Al, Mn, Ni, Zn and Pb (Askaer et al., 2008; Evangelou & Zhang, 1995; Temple & Delchamps, 1953). The so-called acid mine drainage is however not present at all coal mine and waste rock sites. This is due to different physical-chemical properties of the coal residues, such as a low content of sulphide minerals and a large pyrite grain-size (Banks et al., 2002). Tertiary coal near Longyearbyen contains low levels of sulfur (Thomas, 2002), and it is thus likely that the acid mine drainage are of less importance here.

1.3.1.2 Coal power plant

To satisfy the need for electricity and heat in the local community, Longyearbyen power plant has a consumption of approximately 25 000 tons coal per year (Flå, 2012). Burning of bituminous coal releases sulfur oxides (SO_X), some nitrogen oxides (NO_X), volatilized elements, and particulate matter (PM) into the atmosphere (Kopp, 2009; Llorens et al., 2001). However, as mentioned above, the Tertiary coal found near Longyearbyen contains low levels of sulfur (Thomas, 2002). A study of trace elements in Kaffiøyra and Longyearbyen coals also indicate that the trace element content in coal ash are below the average content in bituminous coal worldwide (Lewińska-Preis et al., 2009). Moreover, in December 2015 the power plant adopted an emission control technology, which reduces the emission of sulfur dioxide (SO_2), NO_X and PM in a three-step process (revised March 2015) (Knutsen, 2015). This might also reduce the emission of metals, due to the metals' ability to be adsorbed to the surface of PM (Mandal & Sengupta, 2006). It is important to note that the samples used in this master thesis were collected before the implementation of the emission control technology at Longyearbyen coal power plant. Thus, this technology might change the impact of atmospheric emissions relative to my findings.

A common practice in Longyearbyen is the deposition of slag and ash from the coal power plant at the landfill next to Gruve 6. In the time period 2008-2010 there were 13 332 m^2 slag and ash deposited by the power plant (Lyche & Nedland, 2012). This leaves a considerable amount of coal residues in close contact with abiotic and biotic environments. Ash may be transported by wind or incorporated in the top soil if there are no artificial underground lining that separates the ash pile from the soil beneath (Llorens et al., 2001; Mandal & Sengupta, 2006).

1.3.1.3 Chemical elements related to coal mining and combustion

According to the Geological survey of Norway (NGU), coal mining and/or combustion are sources of increased emissions of boron (B), beryllium (Be), cobalt (Co), lanthanum (La), samarium (Sm), yttrium (Y), ytterbium (Yb), Al, As, Cd, Cr, Hg, Mn, Mo, Ni, Pb, S, Sb, Se, V and Zn to the Svalbard environment (Ottesen et al., 2010). Iron (Fe) is also an important metal related to coal mining and pollution problems, considering its presence as iron sulphide minerals in deposited mine waste rocks (Askaer et al., 2008). Furthermore, extraction and processing of coal might result in the emission of the radionuclides uranium (U) and thorium (Th) to the environment. The concentration of U and Th are higher in ash than in raw coal, suggesting that the emission to the surrounding environment might be higher close to the landfill and coal power plant (Dowdall et al., 2004; Ottesen et al., 2010). Natural sources of the respective elements are the local bedrocks and soil. In addition, sea spray constitutes an important source of B and Hg (Ottesen et al., 2010).

1.4 Chemical element toxicity

All heavy metals might exhibit toxic effects at high concentrations in organisms (Nouri et al., 2009). Even elements essential for living organisms in low concentrations (e.g. Zn), have a potential for toxicity, as they are toxic above a certain threshold value (Casarett & Doull, 2013). Extent of pollution, bioavailability (speciation), persistence and bioaccumulation are examples of factors that might affect the concentration of an element in compartments and hence the potential for toxicity. Most metals are nonbiodegradable (e.g. Pb in soil), which means that unlike many other pollutants, they have a high resistance to degradation. Thus most metals have a long residence time. Some metals, such as Cd and Hg, also tend to accumulate in biological compartments. Bioaccumulation of an element is the net result of uptake and elimination processes, such as uptake from abiotic (water, air, soil, sediment, and fine particles) and biotic (food) compartments, and elimination by biotransformation and excretion processes (Newman, 2010; Newman & Clements, 2008; Walker et al., 2006). Mercury is additionally well known to increase in concentration with higher trophic position in the food web (biomagnify). High concentrations of Hg can cause adverse effects in biota (McMeans et al., 2007). Chronic exposure to methylmercury (MeHg) are associated with toxic effects on the central nervous system, and is thought to cause weaknesses in wings and legs and an inability to coordinate muscle movements in avian species. Reproductive effects such as decreased egg production and reduced hatching success have also been reported (Scheuhammer, 1987). Physiological defects and reproductive impairments considerably reduce the bird's fitness. Furthermore, loss of young of the year might result in a shift in age structure, and reduction in population growth and sustainability. It is consequently important to define an acceptable risk and concentrations of a substance in the environment (Zaidi & Imam, 2008). Moreover, it is important to monitor the concentration of pollutants in the environment and sources of emission.

1.5 Biomonitoring

The species living and breeding on Svalbard are highly specialized to combat the cold and harsh environment. This makes the species particularly vulnerable to anthropogenic activities. Furthermore, due to harsh conditions, the Svalbard ecosystem is characterized by relatively low species diversity (Jaworowski, 1989). A hypothetical population collapse would consequently be detrimental to the overall ecological balance in such a small ecosystem (Zaidi & Imam, 2008). A comprehensive knowledge of human impact on environmental conditions is hence required. Strict environmental laws and regulations are implemented (St.meld. nr. 22 (2008-2009)), and continuous biomonitoring are of interest. Biomonitoring includes systematic sampling and measurements, and implies the use of biological responses (e.g. changes in concentration, biochemical, genetic, physiological, ecological parameters), to assess the changes in and conditions of the environment (Casarett & Doull, 2013; Newman, 2010; Newman & Clements, 2008). Furthermore, it is important to select appropriate reference sites when biomonitoring an area of interest. The given reference conditions are necessary to distinguish natural variation from changes resulting from contamination (Newman & Clements, 2008).

Abiotic compartments, such as soil, can be applied in the assessment of environmental changes. Moreover, related to biomonitoring are bioindicators, which are species that are used in monitoring the health of an environment: e.g. species of mosses, insects and spiders, and birds.

1.6 Soil

Soil is varying in physical and chemical composition. Apart from water content, soil comprise a mixture of other components that might vary, such as clay, organic matter, particles, air and biological entities (Rattan, 2006). Elements may be chelated with or contained in organic matter, adsorbed on oxide minerals or carbonates, or adsorbed on clay (White & Zasoski, 1999). Interaction between chemical elements and clay also depend on factors such as pH, competing elements, cation-exchange capacity, and affinity for the clay relative to the pore water (Rattan, 2006). Moreover, local and remote sources such as glacial erosion, weathering of bedrock, sediment supply from waste disposal, long-range atmospheric transport, and coal dust from mining, loading and transport may affect the concentration of chemical elements in the soil. Pollutants might leach out and be transferred to neighboring soil, or the soil might be contaminated by atmospheric fallout. Whereas topsoil is particularly affected by atmospheric fallout, leaching might affect all soil layers (Mandal & Sengupta, 2006; Ottesen et al., 2010). The content of heavy metals in undisturbed soil (top soil, 0-2 cm depth) was determined at Reinsdyrflya in West Spitsbergen in 1983. The measurements showed the following concentrations in dry weight (dw): 66 μg/g Zn, 7 μg/g Pb, and 25 μg/g Ni. Measurements of soil in Adventdalen were also conducted, where the top soil contained 93 μg/g Zn, 10 μg/g Pb and 33 μg/g Ni dw (Thomas, 1986). Three to four years later (1986-1987), NGU and the Norwegian Energy and Water Resources Directorate (NVE) conducted a regional mapping of geochemical properties of overbank sediments. The concentrations analyzed in samples from Longyearbyen were similar to the measurements conducted by Thomas (1986): 58.9 – 79.2 μg/g Zn, 8.9 – 15.3 μg/g Pb, and 19.7 – 31.2 μg/g Ni (HNO_3 extract ICP) (Ottesen et al., 2010).

1.7 Mosses

Earlier studies have shown that heavy metal concentrations in mosses are closely related to atmospheric deposition. Consequently mosses have been widely used as bioindicators in air pollution monitoring (Aceto et al., 2003; Rühling et al., 1987; Schintu et al., 2005; Steinnes et al., 2003; Vasconcelos & Tavares, 1998). It is assumed that mosses acquire their element supply directly from rainwater and air-borne particles, due to lack of a developed root system (Rühling et al., 1987; Schintu et al., 2005). Furthermore, mosses have a high surface-to-mass ratio, the leaves are only one cell layer thick, and the cuticle is absent or reduced. Hence the cells are highly exposed to atmospheric deposition, and have a high ability to absorb, retain and to accumulate airborne pollutants. Moreover, chemical analyses of mosses are easier and more reliable due to the high concentration levels (Rühling et al., 1987). Mosses are also relatively easy to identify and easy to sample, making them suitable as bioindicators.

1.8 Insects and spiders

The Arctic ecosystem of Svalbard is considered to contain low species diversity. However, emerging research indicates that the invertebrate fauna of Svalbard are rather complex and diverse. Insects (class Insecta) and spiders (order Araneae) comprise an important part of the invertebrate fauna, where 303 species of insects and 14 species of spiders are believed to inhabit the environment. This includes species such as flies and mosquitos (order Diptera), wasps (order Hymenoptera) and beetles (order Coleoptera). Diptera constitute the most common insect groups on Svalbard, including a total of 178 species, which accounts for 59 % of the insect diversity. The Svalbard archipelago additionally contains other invertebrate species, such as mites (subclass Acari) and springtails (subclass Collembola) (Coulson et al., 2014). Hence, the invertebrate biodiversity offers an enormous potential of species in monitoring of the Arctic environment.

Insects and spiders are able to absorb elements through respiration, food intake, as well as absorption of elements deposited on the insects' outer surface. They are additionally capable to retain metals in organs that function as storage compartments (Hongxia et al., Undated). Hence, insects and spiders might be suitable in monitoring of concentrations in the environment. However, insects and spiders have previously been poorly used as bioindicators for metal pollution. Some insects, especially related to the marine environment, have been shown to function as suitable bioindicators (Nummelin et al., 2007; Rosenberg et al., 1986). Furthermore, monitoring of concentrations in insects and spiders might be of importance considering their place in the food web. Snow bunting (*Plectrophenax nivalis*) nestlings are fed with insects and spiders until they are able to fledge, 13 days after hatching (Falconer et al., 2007). Assessment of Hg, which has a tendency to biomagnify, is of special importance, considering its possible toxic effect at higher trophic levels.

1.9 Feathers from snow bunting nestlings

In the summer months, the snow buntings are ubiquitous in Adventdalen, breeding commonly throughout the valley. This is the only passerine bird species that breed regularly at Svalbard (Hoset et al., 2014; Strøm, Undated). The nest consists of straw, moss, feathers and reindeer hair (Hindrum, 1994). Both parents feed the snow bunting nestlings, which are fed mainly by insects and spiders (Fossøy et al., 2014). In addition to natural breeding sites such as cavities in screes, the snow buntings are breeding in crevices and cavities in buildings and trestles located along the cableway. Nest boxes have also been constructed at cabins and on the trestles, functioning as additional breeding sites (Hoset et al., 2014). This makes it relatively easy to find nests and conduct repeated measurements on snow buntings. The Arctic abundant passerine bird is furthermore easy to identify, carrying a characteristic breeding plumage (Strøm, Undated). Hence, snow buntings are theoretically suitable for monitoring environmental conditions and local contamination in Adventdalen.

Several biomonitoring studies on birds have used internal organs as study material. However, the demand of cost-effective and non-invasive monitoring techniques has increased the attention towards the use of feathers as bioindicators (Dauwe et al., 2005). Therefore, feathers are widely used as an indicator tissue of metal exposure in birds (Eens et al., 1999). During the actively growing period, the feathers are connected with blood vessels. Metals tend to accumulate in the feathers at the time of their formation, thus reflecting the concentration in blood in this limited time period. This, in turn, reflects the level of absorption and exposure. Binding to keratin molecules in feathers makes metals (e.g. Hg) chemically stable (Borghesi et al., 2016; Eens et al., 1999; Thompson et al., 1998). External contamination on feathers might be problematic in the analysis of internal concentrations, as it might mask the internal bioaccumulation level. Multiple studies report that no washing procedure was able to remove the total surface contamination on feathers. Because multiple variable factors such as age, moult and migration might affect the element composition in and on feathers, nestling feathers are more suitable for assessment purposes (Borghesi et al., 2016). However, to date, no studies have documented whether feathers from snow bunting nestlings are suitable for biomonitoring.

1.10 Aim of study

There is a scarcity of studies investigating the impact of local pollution on Arctic environments. Thus, the present thesis seeks to acquire information as to overcome this deficiency. The main objective of the study was to assess whether Longyearbyen coal power plant and the coal mining industry have a significant impact on the chemical element distribution (Al, As, B, Be, Cd, Co, Cr, Fe, Hg, La, Mn, Mo, Ni, Pb, S, Sb, Se, Sm, Th, U, V, Y, Yb, Zn) in Adventdalen. Specifically, soil, mosses, insects and spiders, and feathers from snow bunting nestlings were examined. The environmental compartments were chosen based on their presumed suitability in biomonitoring. I hypothesized that distance from point sources of emission (coal power plant and Gruve 6) is related to the element concentration in samples of soil, mosses, insects/spiders and feathers collected. This might be displayed as concentration gradients along the transect of investigation. The concentrations were expected to decrease with the distance away from the coal power plant or Gruve 6.

2 Materials and Methods

2.1 Sampling of soil, mosses, insects/spiders and feathers from snow bunting nestlings

The fieldwork was conducted in Adventdalen and Longyearbyen, where soil, mosses, insects/spiders and feathers from snow bunting nestlings were sampled in June and July 2015. The study area was restricted to a transect along the 8 km long cableway between Longyearbyen and Gruve 6, and samples from 17 stations were collected for analysis. Soil, mosses and insects/spiders were sampled from each of the 17 stations, whereas sampling of feathers was restricted to 13 of the stations, where nests were found. In addition, sampling of soil, mosses, insects/spiders and feathers were conducted at a station located below Gruve 6 (station 18, Figure 2). Sampling permits were given by the Governor of Svalbard in relation to RIS-ID 2272.

Snow bunting nests were located in cavities in the trestles, as well as in constructed nest boxes. Feathers were collected from the back of the nestlings approximately 8-10 days after hatching, 3-5 days prior to fledging. The feathers were subsequently kept in paper envelopes at room temperature. Soil, mosses and insects/spiders were sampled at sites approximately 30 – 40 meters away from the snow bunting nests, with the assumption that the buntings collect food for the nestlings in the vicinity of their nests. When collecting soil, vegetation was removed, and the material was sampled from the humus layer (top soil) at 0-2 cm depth. Same species of moss was attempted collected at each station. The moss and soil samples were subsequently stored in a freezer at -20 °C. Furthermore, pitfall traps containing diluted ethanol (67 %, v/v) were used for catching insects and spiders. Sampling of insects and spiders was continued during an 8 days period to provide sufficient amount of sample material. The insects and spiders were stored in diluted ethanol (75 %, v/v) throughout the summer months to ensure proper preservation of the sample material. To reduce the risk of contamination, all sampling was conducted with use of non-metallic equipment, such as Teflon knife, and plastic gloves, spoons, cups and forceps.

Prior to metal analysis, the insects and spiders were divided into taxonomic groups - springtails, spiders, mites, wasps, mosquitos and flies – and mosses were divided into species at the NTNU University Museum (Table 2, Appendix I).

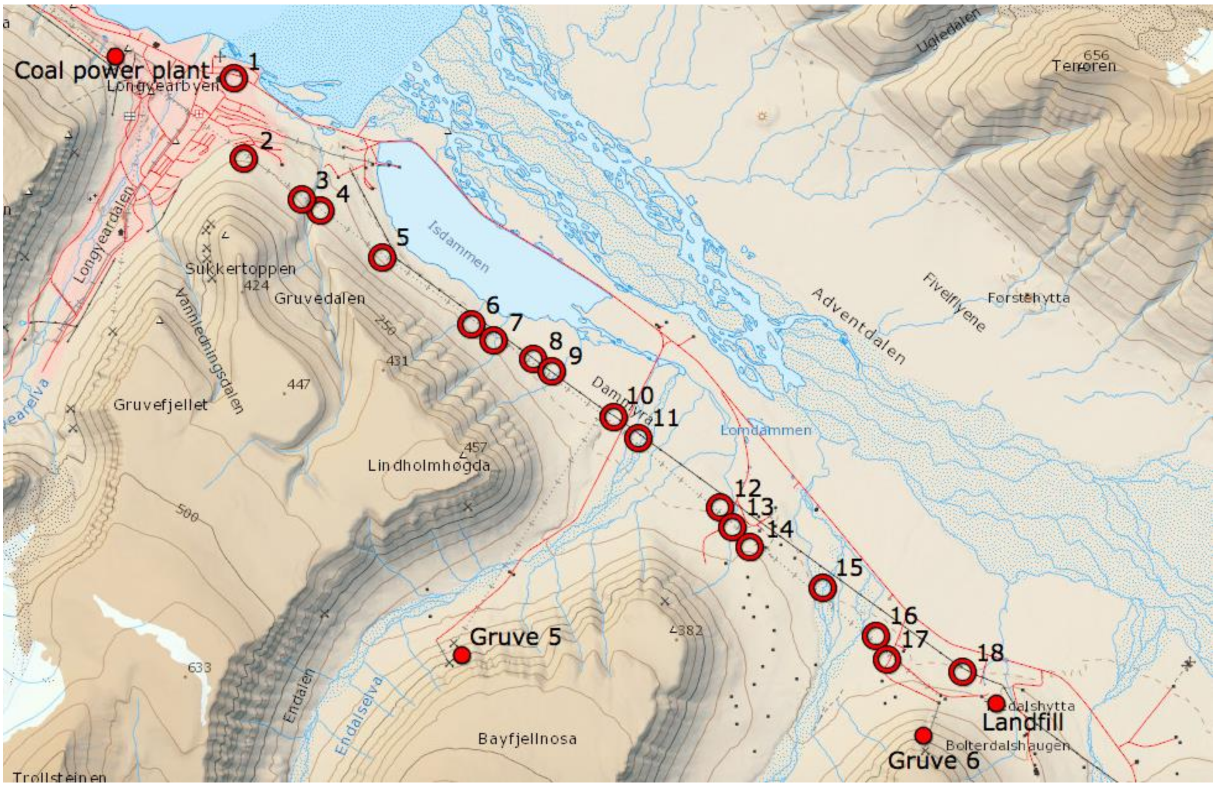


Figure 2. Map representing transect of investigation. The associated 18 stations (numbered), Gruve 5, Gruve 6, landfill and the coal power plant are depicted. Station 2 to 18 are located at trestles along the cableway: B9I, B17I, B19I, B26I, B34I, B36I, B40I, B42I, B40II, B36II, B26II, B24II, B22II, B13II, B8II, B6II and M68BIII, respectively (generated from TopoSvalbard, Norwegian Polar Institute, http://toposvalbard.npolar.no/. Retrieved March 18, 2016. Scale undetermined).

2.2 Element analyses

All laboratory equipment used for analysis was non-metallic, prewashed with nitric acid (HNO_3, 1 M) and rinsed with double deionized water (Milli-Q). Soil samples were air-dried at room temperature (20 °C), and grinded in an agate mortar to homogenize the sample material. Subsequently each soil sample was dry-sieved through 2 mm non-metallic polyester sieves (Gilson company inc., Ohio, USA). Moss shoot apices (1-1.5 cm) were cut from the moss plants. This was done to ensure standardization of study material in terms of exposure time to pollutants (Fernández et al., 2000). A jet of air was then used to remove soil particles bound to the surface. Thereafter, the moss samples were dried at 50 °C until the dry weight was constant. A drying temperature of 50 °C was used to avoid loss of Se from the moss samples through volatility (Fernández et al., 2000; MacNaeidhe, 1995). Furthermore, insects and spiders were dried at 60 °C for 24 hours, as described by Dauwe et al. (2004). Feathers were washed two times with acetone (Sigma-Aldrich, St. Louis, USA), alternating with Milli-Q water, and then air-dried at room temperature (20 °C). Paper filters were placed on top of the drying samples to prevent contamination by air. Soil (0.2-0.3 g), mosses (0.45-0.50 g), insects/spiders (<0.1 g) and feathers (<0.1 g) were finally digested with 6 ml and 3 ml HNO_3 (50 %), respectively, in a high-pressure microwave system (Milestone UltraClave, EMLS, Leutkirch, Germany). Analysis of Al, As, B, Be, Cd, Co, Cr, Fe, Hg, La, Mn, Mo, Ni, Pb, S, Sb, Se, Sm, Th, U, V, Y, Yb, Zn was carried out by high resolution inductively coupled plasma mass spectrometry (HR-ICP-MS) using a Thermo Finnigan model Element 2 instrument (Bremen, Germany) at the Department of Chemistry, NTNU. Blanks containing ethanol (75 %) was stored and analyzed in the same manner as the insect and spider samples. The Thermo Finnigan model Element 2 instrument was additionally used to analyze blanks containing HNO_3.

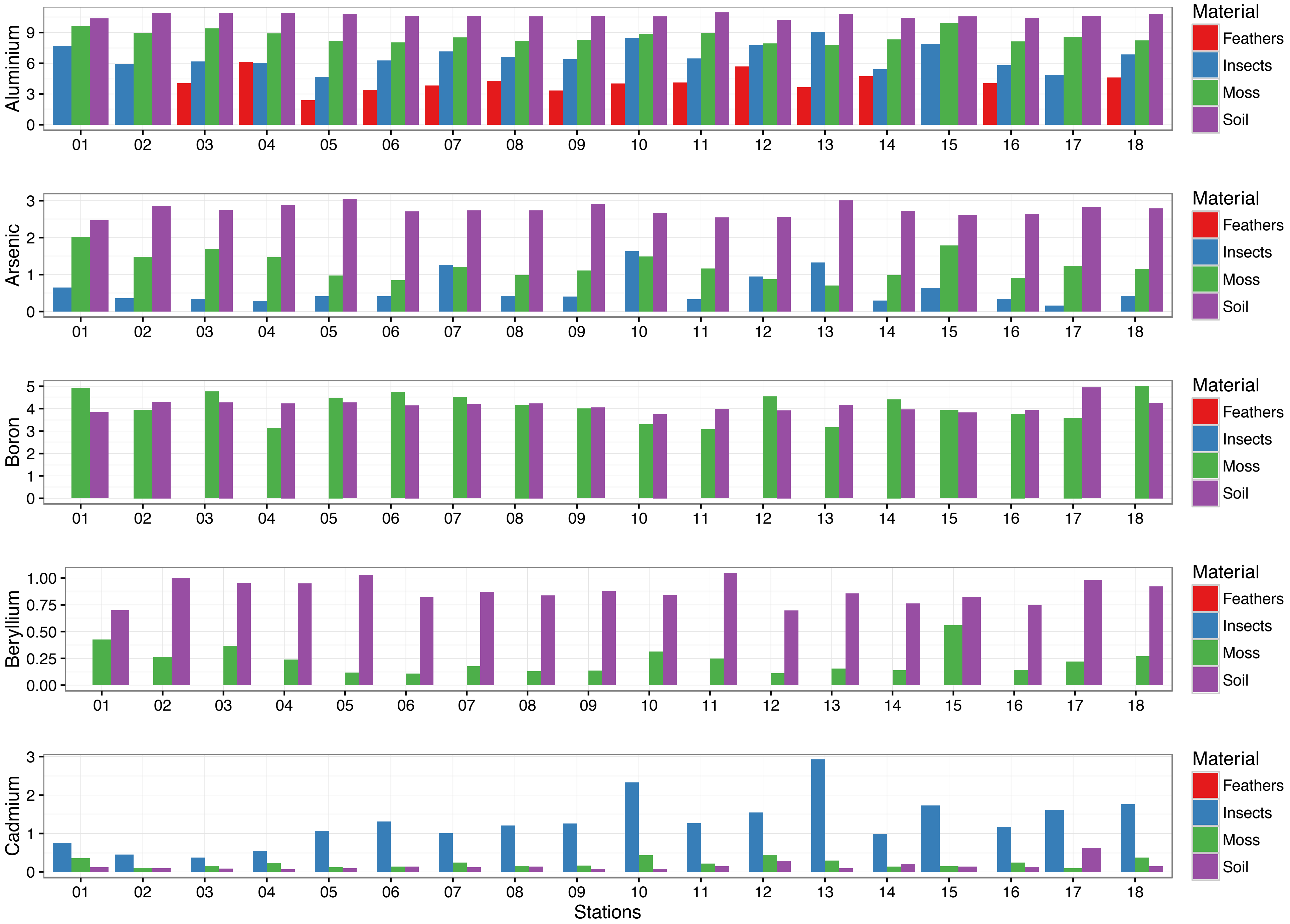
Limits of detection (LODs) were calculated for soil, mosses, insects and spiders and feathers from snow bunting nestlings based on different weight classes for insects/spiders and feathers. Elements where 50 % or more of the analyzed concentrations were below LOD, were excluded from the dataset used for statistics (marked with * in Table 1 in section 3 “Results” and Table 4 in Appendix III). Concentrations are given as µg/g dw. The analytical procedure was verified with the use of INCT-OBTL-5 reference material (Institute of nuclear chemistry and technology Warzava – Poland, oriental basma tobacco leaves) (Table 3, Appendix II).

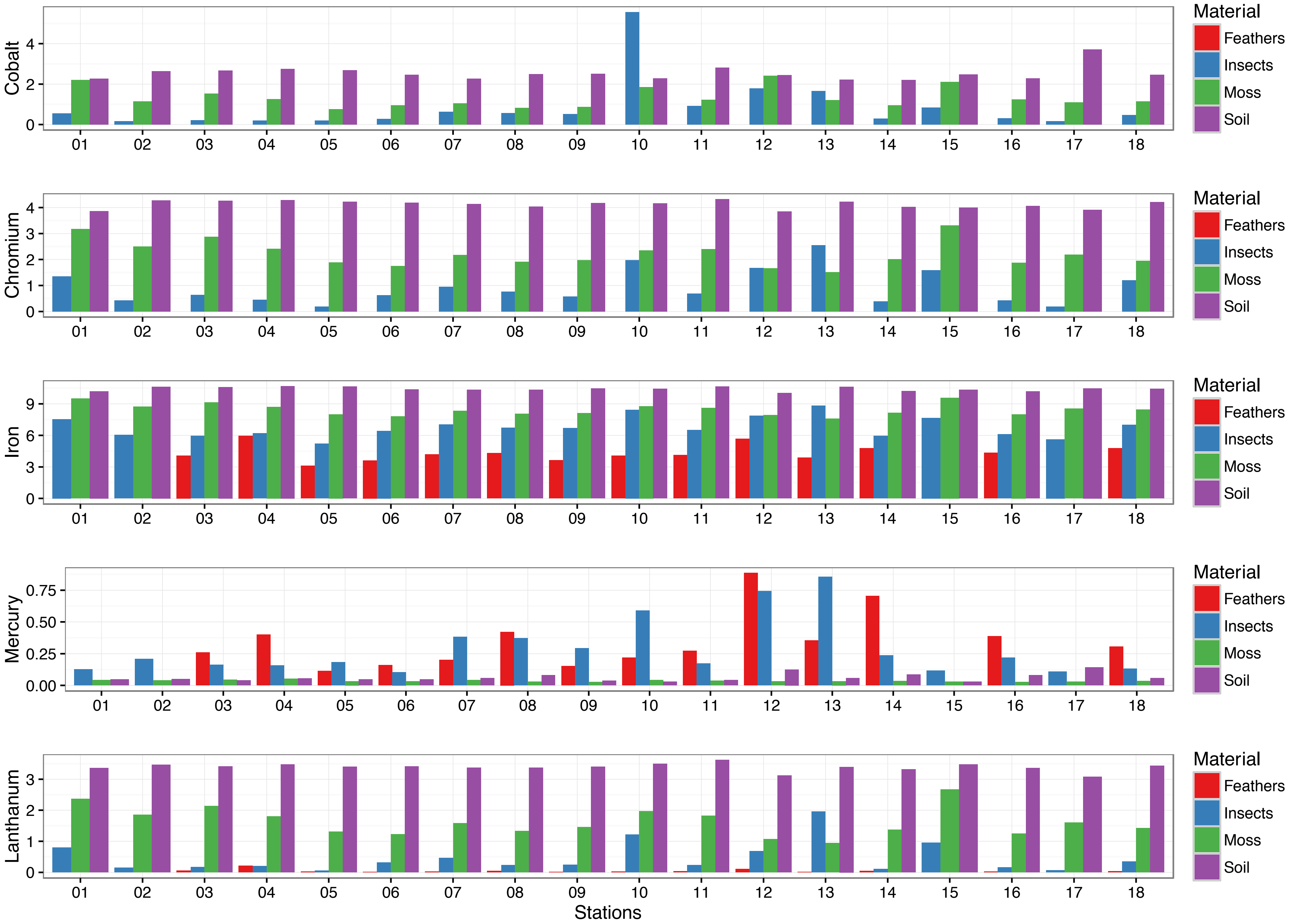
2.3 Statistical analysis

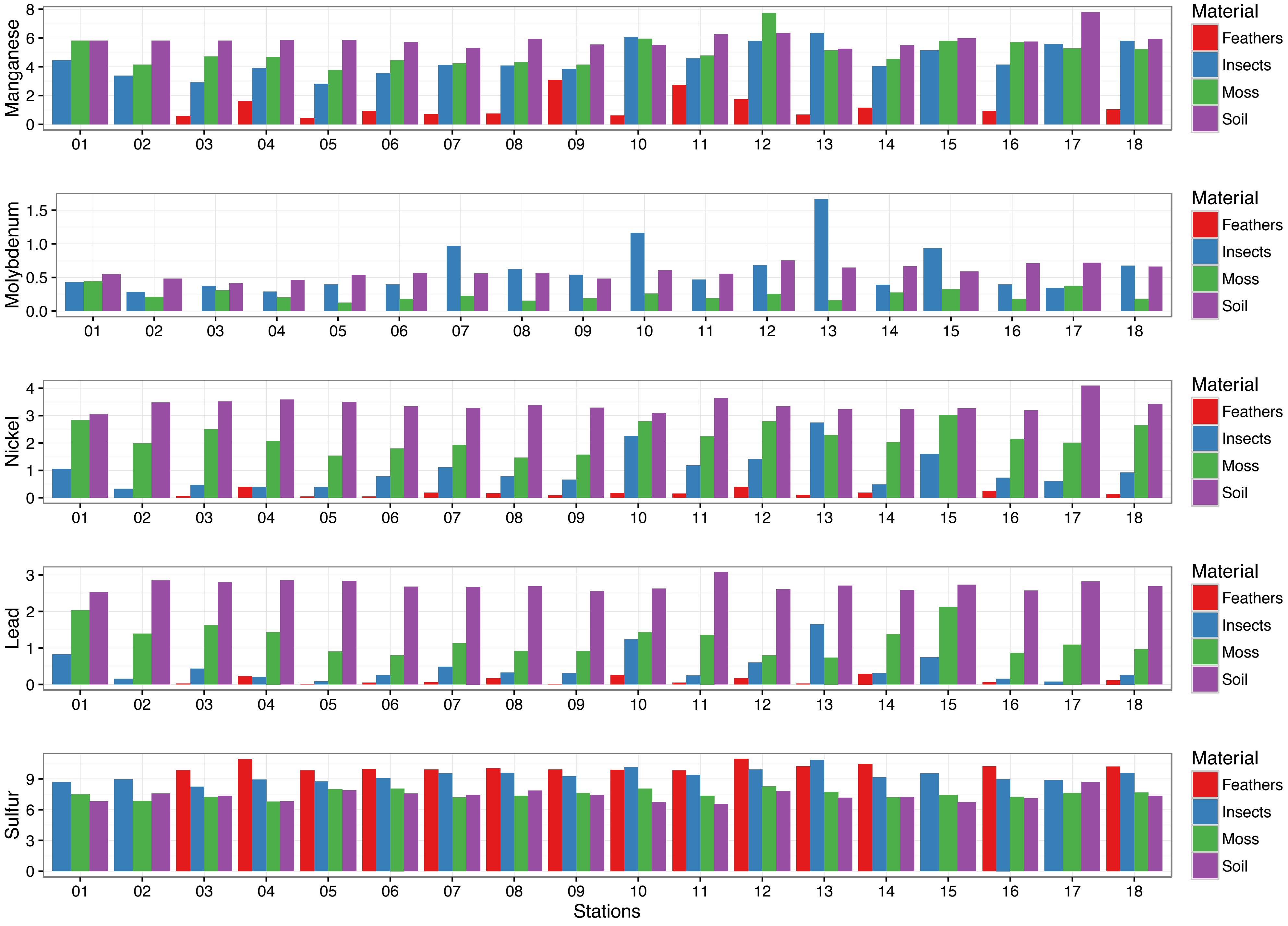
Barplots was created by use of the software R (R Core Team, 2015) using the package ggplot2 (Wickham, 2009) to illustrate the results. Because of illustrative purposes log-scale was used. Spearman rank correlations were further used to test for potential gradients along Adventdalen. These tests aimed to demonstrate the relationship between element concentration in sample and distance (km) from Longyearbyen coal power plant. Spearman rank correlations were additionally used to test for statistically significant relationships between element concentrations in feathers (µg/g dw) and soil, mosses and insects/spiders (µg/g dw). Statistical significance was accepted at $p < 0.05$. Bonferroni correction was used to control for multiple testing.

3 Results

Detailed results of HR-ICP-MS analysis are shown in Appendix VI (Tables 6-9). Mean, standard deviation, median, minimum and maximum concentrations are shown in Appendix III (Table 4). Barplots for the elements related to coal industry are presented in Figure 3. Correlation coefficients (ρ), degree of freedom (df) and p-values acquired from spearman rank correlations are listed in Tables 1 and 5 (Table 5, Appendix IV). Figures 10 and 11 illustrate significant correlations after Bonferroni correction ($p < 0.002$) (Appendix V). These results are further discussed in section 4 “Discussion”.


Aluminium
0
3
6
9
Arsenic
0
1
2
3
Boron
0
1
2
3
4
5
Beryllium
0.00
0.25
0.50
0.75
1.00
Cadmium
0
1
2
3
01
02
03
04
05
06
07
08
09
10
11
12
13
14
15
16
17
18
Stations
Material
Feathers
Insects
Moss
Soil


Cobalt
0
2
4
Chromium
0
1
2
3
4
Iron
0
3
6
9
Mercury
0.00
0.25
0.50
0.75
Lanthanum
0
1
2
3
01
02
03
04
05
06
07
08
09
10
11
12
13
14
15
16
17
18
Stations
Material
Feathers
Insects
Moss
Soil



Manganese
Molybdenum
Nickel
Lead
Sulfur
Stations
01
02
03
04
05
06
07
08
09
10
11
12
13
14
15
16
17
18
Material
Feathers
Insects
Moss
Soil


Antimony
0.0
0.1
0.2
0.3
0.4
0.5
Selenium
0.0
0.5
1.0
1.5
2.0
2.5
Samarium
0.0
0.5
1.0
1.5
2.0
Thorium
0.0
0.5
1.0
1.5
2.0
Uranium
0.0
0.2
0.4
0.6
01
02
03
04
05
06
07
08
09
10
11
12
13
14
15
16
17
18
Stations
Material
Feathers
Insects
Moss
Soil

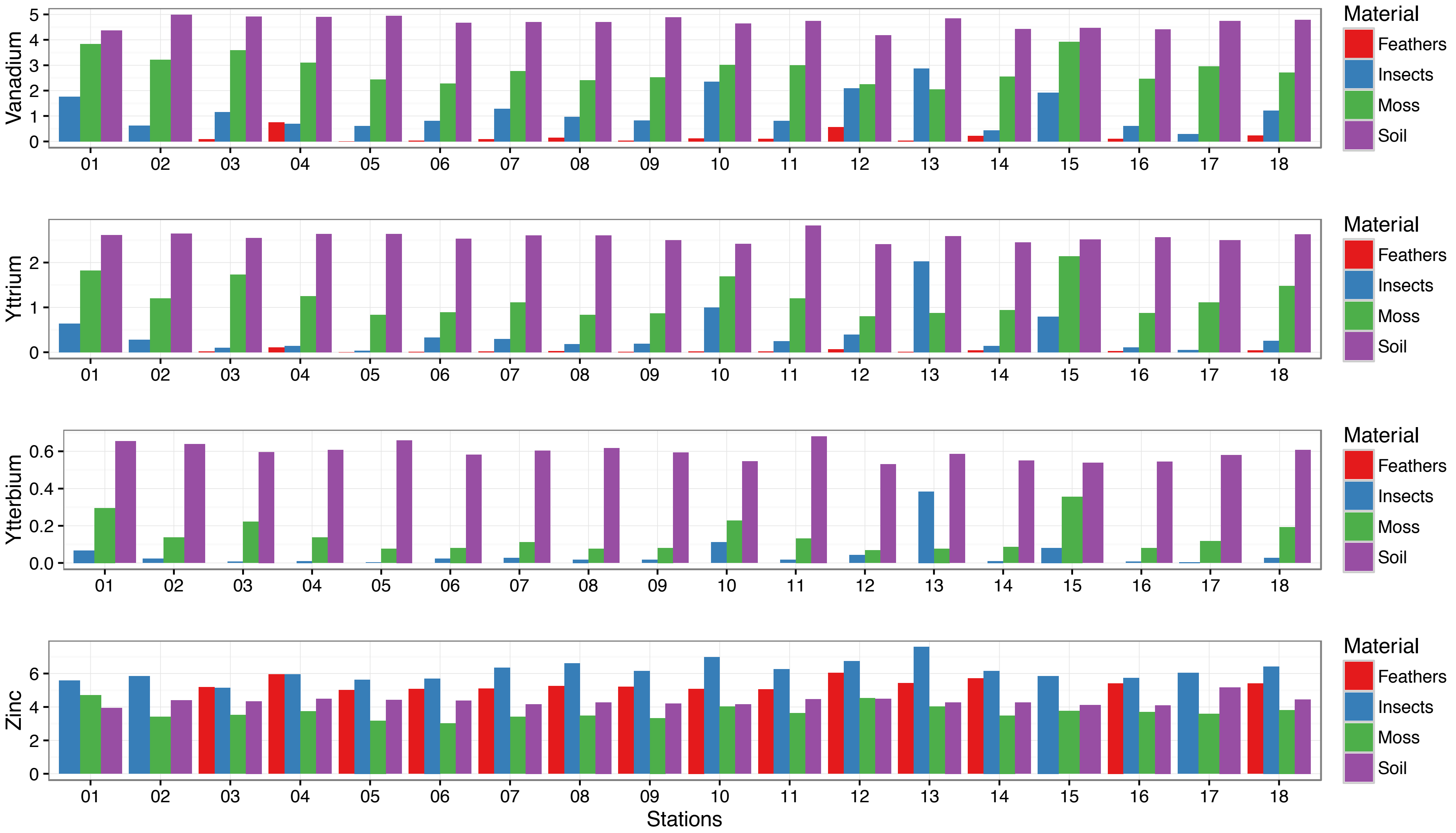


Figure 3. Concentration (µg/g dw, log-scale) of the given elements in soil, mosses, insects/spiders and feathers from snow bunting nestlings at the stations located along the transect. Station 1 is located closest to Longyearbyen coal power plant, whereas station18 is located in vicinity of Gruve 6 (Figure 2). Station 1, 2, 15 and 17 were not included in the analysis of feathers. Missing data at other stations is due to the exclusion of concentrations below LOD or concentrations being absent from the HR-ICP-MS analysis (see Table 1 for more information).

Table 1. Correlation coefficients (ρ), degree of freedom (df) and p-values demonstrating the relationships between element concentration (µg/g dw) within sample type and the distance (km) from Longyearbyen coal power plant

	Soil	Mosses	Insects/spiders	Feathers
Al	$\rho = -0.33$, df = 16, $p = 0.18$	$\rho = -0.33$, df = 16, $p = 0.18$	$\rho = 0.098$, df = 16, $p = 0.70$	$\rho = 0.24$, df = 12, $p = 0.41$
As	$\rho = -0.11$, df = 16, $p = 0.65$	$\rho = -0.33$, df = 16, $p = 0.185$	$\rho = -0.034$, df = 16, $p = 0.90$	*
B	$\rho = -0.20$, df = 16, $p = 0.43$	$\rho = -0.23$, df = 16, $p = 0.36$	-	-
Be	$\rho = -0.17$, df = 16, $p = 0.49$	$\rho = -0.063$, df = 16, $p = 0.81$	*	*
Cd	$\rho = 0.60$, df = 16, **$p = 0.0096$**	$\rho = 0.15$, df = 16, $p = 0.55$	$\rho = 0.70$, df = 16, **$p = 0.0017$****	*
Co	$\rho = -0.16$, df = 16, $p = 0.51$	$\rho = 0.034$, df = 16, $p = 0.90$	$\rho = 0.25$, df = 16, $p = 0.31$	*
Cr	$\rho = -0.33$, df = 16, $p = 0.18$	$\rho = -0.35$, df = 16, $p = 0.16$	$\rho = 0.094$, df = 16, $p = 0.71$	*
Fe	$\rho = -0.30$, df = 16, $p = 0.23$	$\rho = -0.26$, df = 16, $p = 0.30$	$\rho = 0.17$, df = 16, $p = 0.51$	$\rho = 0.34$, df = 12, $p = 0.23$
Hg	$\rho = 0.37$, df = 16, $p = 0.13$	$\rho = -0.54$, df = 16, **$p = 0.021$**	$\rho = 0.059$, df = 16, $p = 0.82$	$\rho = 0.45$, df = 12, $p = 0.11$
La	$\rho = -0.21$, df = 16, $p = 0.41$	$\rho = -0.31$, df = 16, $p = 0.22$	$\rho = 0.090$, df = 16, $p = 0.72$	$\rho = -0.046$, df = 12, $p = 0.88$
Mn	$\rho = 0.19$, df = 16, $p = 0.46$	$\rho = 0.43$, df = 16, $p = 0.079$	$\rho = 0.64$, df = 16, **$p = 0.0048$**	$\rho = 0.32$, df = 12, $p = 0.27$
Mo	$\rho = 0.81$, df = 16, **$p < 0.001$****	$\rho = -0.034$, df = 16, $p = 0.90$	$\rho = 0.36$, df = 16, $p = 0.14$	*
Ni	$\rho = -0.096$, df = 16, $p = 0.70$	$\rho = 0.24$, df = 16, $p = 0.34$	$\rho = 0.39$, df = 16, $p = 0.11$	$\rho = 0.29$, df = 12, $p = 0.32$
Pb	$\rho = -0.12$, df = 16, $p = 0.63$	$\rho = -0.30$, df = 16, $p = 0.22$	$\rho = -0.067$, df = 16, $p = 0.79$	$\rho = 0.29$, df = 12, $p = 0.31$
S	$\rho = -0.073$, df = 16, $p = 0.77$	$\rho = 0.27$, df = 16, $p = 0.27$	$\rho = 0.49$, df = 16, **$p = 0.039$**	$\rho = 0.44$, df = 12, $p = 0.12$
Sb	$\rho = 0.60$, df = 16, **$p = 0.0093$**	$\rho = 0.19$, df = 16, $p = 0.45$	$\rho = 0.34$, df = 16, $p = 0.17$	$\rho = -0.25$, df = 12, $p = 0.38$
Se	$\rho = 0.47$, df = 16, $p = 0.053$	$\rho = -0.090$, df = 16, $p = 0.72$	$\rho = 0.59$, df = 16, **$p = 0.011$**	$\rho = -0.29$, df = 12, $p = 0.31$
Sm	$\rho = -0.36$, df = 16, $p = 0.14$	$\rho = -0.26$, df = 16, $p = 0.30$	$\rho = 0.065$, df = 16, $p = 0.80$	$\rho = 0.26$, df = 12, $p = 0.26$
Th	$\rho = -0.11$, df = 16, $p = 0.65$	$\rho = -0.33$, df = 16, $p = 0.18$	*	*
U	$\rho = 0.053$, df = 16, $p = 0.84$	$\rho = -0.24$, df = 16, $p = 0.34$	$\rho = 0.051$, df = 16, $p = 0.84$	$\rho = 0.43$, df = 12, $p = 0.13$
V	$\rho = -0.35$, df = 16, $p = 0.15$	$\rho = -0.29$, df = 16, $p = 0.25$	$\rho = -0.0010$, df = 16, $p = 1$	$\rho = 0.29$, df = 12, $p = 0.32$
Y	$\rho = -0.41$, df = 16, $p = 0.094$	$\rho = -0.11$, df = 16, $p = 0.66$	$\rho = -0.0010$, df = 16, $p = 1$	$\rho = 0.38$, df = 12, $p = 0.18$
Yb	$\rho = -0.58$, df = 16, **$p = 0.014$**	$\rho = -0.13$, df = 16, $p = 0.61$	$\rho = 0.038$, df = 16, $p = 0.88$	*
Zn	$\rho = 0.051$, df = 16, $p = 0.84$	$\rho = 0.29$, df = 16, $p = 0.24$	$\rho = 0.49$, df = 16, **$p = 0.042$**	$\rho = 0.41$, df = 12, $p = 0.15$

- : HR-ICP-MS analysis was not conducted on this element.

* : ≥ 50 % of the concentrations were below LOD, and the corresponding element was deleted from the dataset.

p-values below 0.05 are written in bold.

** : significant after Bonferroni correction, controlling for the number of elements ($p < 0.002$).

4 Discussion

Correlation analyses (Table 1) indicate that there were a statistical significance in the relationships between distance from the coal power plant and concentration of Cd, Mo, Sb and Yb in soil, Hg in mosses, and concentration of Cd, Mn, S, Se and Zn in insects/spiders. The correlation coefficient for Cd, Mo and Sb in soil, and Cd, Mn, S, Se, Zn in insects/spiders was positive, which implies that the concentration in the samples increased with increasing distance away from the coal power plant. According to NGU, main anthropogenic sources to Cd, Mo, Sb, S, Se and Zn on Spitsbergen include coal combustion (Ottesen et al., 2010). Conversely, the findings in the present master thesis suggests that Gruve 6 and/or Gruve 7 constitute main sources of emission to the transect. Pollution sources to Cd, Mn, Mo, S, Sb, Se and Zn may include mine waste rocks or mining, loading and transport activities resulting in emission of dust to the environment. Household waste, slag and ash deposited on the landfill might also constitute sources of emission. The positive concentration gradients for Cd, Mn, Mo, S, Sb, Se and Zn may alternatively constitute natural gradients resulting from deposition from rivers and glacial activity over geological time.

The correlation coefficient for Yb in soil and Hg in mosses was negative (Table 1), indicating that the concentrations in the samples decreased with increasing distance away from the coal power plant. This suggests that Longyearbyen coal power plant and/or other city related activities constitute the main points sources of Yb and Hg emission to the transect. Elements primarily emitted to the atmosphere through coal combustion are Hg and Se (Llorens et al., 2001), and a concentration gradient for Hg was thus expected. Moreover, much of the Hg entering the atmosphere from coal combustion does so as the volatile elemental species (Hg^0 (g)). A minor portion associates with particulate matter (Manahan, 2010). Hence, Hg is easily available to absorption of mosses, which might explain why Hg concentrations in mosses reflected the distance away from the coal power plant in a higher degree than soil, insect/spider and feather samples. In contrast to Hg, Yb is commonly retained in the solid wastes (Llorens et al., 2001), and Yb is thus considered less likely emitted to the atmosphere. Nevertheless, Yb might escape from the particulate retention devices and deposit in soil.

Thus, the analyses suggest that Gruve 6 and/or Gruve 7 have a significant impact on the chemical element distribution of Cd, Mo and Sb in soil, and Cd, Mn, S, Se, Zn in insects/spiders. They also suggest that chemical element distribution of Yb in soil and Hg in mosses is significantly impacted by Longyearbyen coal power plant. However, as 96 correlations were tested, the probability for identifying a false-positive result (Type-I error) is relatively high. This leads to speculations whether the results constitute as errors. Nevertheless, a strong positive relationship ($p < 0.001$) between distance from the coal power plant and concentrations of Mo in soil was found (Table 1 and Figure 10), and the relationships remained statistical significant after Bonferroni correction (significance at $p < 0.002$). Molybdenum is essential to various biological processes in higher plants, and is commonly taken up in soil (Schulte, 1992). This might explain why a concentration gradient was detected for Mo in soil, and not for the other sample materials. Furthermore, the positive relationship between distance from the coal power plant and concentrations of Cd in insects/spiders remained statistical significant after Bonferroni correction ($p = 0.0017$) (Table 1). The plot in Figure 10 (Appendix V) indicates that there were two outliers in Cd concentration in insects/spiders along the transect – station 10 and 13 (Table 8 Appendix VI, Figure 3). These outliers may be due to other local sources of pollution than Gruve 6 or 7, which are further discussed in the sections 4.1.2 and 4.1.3 below. Nevertheless, when excluding the two outliers the relationship remained statistical significant after Bonferroni correction ($p = 0.0006$). The concentration gradient might be detectable with regard to insects/spiders due to invertebrates' ability to accumulate Cd. Moreover, a positive concentration gradient in soil was also detected for Cd (Table 1). Soil constitutes an important exposure route for soil dwelling invertebrates (Veltman et al., 2008), and the concentration gradient in insects/spiders might hence be coupled to the concentration gradient in soil. However, bioaccumulation can be complex (Veltman et al., 2008). Soil properties (e.g. pH, water, organic matter and clay content) determine Cd bioavailability, and uptake and elimination are often species dependent. Springtails, for instance, have an effective excretion mechanism (van Leeuwen & Hermens, 2004). Due to differences in sample material, e.g. differences in soil properties and species composition, it might be problematic to compare the stations along the transect. Moreover, it might be difficult to observe the impact of the coal power plant and Gruve 6 on the transect due to multiple pollution sources and difference in topography. Multiple pollution sources, and differences in topography and sample material are discussed in further detail in the sections below. These differences might additionally explain why no statistical significant relationship was observed for most of the elements and sample materials (Table 1).

4.1 Multiple pollution sources and topography

Analyzed element concentrations at the stations were probably affected by multiple pollution sources. Apart from being affected by the coal power plant and the coal mining, there are stations located in the vicinity of cruise ships, snowmobiles, road traffic, landfill, cableway station and cabins. Multiple sources consequently makes it difficult to observe the isolated impact of the coal power plant and coal mining on the transect. Topography, such as mountains and rivers, might additionally have an effect on the element concentration at specific stations. Endal river, Todal river and other rivers of smaller sizes pass through the transect before they drain into Advent river or lake Isdammen (Figure 2). The water discharge might supply the ambient environment with natural products from glacial erosion and weathering of bedrock, as well as anthropogenic pollutants carried by the river from mine waste rocks (e.g. Gruve 5 and 6) and cabin areas. Station 1, 10, 12, 13, 15, 17 and 18 constitute stations along the transect that contained particularly high concentrations of specific elements (Figures 2 and 3). Types of elements that were dominating varied for the different stations. However, Al, Cd, Co, Fe, La, Pb, U, V, Y and particularly Se were quantified in high concentrations at most or all of the stations. These stations will therefore be considered in the following text.

4.1.1 Station 1

Station 1 is located in Longyearbyen next to a road and The University Centre in Svalbard (UNIS) (Figures 2 and 4). Here, mosses contained particularly high levels of As, Mo, Se, U, V and Zn, in addition to high levels of Al, B, Cd and Pb (Figure 3). Aluminum, Cd, Pb, V and Zn are elements associated with traffic (Ottesen et al., 2010), and high concentrations of these elements were thus expected considering the location of the station. Some of the elements present in high quantities in mosses are also associated with human activities other than traffic, coal combustion and coal mining. Arsenic is being used in wood preservatives, batteries, ammunition, paints and textiles, B (boron) is used in laundry products, glass, enamel, insulation fiberglass and as flame retardant, whereas waste

Figure 4. Station 1 is located next to a road, cabins and UNIS (photo: Beitveit, G. 2015)

water constitutes a source for Mo, Se and Zn. Molybdenum is additionally found in phosphate detergents, and Zn is found in anti-corrosion agents (Ottesen et al., 2010). Being located in Longyearbyen, next to cabins, the university, and human settlement, mosses are constantly being exposed to these elements. Moreover, concentrations of B and Se might be affected by natural local sources such as sea spray (Steinnes & Jacobsen, 1994). Station 1 is located in vicinity of the marine environment, and might be subject to airborne supply of related elements (Figure 2). Nevertheless, high concentrations were also quantified in soil, which might have contributed to the high concentrations determined in the moss samples. Although particles were removed from the moss samples with compressed air, this procedure do not remove all of the particles from the surface, and may thus have affected the results (Steinnes & Jacobsen, 1994).

4.1.2 Station 10

Station 10 is located close to the cableway station (Vinkelstasjonen) (Figures 2 and 5), which constitutes a linkage between coal transport from Endalen and Gruve 6. Here, insects/spiders contained particularly high concentrations of elements associated with coal mining, such as Al, Fe, La and Y (Figure 3). High concentrations of these elements might be due to the large amounts of coal found scattered on the ground. Moreover, discarded iron wired was also observed close to the station. The insects and spiders were hence continuously exposed to Al, Fe, La and Y. Relatively low concentrations of Al, Fe and Y in soil in comparison to other stations (Figure 3) suggests that these elements are not well adsorbed on soil constituents, being bioavailable for insects/spiders and other organisms. Furthermore, high concentrations of Cd, Mn, Pb and V were quantified in the insect/spider sample (Figure 3). The station is located in vicinity of a road, and high concentrations of these traffic related elements (Ottesen et al., 2010) were thus expected. Traffic might additionally have increased the burden of Al in the environment (Ottesen et al., 2010), and hence contributed to the high concentration of Al in the insect/spider sample.

Figure 5. Station 10 is located next to a road, a cableway station and iron wires (photo: Beitveit, G. 2015)

4.1.3 Station 12 and 13


Figure 6. Station 13 is located next to a river originating in the mountain where mining activity have been situated (photo: Beitveit, G. 2015)

Station 12 and 13 are located in the vicinity of cabins, snowmobile and road traffic. Moreover, a historically German weather station named *Bansø* existed below the stations in 1941/1942. Remainings from the weather station can still be found in this area (Riksantikvaren, 2013). In addition, the stations might be affected by runoff from cabins and Gruve 5 situated in Endalen (Figure 2). Analyses show that station 12 had some of the highest concentrations along the transect, where especially high concentrations of Cd, Co, Mn, Ni, S, Sb and Zn in mosses, Al, Fe, Hg, La, Pb, S, Se, Sm, U, V, Y and Zn in feathers, and Hg, Ni and Sb in soil were quantified (Figure 3). Apart from the coal industry, cabins might supply the environment with excessive amounts of elements through the use of batteries (Hg and Cd), shotgun pellets (Pb), waste (Ni, Pb, Sb, Zn) and wastewater (Cd, Zn), waste burning (Pb) and wood impregnation (Hg). Traffic might constitute an additional source of Cd, Mn, Ni, Pb, Sb and Zn (Ottesen et al., 2010). Whereas high concentrations were quantified in soil, mosses and feathers at station 12, high concentrations were determined in insects/spiders at station 13. This might be due to a different sample composition at station 13, where spiders and mosquitos were collected in higher quantities (Table 2, Appendix I). The large spider and mosquito collection may be due to a semi-wet environment that favors growth of food supply. The concentrations were high for all the elements in the insects/spider sample at station 13, except from B, Be, Co and Th (Figure 3), indicating that the station might be considerably polluted. In addition to being exposed to cabins, snowmobile and road traffic and runoff from Endalen, station 13 is located close to a small river originating in the mountains (Figures 2 and 6). According to Norwegian Polare Institute (TopoSvalbard), mining activity has previously existed where the river originates. Further studies are recommended.

4.1.4 Station 15


Figure 7. Station 15 is located next to Todalselva (photo: Beitveit, G. 2015)

Station 15 is situated next to the river Todalselva originating in Todalen (Figures 2 and 7). Products from glacial erosion and weathering of bedrock as well as anthropogenic pollutants from cabins can be carried by the river and deposited in areas downstream. The analyses show that station 15 contained the highest concentrations of La, Sm, Y and Yb in mosses (Figure 3), for which natural sources such as local bedrock are more important than anthropogenic sources (Ottesen et al., 2010). Furthermore, the station contained the highest concentrations of Al, Be, Cr, Fe, Pb, Se, Th, U and V in mosses along the transect (Figure 3). However, as mosses acquire their element supply from atmospheric deposition, it is unlikely that the river had a direct effect on the concentrations quantified in the moss sample. One explanation to the notably high concentrations in mosses might be contamination of particles on the surface of the moss plant, as a result of wind erosion of soil and an incomplete removal of the particles in the cleaning procedure.

4.1.5 Station 17


Figure 8. Station 17 is located next to a road, Gruve 6 and a river (photo: Beitveit, G. 2015)

Station 17 is situated next to a road that is passing through the transect between Gruve 6 and station 17. An iron pipe placed under the road connects runoff from Gruve 6 to the station (Figure 8). Moreover, a small river originating above Gruve 6, where the extraction of coal is conducted, also seemed to end at station 17 (TopoSvalbard) (Figures 2 and 8). As a result, the area was very wet, and the sample materials may have been continually exposed to elements associated with coal mining activity. Soil samples at station 17 contained particularly high concentrations of B, Cd, Co, Hg, Mn, Pb, S, Se, U, Zn (Figure 3). While all of these elements are associated with coal industry, some are additionally associated with traffic, such as Cd, Mn and Pb. Cadmium are also associated with iron and steel mills (Ottesen et al., 2010), and might consequently be added to the environment through old mining constructions at Gruve 6.

4.1.6 Station 18

A road, Gruve 6, a landfill and a dogyard are located in the vicinity of station 18 (Figures 2 and 9). The analyses quantified considerable high concentrations of B and Cd in the moss sample, as well as high concentrations of Se and Mn in the insect/spider sample (Figure 3). Boron is typically being used in laundry products, alloys, ceramics, glass, enamel, insulation fiberglass and in flame retardants (Ottesen et al., 2010). Cadmium is being present in electroplating, batteries and sewage sludge (Ottesen et al., 2010). High concentrations of B and Cd in the moss samples might consequently be a result of contamination from the landfill. Similar concentrations were quantified in mosses collected from station 1 (Figure 3) – a location that is constantly exposed to the products associated with B – which strengthens this assumption. In addition, coal mining might function as a pollution source, where particularly Mn is associated with mining activity. Cd and Mn can additionally be supplied to the ambient environment through road traffic (Ottesen et al., 2010). Nevertheless, although high concentrations were quantified at station 18, higher concentrations were expected, considering the location of the station.

Figure 9. Station 18 is located next to road (not shown), below Gruve 6 and landfill (photo: Beitveit, G. 2015)

Thus, the different pollution sources and topography affecting the different stations might make it difficult to observe the isolated impact of the coal power plant and Gruve 6 on the transect. Similarly, it might be problematic to compare the stations and to observe gradients in chemical element distribution due to differences in the sample materials collected at each station. The sample materials, soil, mosses, insects/spiders and feathers from snow bunting nestlings, are discussed in the following sections.

4.2 Limitations in sample materials

4.2.1 Soil

Along the transect, soil might have varied in physical properties and chemical composition. Some stations were clearly dominated by stones and dryness (e.g. station 3 and 9), whereas other areas consisted of flourishing plants and mosses anchored in wet or semi-wet soil (e.g. station 16 and 17). Apart from water content, the content of clay, organic matter, particles and biological entities might additionally have differed between the stations. Metals particularly adsorb to clay, and a low content of this component might hence result in less binding of metals in the soil. Furthermore, the stations might also have differed in pH, competing elements and cation-exchange capacity, which have an impact on the adsorption of elements to soil components (Rattan, 2006). Despite the importance of these factors in element adsorption to soil, no analyses of soil components except specific element composition have been conducted in the present study. Hence, the strong positive relationship between distance from the coal power plant and concentrations of Mo in soil might be due to gradients in pH, clay content, or other factors affecting adsorption of Mo to soil components.

4.2.2 Mosses

The same moss species was attempted collected at each station. However, due to logistic constrains and difficulties in species determination it was not always possible to distinguish between taxa. Different moss species might have different abilities to absorb, retain and accumulate airborne pollutants. Thus few statistically significant correlations between element concentration in moss and distance from the coal power plant might be explained by variation in species composition in the samples (Table 2, Appendix I). It might also question the strong negative relationship observed between the distance from the coal power plant and concentrations of Hg in moss. Rühling et al. (1987) have tried to compare the results of different investigations of mosses, and reports that this was not easy due to the use of different moss species. Moreover, differences in airflow along the transect might have an impact on atmospheric deposition at the different stations. Wind erosion of soil might additionally result in deposition of windblown soil dust on the moss surface. This problem particularly applied to areas with sparse vegetation (Steinnes & Jacobsen, 1994). In the present study, the stations differed in dryness and vegetation. Hence, the relative contribution of wind erosion of soil on the analyzed element concentration might vary between the stations. Besides, the previous study concluded that the treatment of mosses by washing or shaking did not remove all of the particles from the surface (Steinnes & Jacobsen, 1994). Hence, the cleaning procedure used in the present study may not have removed all of the soil particles. Nevertheless, chemical analysis is easier than in insects and feathers due to higher concentrations, which makes moss a more reliable material for biomonitoring.

4.2.3 Insects and spiders

The adsorption of elements to soil affects their mobility and bioavailability in the ambient environment. The varying soil properties at each station may consequently have had an impact on the concentration gradients for the insects/spiders and feathers. Apart from soil properties, some of the quantified element concentrations may have been affected by logistic problems with insect sampling and analytical difficulties related to the chemical analysis. Due to limited time available for sampling it was difficult to collect large amounts of individuals enough for a reliable chemical analysis. Even though the limited sample quantities have been taken into account when estimating LODs, the diverse species composition (Table 2, Appendix I) may, on the other hand, pose a problem for comparison of the stations because of differences in bioaccumulation potential of specific elements in different insect species. Furthermore, the origin of some of the species collected is unknown due to their flying ability. Thus, these insects might consequently reflect exposure from other areas (Nummelin et al., 2007). Moreover, the insects were caught and stored in 67 and 75 % v/v ethanol/water solution, respectively, a practice that may have resulted in leakage of elements from the body fluids and tissues into the ethanol solution. Different insects have different cuticle properties, and due to variation in species composition at different stations this might make it even more difficult to compare the stations along the transect. The ideal method would have been to catch insects with nets and freeze/dry them after catching, which due to logistic problems could not be applied in this study.

4.2.4 Feathers

No statistical significance was quantified in the relationship between distance from the coal power plant and concentration of the analyzed elements in feathers from snow bunting nestling (Table 1). This may be due to differences between and within nests, such as multiple routs of exposure, individual differences in absorption and disposition, pulmonary ventilation, clutch size, feeding rate, elimination rate or body size. In general, snow buntings have a clutch size of 4-7 eggs (Falconer et al., 2007). Fetching food is an energetically demanding task, and a limited amount of food resources are hence available for feeding of the nestlings.

During nest inspection, difference in body condition was observed among the nestlings and between nests. Thus all of the nestlings may not have acquired equal amounts of food, and gastrointestinal absorption of pollutants may have varied between the nestlings. At some cases the parents additionally have to travel long distances to acquire food provisioning (Falconer et al., 2007). This may result in lower feeding rate at some of the stations. Moreover, the locations where the parents acquired prey might overlap. Thus contamination exposure might include contaminants form different locations. However, because flight and time spent away from the nest is energetically costly, it is assumed that the parents fetch food in close proximity to the nest if possible. Both sexes were often observed close to the breeding sites traversing the area, which strengthens this assumption. Yet, some stations along the transect possibly constitute as a more preferable place to catch insects and spiders for birds than others (e.g. station 13). This might result in a better correlation between concentration in feathers and the ambient environment at these stations. Nevertheless, the multiple differences between nests and individual nestlings makes it difficult to identify gradients for element concentration along the transect.

Maternal transfer to the egg at the time of its formation might additionally affect the element concentrations within nestlings post hatching (Agusa et al., 2005). Maternal transfer of essential elements is vital to the chick development. However, also toxicants might be transferred from the mother to the egg. The transfer is assumed to be related to the concentrations in tissue of the mother and the environment that the mother has been exposed to (Dauwe et al., 2005). Snow buntings migrate from Svalbard in the summer to southern wintering grounds, where they spend the winter at the steppes north of the Caspian Sea (F. Fossøy, pers. com.). Thus multiple environments encountered by the birds during migration probably affect total element content within the females. This might vary between individuals, and consequently maternal transfer might vary between nests. Moreover, previous studies have reported differences between elements in maternal transfer. An earlier study on black-tailed gulls (*Larus crassirostris*) reports that Se, in particular, was easily transferred to eggs, whereas maternal transfer of Cd to eggs was limited (Agusa et al., 2005). Similarly, another study reports that only small amounts of Pb are transferred into eggs of seabirds (Dauwe et al., 2005). However, only few studies have investigated the maternal transfer of passerine birds (Dauwe et al., 2005).

4.2.5 Comparison of concentrations of elements to other areas

To assess whether the assumed contaminated transect were in fact contaminated and to what extent, it is a requisite to have information on natural variations. It was however challenging to select appropriate reference sites as it was difficult to find minimally disturbed sites located close to Longyearbyen. Areas located at the opposite side of Adventdalen could have functioned as appropriate candidates, considering its more remote location. However, cabins and emission from Longyearbyen coal power plant may also affect these areas. Considering practical feasibility, the collection of feathers from hypothetical reference sites would additionally be difficult. Searching for nests in cavities in screes would be a time consuming process. Furthermore, nests located in natural breeding sites are more susceptible to predation, which reduces the likelihood of the eggs and nestlings surviving until day 8-10 post hatching. However, as mentioned previously the content of heavy metals in undisturbed soil (top soil) was determined at Reinsdyrflya in West Spitsbergen in 1983, and might constitute reference conditions for soil in the present study. The concentration of Zn, Pb and Ni in the top soil was quantified to 66, 7 and 25 µg/g, respectively. Whereas the mean values for the quantified concentrations in soil in the present study were 77.70, 14.29 and 29.47 µg/g for Zn, Pb and Ni, respectively (Table 4, Appendix III). Hence, in comparison to reference condition from 1986, the results indicate that the transect are somewhat more polluted with respect to the given heavy metals, especially considering Pb. Anthropogenic sources of Pb include traffic, steel works, batteries, sewage sludge and waste incineration (Ottesen et al., 2010). Moreover, a study conducted by NGU near Longyearbyen in 1986 showed the following concentrations: 58.9 – 79.2 µg/g Zn, 8.9 – 15.3 µg/g Pb, and 19.7 – 31.2 µg/g Ni (HNO_3 extract ICP) (Ottesen et al., 2010). Thus the mean values for the quantified concentrations in soil in the present study are in accordance with data from 1986, which indicates that pollution is not a new phenomenon in Adventdalen and Longyearbyen.

4.3 Feathers as bioindicators

To assess the suitability of feathers from snow bunting nestlings in biomonitoring, a spearman rank correlation test was used to investigate whether concentrations in feathers correlated with the concentrations in soil, mosses and insects/spiders (Table 5, Appendix IV). The results indicate that there was a statistical significance ($p < 0.05$) in the relationship between Hg concentrations in feather and soil samples and in the relationship between Zn concentrations in feather and moss samples. The relationships between Hg concentrations in feathers and soil remained statistical significant after Bonferroni correction (significance at $p < 0.002$, Figure 11 Appendix V). The correlation coefficients were positive, which implies that the concentrations of Hg and Zn in feathers increased with increasing concentrations in soil and mosses, respectively. These results are interesting, considering the non-essential and toxic properties of Hg and Zn in organisms, and the bioaccumulative ability of Hg. A study conducted on Eurasian Greater Flamingo (*Phoenicopterus roseus*) found that Hg bioaccumulated from soil (Borghesi et al., 2016). Nevertheless, the positive relationship between Hg concentrations in feathers and soil might be due to contamination of soil particles deposited on the feathers. Previous studies report that no washing procedure was able to ensure the total removal of the surface contamination from feathers (Borghesi et al., 2016). Thus the four-step washing procedure – acetone/water/acetone/water – conducted in the present study may not have successfully removed the total amount of particles on the surface of the feathers. Moreover, in comparison to feathers, soil can integrate deposited pollutants over a longer time period, which makes it less likely to detect a correlation between concentrations in nestling feathers and soil.

The relationship between concentrations in feathers and soil, moss and insects/spiders were found to be not statistically significant for the other elements (Table 5, Appendix IV). Few statistical significant relationships between concentrations in feathers and mosses may be due to multiple exposure routes for the nestlings, in comparison to mosses, which have mainly one. Inhalation, dietary intake and maternal transfer all accounts for possible exposure routs for nestlings. Mosses, on the other hand, mainly reflect atmospheric deposition. Moreover, the carpet of mosses is built up over a period of 3-5 years (Rühling et al., 1987), whereas feathers are growing during the first 8-10 days post hatching. Although only the apices of the shoots were used in the analysis of mosses, moss apices still reflect exposure in a much longer time period than feathers. Therefore it may be problematic to compare concentrations within the two sample types.

The lack of statistical significant relationships between concentrations in feathers and insects/spiders might also be due to multiple routes of exposure to elements (other than dietary intake) for the nestlings. The snow bunting nest consists of straw, moss, feathers and reindeer hair, and the nestlings were hence continually exposed to elements adsorbed to the surfaces of these materials. Moreover, the environment on Svalbard is dry and windy, which might lead to increased inhalation of volatile elements (Hg) and elements associated with particles. As mentioned previously, wind erosion of soil might additionally have led to contamination of soil particles on the surface of the feathers. The study conducted on the Eurasian Greater Flamingo concluded that the external contamination of specific elements were capable of masking the bioaccumulation level within the feathers (Borghesi et al., 2016). Thus, a relationship between concentration in feathers and insects/spiders might have been difficult to detect. Furthermore, because the insects were stored in ethanol throughout the summer months, elements might have leaked out into the ethanol solution. The ethanol might additionally have washed away the elements adsorbed to the surfaces. Nestlings ingesting insects and spiders are not only exposed to elements incorporated in tissue and body fluid, but also to elements adsorbed to the surface (Dauwe et al., 2004). The analyzed concentrations in the insect/spider samples may consequently not reflect the burden that the nestlings were exposed to through food. Moreover, lack of correlation between feathers and insects/spiders can be explained by the fact that nestlings may feed on different species (or different ratios of species) than those that have been collected in the present study. As the potential to accumulate specific elements differs for different species, the element composition that the nestlings were exposed to through food depends on the species and the ratio between species that the nestlings ingested. The collected insect and spider samples might not be representative to the nestlings diet composition at a daily basis. The study on black-tailed gulls also reported that some elements, such as Cd, are hardly excreted into feathers (Agusa et al., 2005). Thus, the analyzed feather concentrations may not reflect the internal tissue concentrations in nestlings for all the elements.

4.4 Recommendations for future studies

The impact of the coal power plant and Gruve 6 on the chemical element distribution in Adventdalen may have been difficult to identify due to the stations being located in vicinity of each other and of the two point sources (Figure 2). Thus the stations might be relatively equally affected (particularly considering atmospheric deposition). Future studies should seek to analyze concentrations at stations located with further distance apart. Moreover, to assess the impact of the coal power plant and Gruve 6 on the transect, future studies should try to collect soil, mosses, insect/spider and feather samples from appropriate reference sites.

In addition, physical properties and chemical composition of soil should be analyzed when comparing element concentrations at stations. Content of clay, organic matter, particles, biological entities, pH, competing elements and cation-exchange capacity are factors that might have an impact on element adsorption in soil, and should be determined. Careful selection of sampling sites with respect to impacts from wind erosion should also be conducted to ensure meaningful information when studying element distribution in mosses and feathers. Moreover, washing treatments should be improved to ensure total removal of soil particles from the surfaces (Steinnes & Jacobsen, 1994). This might improve the feasibility of the biomonitoring by the use of mosses and feathers. Furthermore, the same moss species should be sampled and analyzed when using mosses as bioindicator. Insects and spiders should be caught with nets and freeze/dried after catching.

Despite the fact that station 13 is located relatively far from industrial activities in comparison to other stations closer to Longyearbyen or Gruve 6 (Figure 2), the results indicate considerable pollution at this station (Figure 3). According to cartographical sources (Norwegian Polar Institute, TopoSvalbard) there have been some mining activities above the station. Thus further studies at this station are recommended. A closer assessment of areas around cabins, the historically German weather station (*Bansø*) and runoff from mining activities above the station could elucidate the source of emissions. Furthermore, a closer assessment of the areas around the landfill (station 18, Figure 2) is recommended. Of particular concern is pollution from the landfill, as household waste, slag and ash from the coal power plant are deposited here.

Due to multiple confounding factors it was difficult to conclude whether feathers from snow bunting nestlings are suitable for biomonitoring of the environment on Svalbard. Further studies should be conducted to investigate the feathers suitability for bioindication purposes, as this would be a useful tool for environmental monitoring in a non-invasive way. Washing methods should be improved in order to obtain meaningful information about the internal accumulation of elements.

As the fieldwork for this master thesis was conducted in June/July 2015, the analyses reflects the chemical element distribution prior to the installation of the emission control technology at Longyearbyen coal power plant. Future studies should repeat the present study, as to analyze the chemical element distribution post installation. This will provide information to whether the emission control technology have had a positive impact on atmospheric pollution, and might constitute an important supplement in the reporting to environmental authorities. Mosses should be used as study material, as mosses mainly reflect atmospheric deposition.

5 Conclusion

Soil, mosses, insects/spiders and feathers from snow bunting nestlings was sampled from 18 stations located in Longyearbyen and Adventdalen (Figure 2). Subsequently, analyses of element concentrations (Al, As, B, Be, Cd, Co, Cr, Fe, Hg, La, Mn, Mo, Ni, Pb, S, Sb, Se, Sm, Th, U, V, Y, Yb, Zn) in the samples were conducted. The analyses indicate that there were a statistical significance ($p < 0.05$) in the relationship between the distance from the coal power plant and concentration of Cd, Mo, Sb and Yb in soil, Hg in mosses, and concentration of Cd, Mn, S, Se and Zn in insects/spiders. The correlation coefficient for Cd, Mo and Sb in soil, and Cd, Mn, S, Se, Zn in insects/spiders was positive, which implies that Gruve 6 and/or Gruve 7 constitute main point sources of emission of Cd, Mo, S, Sb, Se and Zn to the transect. Furthermore, the correlation coefficient for Yb in soil and Hg in mosses was negative. This suggests that Longyearbyen coal power plant and/or other city related activities constitute main points sources of Yb and Hg emission. Nevertheless, a strong positive relationship ($p < 0.002$) was only determined between the distance from the coal power plant and the concentrations of Cd in insects/spiders and of Mo in soil.

However, due to multiple confounding factors, it is difficult to detect the isolated impact of the coal power plant and Gruve 6 on the transect. Field studies are complex, and include many sources that might have an impact on the chemical element distribution: local and remote natural sources, and local and remote anthropogenic sources. Apart from the coal power plant and Gruve 6, local anthropogenic sources include cruise ships, snowmobiles, air and road traffic, landfill, Gruve 5, the cableway station, coal mining activity above station 13 (Figure 2), the German weather station (*Bansø*) and cabins. A closer assessment of areas around the local anthropogenic sources could elucidate the source of emissions and determine the relative contribution from these additional sources. Differences in topography, such as mountains and rivers, might additionally have had an impact on the chemical element distribution along the transect.

Differences in sample materials may have lead to limitations in the comparisons of the stations:

- Soil may have varied in physical properties and chemical composition (e.g. content of clay, organic matter, pH, competing elements, cation-exchange capacity) at the different stations. These are factors that will affect the impact of the coal power plant and Gruve 6 on the soil compartment. Nevertheless, analyses of physical properties and chemical composition should have been analyzed to determine the contribution of these factors in adsorption of elements to soil.

- Different moss species was collected at each station. Also, stations differed in dryness and vegetation. Thus, the relative contribution of wind erosion of soil on the analyzed element concentration in moss (and feathers) might vary between the stations.
- Differences in species composition in the insect/spider samples might also pose a problem for comparison of the stations because of differences in bioaccumulation potential in different species. Other confounding factor is the mobility for some of the insect species and the catching and storage of the insects/spiders in ethanol. Hence, some of the insects might reflect exposure from different areas, and the storage in ethanol might have resulted in leakage of elements from the body fluids and tissues out into the ethanol solution.
- Variations between and within nests, such as multiple routs of exposure, individual differences in absorption and disposition, pulmonary ventilation, clutch size, feeding rate, elimination rate and maternal transfer makes it difficult to detect the impact of the coal power plant and Gruve 6 on the element concentration in nestling feathers.

The impact of the coal power plant and Gruve 6 on the chemical element distribution in Adventdalen was also difficult to assess due to lack of appropriate reference sites. Nevertheless, in comparison to a study conducted on undisturbed soil in 1983, the results indicate that the soil samples were somewhat polluted with Zn, Pb and Ni, especially Pb. The results also suggest that pollution is not a new phenomenon in Advendalen and Longyearbyen.

The present master thesis might represent the start of a long-term monitoring of chemical element distribution in Adventdalen by the use of soil, mosses, insects/spiders and feathers from snow bunting nestlings. Further studies may provide information to whether the installation of the emission control technology at Longyearbyen coal power plant will have a positive impact on atmospheric emission.

6 References

Aceto, M., Abollino, O., Conca, R., Malandrino, M., Mentasti, E., & Sarzanini, C. (2003). The use of mosses as environmental metal pollution indicators. *Chemosphere, 50*(3), 333-342.

Agusa, T., Matsumoto, T., Ikemoto, T., Anan, Y., Kubota, R., Yasunaga, G., . . . Shibata, Y. (2005). Body distribution of trace elements in black-tailed gulls from Rishiri Island, Japan: age-dependent accumulation and transfer to feathers and eggs. *Environ Toxicol Chem, 24*(9), 2107-2120.

AMAP. (1997). Heavy metals (pp. 94-109): Arctic Monitoring and Assessment Programme.

Anderson, K. A. , & Hillwalker, W. E. (2008). Bioavailability. In S. E. Jørgensen (Ed.), *Ecotoxicology: A derivative of encyclopedia of ecology*. USA: Academic Press, Elsevier.

Askaer, L., Schmidt, L. B., Elberling, B., Asmund, G., & Jónsdóttir, I. S. (2008). Environmental Impact on an Arctic Soil–Plant System Resulting from Metals Released from Coal Mine Waste in Svalbard (78° N). *Water, Air, and Soil Pollution, 195*(1), 99-114.

Avango, D., Hacquebord, L., & Wråkberg, U. (2014). Industrial extraction of Arctic natural resources since the sixteenth century: Technoscience and geo-economics in the history of northern whaling and mining. *Journal of Historical Geography, 44*, 15-30.

Banks, D., Parnachev, V. P. , Frengstad, B., Holden, W., Vedernikov, A. A. , & Karnachuk, O. V. (2002). Alkaline mine drainage from metal sulphide and coal mines: Examples from Svalbard and Siberia. *198*, 287-296.

Bhuiyan, M. A., Parvez, L., Islam, M. A., Dampare, S. B., & Suzuki, S. (2010). Heavy metal pollution of coal mine-affected agricultural soils in the northern part of Bangladesh. *Journal of Hazardous Materials, 173*(1–3), 384-392.

Borghesi, F., Migani, F., Andreotti, A., Baccetti, N., Bianchi, N., Birke, M., & Dinelli, E. (2016). Metals and trace elements in feathers: A geochemical approach to avoid misinterpretation of analytical responses. *Science of The Total Environment, 544*, 476-494.

Casarett, L. J., & Doull, J. (2013). *Casarett and Doull's Toxicology, the basic science of poisons* (C. D. Klaassen Ed. Eighth ed.): McGraw-Hill.

Ćmiel, S. R., & Fabiańska, M. J. (2004). Geochemical and petrographic properties of some Spitsbergen coals and dispersed organic matter. *International Journal of Coal Geology, 57*(2), 77-97.

Coulson, S. J., Convey, P., Aakra, K., Aarvik, L., Ávila-Jiménez, M. L., Babenko, A., . . . Zmudczyńska-Skarbek, K. (2014). The terrestrial and freshwater invertebrate biodiversity of the archipelagoes of the Barents Sea; Svalbard, Franz Josef Land and Novaya Zemlya. *Soil Biology and Biochemistry, 68*, 440-470.

Dauwe, T., Janssens, E., Bervoets, L., Blust, R., & Eens, M. (2005). Heavy-Metal Concentrations in Female Laying Great Tits (*Parus major*)and Their Clutches. *Archives of Environmental Contamination and Toxicology, 49*(2), 249-256.

Dauwe, T., Janssens, E., Bervoets, L., Blust, R., & Eens, M. (2004). Relationships between metal concentrations in great tit nestlings and their environment and food. *Environmental Pollution, 131*(3), 373-380.

Dowdall, M., Vicat, K., Frearson, I., Gerland, S., Lind, B., & Shaw, G. (2004). Assessment of the radiological impacts of historical coal mining operations on the environment of Ny-Ålesund, Svalbard. *Journal of Environmental Radioactivity, 71*(2), 101-114.

Eckhardt, S., Hermansen, O., Grythe, H., Fiebig, M., Stebel, K., Cassiani, M., . . . Stohl, A. (2013). The influence of cruise ship emissions on air pollution in Svalbard – a harbinger of a more polluted Arctic? *Atmos. Chem. Phys., 13*(16), 8401-8409.

Eens, M., Pinxten, R., Verheyen, R. F., Blust, R., & Bervoets, L. (1999). Great and Blue Tits as Indicators of Heavy Metal Contamination in Terrestrial Ecosystems. *Ecotoxicology and Environmental Safety, 44*(1), 81-85.

Evangelou, V. P. , & Zhang, Y. L. (1995). A review: Pyrite oxidation mechanisms and acid mine drainage prevention. *25*(2).

Falconer, C. M., Mallory, M. L., & Nol, E. (2007). Breeding biology and provisioning of nestling snow buntings in the Canadian High Arctic. *Polar Biology, 31*(4), 483-489.

Fernández, J. A., Rey, A., & Carballeira, A. (2000). An extended study of heavy metal deposition in Galicia (NW Spain) based on moss analysis. *Science of The Total Environment, 254*(1), 31-44.

Flå, K. (Longyearbyen Lokalstyre). (2012). Energiverket - Produksjon. Retrieved 20.03, 2016, from http://www.lokalstyre.no/energiverket.247428.no.html

Fossøy, F., Stokke, B. G., Kåsi, T. K., Dyrset, K., Espmark, Y., Hoset, K. S., . . . Moksnes, A. (2014). Reproductive success is strongly related to local and regional climate in the Arctic snow bunting (*Plectrophenax nivalis*). *Polar Biology, 38*(3), 393-400.

Higman, C., & van der Burgt, M. (2008). *Coal gasification* (2 ed.): Gulf Professional Publishers.

Hindrum, R. (1994). *Snøspurv Plectrophenax nivalis*. Norsk fugleatlas Norsk Ornitologisk Forening.

Hisdal, V. (1998). *Svalbard, nature and history* (Polarhåndbok No. 12 ed.). Oslo: Norsk Polarinstitutt.

Hongxia, S., Ying, L., & Guren, Z. (Undated). Effects of heavy metal pollution on insects.

Hoset, K. S., Espmark, Y., Fossøy, F., Stokke, B. G., Jensen, H., Wedege, M. I., & Moksnes, A. (2014). Extra-pair paternity in relation to regional and local climate in an Arctic-breeding passerine. *Polar Biology, 37*(1), 89-97.

Jaworowski, Z. (1989). Pollution of the Norwegian Arctic: A rewiev (Vol. 55). Oslo.

Knutsen, K. D. (Longyearbyen Lokalstyre). (2015). Renseanlegg for røykgass. Retrieved 20.03, 2016, from http://www.lokalstyre.no/renseanlegg.349440.no.html

Kopp, O. C. (Encyclopædia Britannica). (2009). Bituminous coal - Coal classification. Retrieved 01.03, 2016, from http://global.britannica.com/science/bituminous-coal

Lewińska-Preis, L., Fabiańska, M. J., Ćmiel, S., & Kita, A. (2009). Geochemical distribution of trace elements in Kaffioyra and Longyearbyen coals, Spitsbergen, Norway. *International Journal of Coal Geology, 80*(3–4), 211-223.

Llorens, F. J., Fernández-Turiel, L. J., & Querol, X. (2001). The fate of trace elements in a large coal-fired power plant. *Environmental Geology, 40*(4), 409-416.

Lyche, C., & Nedland, K. T. (2012). Avfallsplan Longyearbyen 2012-2015. Longyearbyen.

MacNaeidhe, F. (1995). Procedures and precautions used in sampling techniques and analysis of trace elements in plant matrices. *Science of The Total Environment, 176*(1–3), 25-31.

Manahan, S. E. (2010). *Environmental chemistry* (9 ed.). USA: CRC Press, Taylor & Francis group.

Mandal, A., & Sengupta, D. (2006). An assessment of soil contamination due to heavy metals around a coal-fired thermal power plant in India. *Environmental Geology, 51*(3), 409-420.

McMeans, B. C., Borgå, K., Bechtol, W. R., Higginbotham, D., & Fisk, A. T. (2007). Essential and non-essential element concentrations in two sleeper shark species collected in arctic waters. *Environmental Pollution, 148*(1), 281-290.

Newman, M. C. (2010). *Fundamentals of Ecotoxicology* (3 ed.). USA: Taylor & Francis Group.

Newman, M. C., & Clements, W. H. (2008). *Ecotoxicology: A comprehensive treatment*. USA: Taylor & Francis Group.

Nouri, J., Khorasani, N., Lorestani, B., Karami, M., Hassani, A. H., & Yousefi, N. (2009). Accumulation of heavy metals in soil and uptake by plant species with phytoremediation potential. *Environmental Earth Sciences, 59*(2), 315-323.

Norwegian Polar Institute. (Undated). The Zeppelin Observatory in Ny-Ålesund. Retrieved 10.04, 2016, from http://www.npolar.no/en/about-us/stations-vessels/zeppelin/

Nriagu, J. O. (1989). A global assessment of natural sources of atmospheric trace metals. *Nature, 338*(6210), 47-49.

Nummelin, M., Lodenius, M., Tulisalo, E. , Hirvonen, H., & Alanko, T. (2007). Predatory insects as bioindicators of heavy metal pollution. *Environmental Pollution, 145*(1), 339-347.

Ottesen, R., Bogen, J., & Finne, T. E. (2010). *Geochemical atlas of Norway - Part 2: Geochemical atlas of Spitsbergen. Chemical composition of overbank sediments*. Trondheim: Norges geologiske undersøkelse (NGU).

Pacyna, J. M., Ottar, B., Tomza, U., & Maenhaut, W. (1985). Long-range transport of trace elements to Ny Ålesund, Spitsbergen. *Atmospheric Environment (1967), 19*(6), 857-865.

Pacyna, J. M., & Pacyna, E. G. (2001). An assessment of global and regional emissions of trace metals to the atmosphere from anthropogenic sources worldwide. *Environmental Reviews, 9*(4), 269-298.

Piepjohn, K., Stange, R., Jochmann, M., & Hübner, C. (2012). *The Geology of Longyearbyen*

Paatero, J., Hatakka, J., Holmén, K., Eneroth, K., & Viisanen, Y. (2003). Lead-210 concentration in the air at Mt. Zeppelin, Ny-Ålesund, Svalbard. *Physics and Chemistry of the Earth, Parts A/B/C, 28*(28–32), 1175-1180.

R Core Team. (2015). R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing.

Rattan, L. (2006). *Encyclopedia of Soil Science* (2 ed. Vol. 2). USA: Taylor & Francis.

Riksantikvaren (Direktoratet for kulturminneforvaltning). (2013). Tysk værstasjon, Bansø. Retrieved 29.04, 2016, from http://www.kulturminnesok.no/Lokaliteter/Svalbard/Longyearbyen-arealplanomraade/Tysk-vaerstasjon-Adventdalen

Rosenberg, D. M., Danks, H. V., & Lehmkuhl, D. M. (1986). Importance of insects in environmental impact assessment. *Environmental Management, 10*(6), 773-783.

Rühling, Å., Rasmussen, L., Pilegaard, K., Mäkinen, A., & Steinnes, E. (1987). *Survey of atmospheric heavy metal deposition: Monitored by moss analysis*: Nordic Council of Ministers.

Scheuhammer, A. M. (1987). The chronic toxicity of aluminium, cadmium, mercury, and lead in birds: A review. *Environmental Pollution, 46*(4), 263-295.

Schintu, M., Cogoni, A., Durante, L., Cantaluppi, C., & Contu, A. (2005). Moss (*Bryum radiculosum*) as a bioindicator of trace metal deposition around an industrialised area in Sardinia (Italy). *Chemosphere, 60*(5), 610-618.

Schulte, E. E. (1992). Soil and applied molybdenum. A3555: University of Wisconsin-Extension.

Simões, J. C., & Zagorodnov, V. S. (2001). The record of anthropogenic pollution in snow and ice in Svalbard, Norway. *Atmospheric Environment, 35*(2), 403-413.

SNSK (Store Norske Spitsbergen Kullkompani AS). (Undated-a). Coal and the environment. Retrieved 02.02, 2016, from http://www.snsk.no/coal-and-the-environment.151499.en.html

SNSK (Store Norske Spitsbergen Kullkompani AS). (Undated-b). Gruve 7. Retrieved 11.04, 2016, from http://www.snsk.no/ - !gruve7/vpjt2

SNSK (Store Norske Spitsbergen Kullkompani AS). (Undated-c). Gruve 7. Retrieved 02.02, 2016, from http://www.snsk.no/gruve-7.145618.en.html

SNSK (Store Norske Spitsbergen Kulkompani AS). (Undated-d). Svea. Retrieved 11.04, 2016, from http://www.snsk.no/ - !svea/m5hoe

Speight, J. G. (2013). *The Chemistry and Technology of Coal* (Third ed.). USA: CRC Press, Taylor & Francis Group.

St.meld. nr. 22 (2008-2009). (2009). *Svalbard.* Oslo: Det kongelige justis- og politidepartementet.

Steinnes, E., Berg, T., & Sjøbakk, T. E. (2003). Temporal and spatial trends in Hg deposition monitored by moss analysis. *Science of The Total Environment, 304*(1–3), 215-219.

Steinnes, E., & Jacobsen, L. B. (1994). The use of mosses as monitors of trace element deposition from the atmosphere in arctic regions: A feasibility study from Svalbard (Vol. 88). Oslo: Norsk Polarinstitutt.

Strøm, H. (Undated). Snow bunting (*Plectrophenax nivalis*). Retrieved 09.09, 2015, from http://www.npolar.no/en/species/snow-bunting.html

Temple, K. L., & Delchamps, E. W. (1953). Autotropic Bacteria and the Formation of Acid in Bituminous Coal Mines. *Applied Microbiology, 1*(5), 255-258.

Textor, C., Graf, H., Timmreck, C., & Robock, A. (2004). Emission from volcanoes. In K. A. Publishers (Ed.), *Advances in global change research: Emission of atmospheric trace compounds*.

Thomas, L. (2002). *Coal geology*. England: John Wiley & Sons, LTD.

Thomas, W. (1986). Accumulation of airborne trace pollutants by Arctic plants and soil. *Wat. Sci. Tech, 18*, 47-57.

Thompson, D. R., Bearhop, S., Speakman, J. R., & Furness, R. W. (1998). Feathers as a means of monitoring mercury in seabirds: Insights from stable isotope analysis. *Environmental Pollution, 101*(2), 193-200.

van Leeuwen, C. J. , & Hermens, J. L. (2004). *Risk assessment of chemicals: An introduction* (6 ed.): Springer-Science and Business Media, B. V.

Vasconcelos, M. T. , & Tavares, H. M. (1998). Atmospheric metal pollution (Cr, Cu, Fe, Mn, Ni, Pb and Zn) in Oporto city derived from results for low-volume aerosol samplers and for the moss *Sphagnum auriculatum* bioindicator. *Science of The Total Environment, 212*(1), 11-20.

Veltman, K., Huijbregts, M. A., & Hendriks, A. J. (2008). Cadmium bioaccumulation factors for terrestrial species: application of the mechanistic bioaccumulation model OMEGA to explain field data. *Sci Total Environ, 406*(3), 413-418.

Walker, C. H., Sibly, R. M., Hopkin, S. P., & Peakall, D. B. (2006). *Principles of Ecotoxicology* (3 ed.). USA: CRC Press, Taylor & Francis Group.

WCA (World Coal Association). (Undated). What is coal. Retrieved 03.02, 2016, from http://www.worldcoal.org/coal/what-coal

White, J. G., & Zasoski, R. J. (1999). Mapping soil micronutrients. *Field Crops Research, 60*(1–2), 11-26.

Wickham, H. (2009). ggplot2: Elegant Graphics for Data Analysis. New York: Springer-Verlag.

Winther, J. (Store Norske Leksikon). (2014). Næringsliv på Svalbard. Retrieved 03.02, 2016, from https://snl.no/N%C3%A6ringsliv_p%C3%A5_Svalbard#menuitem0

Zaidi, B. R., & Imam, S. H. (2008). Biodegradability In S. E. Jørgensen (Ed.), *Ecotoxicology: A derivative of encyclopedia of ecology*. USA: Elsevier.

Zhao, Y., Wang, S., Duan, L., Lei, Y., Cao, P., & Hao, J. (2008). Primary air pollutant emissions of coal-fired power plants in China: Current status and future prediction. *Atmospheric Environment*, *42*(36), 8442-8452.

Appendices

Appendix I

Table 2. Division of collected mosses into species, and spiders and insects into taxonomic groups. For mosses, the most dominating species are shown in order. Spiders and insects have been counted, and size has been determined (Small, Medium, Large)

Stations	**Sample type**	**Species or taxonomic groups**
1	Mosses	*Sanionia nivalis*
	Insects	78 springtails (L), 4 mites, 9 spiders (L), 6 mosquitos (M), 1 fly (M)
2	Mosses	*Sanionia uncinata* > *Hylocomium splendens*
	Insects	1 springtail (M), 4 mites, 20 spiders (M), 1 mosquito (M)
3	Mosses	*Sanionia nivalis* > *Aulacomnium turgidum* > *Hylocomium splendens* > *Tomentypnum nitens*
	Insects	4/8 springtails (M/L), 1 mite, 6 spiders (M)
4	Mosses	*Tomentypnum nitens* > *Polytrichum hyperboreum*
	Insects	4/12 spiders (S/M), 1 mosquito (M), 1 fly (M)
5	Mosses	*Tomentypnum nitens* > *Aulacomnium turgidum* > *Sanionia nivalis*
	Insects	24/4 springtails (S/M), 4 spiders (M), 1 mosquito (M)
6	Mosses	*Tomentypnum nitens* > *Sanionia nivalis*
	Insects	20/6/4 springtails (S/M/L), 6/29 mosquitos (S/M)
7	Mosses	*Tomentypnum nitens* > *Aulacomnium turgidum* > *Sanionia nivalis* > *Hylocomium splendens*
	Insects	104/12 springtails (S/M), 1 mite, 4 spiders (M)
8	Mosses	*Tomentypnum nitens* > *Sanionia nivalis*
	Insects	47 springtails (S), 5 mites, 6 spiders (M), 1 mosquito (M)
9	Mosses	*Tomentypnum nitens* > *Sanionia nivalis*
	Insects	14 springtails (M), 6 mites, 10 spiders (M), 3 mosquitos (M)
10	Mosses	*Sanionia uncinata* > *Tomentypnum nitens*
	Insects	69/2 springtails (S/L), 2 mites, 5/1 spiders (S/M), 20/1 mosquitos (S/M)
11	Mosses	*Tomentypnum nitens* > *Sanionia* sp., *Hylocomium splendens*
	Insects	36/3 springtails (S/M), 3 mites, 8/4 spiders (S/M), 3 mosquitos (M)
12	Mosses	*Tomentypnum nitens* > *Sanionia* sp.
	Insects	10/3 springtails (S/M), 1 mite, 2/4 spiders (S/M), 8 mosquitos (S)
13	Mosses	*Aulacomnium turgidum* > *Sanionia nivalis* > *Polytrichum* sp.
	Insects	38/4 springtails (S/M), 25 spiders (M), 102 mosquitos (M), 1 fly (S)
14	Mosses	*Tomentypnum nitens* > *Sanionia uncinata*
	Insects	11/16 springtails (S/M), 8 mites, 6 spiders (M), 1 mosquito (S)
15	Mosses	*Sanionia nivalis*
	Insects	85/6 springtails (S/M), 2 mites, 32 and 1 mosquitos (S, L)
16	Mosses	*Aulacomnium turgidum* > *Tomentypnum nitens*
	Insects	115/70 springtails (S/M), 9 spiders (M), 8 mosquitos (M)
17	Mosses	*Aulacomnium turgidum* > *Sanionia nivalis*
	Insects	4 springtails (S), 1 mite, 14 spiders (M), 42 mosquitos (M)
18	Mosses	*Sanionia nivalis* > *Tomentypnum nitens*
	Insects	2/1 springtails (S/M), 10 mites, 1 spider (S), 5/11 mosquitos (S/M)

Appendix II

Table 3. Certified concentrations (± standard deviation), analyzed concentrations (average ± standard deviation), and analysis accuracy (analyzed/certified concentrations, %) of trace elements in INCT-OBTL-5 reference material (oriental basma tobacco leaves)

	Certified concentrations ± SD	Analyzed concentrations ± SD	Accuracy %
Al	1980 ± 280	1786.452 ± 195	90.2
As	0.668 ± 0.086	0.674 ± 0.024	100.8
B	33.6 ± 2.2	33.003 ± 0.6	98.2
Be	0.081*	0.006 ± 0.0063	85.3
Cd	2.64 ± 0.14	2.627 ± 0.031	99.5
Co	0.981 ± 0.067	0.771 ± 0.005	78.6
Cr	6.3*	5.241 ± 0.05	83.2
Fe	1490*	1456.477 ± 150	97.8
Hg	0.021 ± 0.001	0.0197 ± 0.0007	94.2
La	1.69 ± 0.09	1.412 ± 0.022	83.5
Mn	180 ± 6	175 ± 16	97.2
Mo	0.414 ± 0.062	0.285 ± 0.004	68.8
Ni	8.5 ± 0.49	6.824 ± 0.08	80.3
Pb	2.01 ± 0.31	1.725 ± 0.089	85.8
S	4550 ± 910	3891.470 ± 76	85.5
Sb	0.076 ± 0.013	0.0305 ± 0.0004	40.4
Se	-	0.034 ± 0.001	-
Sm	0.264 ± 0.013	0.237 ± 0.009	89.8
Th	0.503 ± 0.043	0.423 ± 0.018	84.1
U	0.113*	0.083 ± 0.002	73.2
V	4.12 ± 0.55	4.251 ± 0.07	103.2
Y	0.963*	1.069 ± 0.015	110.9
Yb	0.115 ± 0.023	0.088 ± 0.002	76.9
Zn	52.4 ± 1.8	44.352 ± 0.5	84.6

* : not certified

Appendix III

Table 4. N (number of values above LOD), standard deviation, mean, median, minimum and maximum values for the given elements and sample type. Total number of stations where feathers, soil, mosses and insects/spiders were collected: 14, 18, 18 and 18, respectively

	Sample type	N	Mean (µg/g)	Median (µg/g)	Minimum (µg/g)	Maximum (µg/g)	Standard deviation
Al	**Feathers**	12	96.74	55.88	9.95	459.56	121.43
	Insects	18	1529.45	626.79	107.98	8685.54	2143.20
	Soil	18	44290.29	42570.70	27478.91	58690.29	8809.02
	Mosses	18	6883.84	5101.33	2458.70	20266.79	4762.46
As	**Feathers**	1*	0.15	0.12	0.05	0.44	0.10
	Insects	17	0.99	0.51	0.17	4.12	1.08
	Soil	18	14.72	14.34	10.84	19.98	2.36
	Mosses	18	2.71	2.21	1.01	6.51	1.45
B	**Feathers**	-	-	-	-	-	-
	Insects	-	-	-	-	-	-
	Soil	18	64.04	64.10	42.10	139.90	20.47
	Mosses	18	73.26	72.56	20.79	149.44	39.98
Be	**Feathers**	1*	0.06	0.04	0.02	0.14	0.04
	Insects	3*	0.08	0.05	0.01	0.26	0.07
	Soil	18	1.41	1.37	1.01	1.86	0.24
	Mosses	18	0.27	0.22	0.11	0.75	0.17
Cd	**Feathers**	0*	0.07	0.05	0.02	0.18	0.05
	Insects	18	3.59	2.43	0.45	17.60	4.06
	Soil	18	0.17	0.13	0.07	0.87	0.18
	Mosses	18	0.25	0.21	0.10	0.55	0.14
Co	**Feathers**	5*	6.20	0.15	0.03	55.79	15.24
	Insects	18	15.46	0.64	0.18	260.43	61.15
	Soil	18	12.51	10.86	8.10	40.18	6.92
	Mosses	18	3.25	2.25	1.15	10.14	2.51
Cr	**Feathers**	3*	0.55	0.41	0.11	1.76	0.41
	Insects	15	2.25	0.94	0.22	11.85	2.92
	Soil	18	62.36	64.60	46.26	74.84	8.74
	Mosses	18	9.81	7.76	3.56	26.45	6.30
Fe	**Feathers**	14	98.92	60.98	21.64	387.94	103.18
	Insects	18	1439.40	741.74	182.08	6871.11	1751.08
	Soil	18	34457.29	33510.75	22506.93	44216.76	6338.85
	Mosses	18	5586.78	4428.40	2005.74	14494.53	3493.86
Hg	**Feathers**	14	0.43	0.31	0.12	1.42	0.36
	Insects	18	0.37	0.22	0.11	1.35	0.36
	Soil	18	0.06	0.05	0.03	0.15	0.03
	Mosses	18	0.04	0.04	0.03	0.05	0.01
La	**Feathers**	13	0.05	0.04	0.01	0.24	0.06
	Insects	18	0.86	0.27	0.06	6.10	1.45
	Soil	18	28.79	29.12	20.67	36.33	3.34
	Mosses	18	4.75	3.85	1.58	13.45	2.95

	Sample type	N	Mean (µg/g)	Median (µg/g)	Minimum (µg/g)	Maximum (µg/g)	Standard deviation
Mn	**Feathers**	14	3.90	1.55	0.54	21.25	5.92
	Insects	18	150.99	62.28	15.86	559.75	163.86
	Soil	18	436.40	337.72	192.49	2455.52	484.91
	Mosses	18	261.21	111.01	42.49	2310.38	493.54
Mo	**Feathers**	4*	0.13	0.10	0.05	0.35	0.08
	Insects	18	0.99	0.57	0.33	4.31	0.98
	Soil	18	0.79	0.76	0.52	1.12	0.17
	Mosses	18	0.28	0.24	0.14	0.56	0.11
Ni	**Feathers**	10	0.21	0.17	0.05	0.49	0.14
	Insects	18	2.54	1.18	0.39	14.53	3.57
	Soil	18	29.47	27.25	19.94	59.39	8.38
	Mosses	18	9.03	7.25	3.34	19.49	4.69
Pb	**Feathers**	11	0.12	0.06	0.02	0.34	0.11
	Insects	18	0.76	0.37	0.09	4.19	1.03
	Soil	18	14.29	13.70	11.64	20.66	2.14
	Mosses	18	2.73	2.06	1.09	7.38	1.74
S	**Feathers**	14	27118.58	20634.96	18176.23	56754.47	12560.02
	Insects	18	13330.68	9840.44	3716.87	51278.72	10908.31
	Soil	18	1772.52	1547.44	702.04	6104.87	1171.04
	Mosses	18	1907.24	1649.71	882.69	3888.54	799.29
Sb	**Feathers**	13	0.03	0.02	0.01	0.09	0.03
	Insects	11	0.17	0.13	0.02	0.62	0.16
	Soil	18	0.02	0.02	0.01	0.07	0.01
	Mosses	18	0.01	0.01	0.01	0.04	0.01
Se	**Feathers**	14	3.57	3.11	1.60	8.65	1.69
	Insects	18	4.35	4.03	1.26	10.44	2.74
	Soil	18	0.85	0.81	0.55	1.91	0.29
	Mosses	18	0.32	0.29	0.15	0.55	0.11
Sm	**Feathers**	11	0.01	0.01	0.00	0.06	0.01
	Insects	18	0.26	0.07	0.01	2.32	0.54
	Soil	18	5.13	5.24	3.93	6.31	0.55
	Mosses	18	0.99	0.77	0.38	2.90	0.64
Th	**Feathers**	0*	0.08	0.05	0.02	0.24	0.07
	Insects	8*	0.20	0.08	0.01	1.07	0.26
	Soil	18	6.74	6.63	5.14	9.51	1.00
	Mosses	18	1.18	0.90	0.37	4.11	0.87
U	**Feathers**	12	0.00	0.00	0.00	0.01	0.00
	Insects	18	0.05	0.02	0.00	0.41	0.10
	Soil	18	0.85	0.84	0.68	1.07	0.10
	Mosses	18	0.15	0.11	0.06	0.39	0.09
V	**Feathers**	10	0.23	0.11	0.04	1.12	0.30
	Insects	15	3.39	1.46	0.34	16.64	4.18
	Soil	18	111.62	112.49	65.09	146.04	23.18
	Mosses	18	19.55	15.04	6.82	49.49	12.40

	Sample type	**N**	**Mean (µg/g)**	**Median (µg/g)**	**Minimum (µg/g)**	**Maximum (µg/g)**	**Standard deviation**
Y	**Feathers**	13	0.03	0.02	0.01	0.11	0.03
	Insects	18	0.75	0.28	0.04	6.60	1.52
	Soil	18	12.14	12.15	10.17	15.91	1.28
	Mosses	18	2.70	2.03	1.23	7.54	1.72
Yb	**Feathers**	5*	0.00	0.00	0.00	0.01	0.00
	Insects	18	0.05	0.02	0.00	0.47	0.11
	Soil	18	0.82	0.82	0.70	0.98	0.08
	Mosses	18	0.16	0.12	0.07	0.43	0.10
Zn	**Feathers**	14	217.92	179.69	148.45	422.54	84.73
	Insects	18	561.45	442.38	170.22	1976.02	419.64
	Soil	18	77.70	73.53	49.79	176.17	25.48
	Mosses	18	41.77	33.84	19.33	109.21	22.27

- : values were absent in the dataset resulting from the HR-ICP-MS analysis

* : ≥ 50 % of the values were below LOD, and the corresponding metal was deleted from the dataset

Appendix IV

Table 5. Correlation coefficient (ρ) and p-values demonstrating the relationship between element concentration (µg/g dw) in feathers and soil, mosses and insects/spiders, respectively

	Feathers - Soil	Feathers - Mosses	Feathers - Insects/spiders
Al	ρ = -0.073, p = 0.81	ρ = 0.26, p = 0.37	ρ = 0.015, p = 0.96
As	-	-	-
B	-	-	-
Be	-	-	-
Cd	-	-	-
Co	-	-	-
Cr	-	-	-
Fe	ρ = -0.36, p = 0.20	ρ = 0.23, p = 0.44	ρ = 0.055, p = 0.86
Hg	ρ = 0.78, **p = 0.0014****	ρ = -0.020, p = 0.95	ρ = 0.24, p = 0.42
La	ρ = -0.08, p = 0.78	ρ = 0.27, p = 0.35	ρ = -0.28, p = 0.33
Mn	ρ = 0.35, p = 0.23	ρ = 0.090, p = 0.76	ρ = 0.11, p = 0.70
Mo	-	-	-
Ni	ρ = -0.19, p = 0.51	ρ = 0.30, p = 0.30	ρ = 0.14, p = 0.64
Pb	-	-	-
S	ρ = -0.055, p = 0.86	ρ = -0.11, p = 0.72	ρ = 0.21, p = 0.46
Sb	ρ = -0.23, p = 0.44	ρ = 0.28, p = 0.33	ρ = -0.29, p = 0.31
Se	ρ = -0.12, p = 0.68	ρ = 0.064, p = 0.83	ρ = -0.53, p = 0.057
Sm	ρ = -0.18, p = 0.53	ρ = 0.081, p = 0.78	ρ = -0.21, p = 0.47
Th	-	-	-
U	ρ = -0.49, p = 0.078	ρ = -0.14, p = 0.64	ρ = 0.27, p = 0.27
V	ρ = -0.38, p = 0.18	ρ = 0.30, p = 0.30	ρ = 0.0022, p = 1
Y	ρ = 0.015, p = 0.96	ρ = 0.14, p = 0.63	ρ = 0.0022, p = 1
Yb	-	-	-
Zn	ρ = 0.12, p = 0.68	ρ = 0.56, **p = 0.040**	ρ = 0.32, p = 0.26

- : analyzed concentrations were absent for one or more of the sample types (see Table 1 for more information).
p-values below 0.05 are written in bold.
** : significant after Bonferroni correction, controlling for the number of elements (p < 0.002).

Appendix V

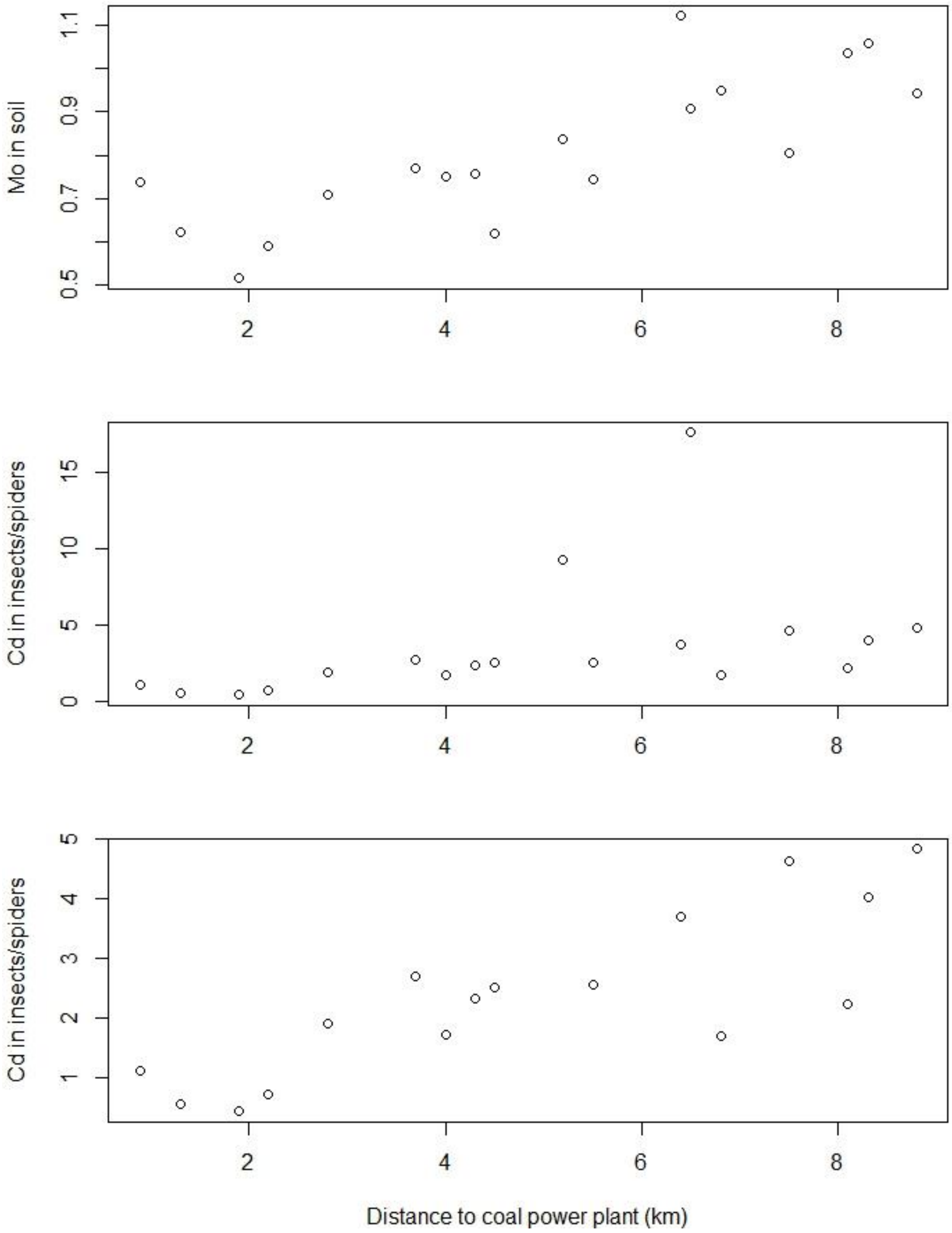


Figure 10. Correlations between element concentration (µg/g dw) in sample material and the distance (km) from Longyearbyen coal power plant, that were statistical significant after Bonferroni correction ($p < 0.002$). A spearman rank correlation test quantified a p-value of 0.0017 and < 0.001 for Cd in insects/spiders and Mo in soil, respectively (Table 1). All of the 18 stations are included in the two first plots. In the third plot, two outliers from the second plot were deleted to assess whether the concentration gradient remained statistical significant. A spearman rank correlation test revealed a p-value of 0.0006 where the two outliers were excluded.

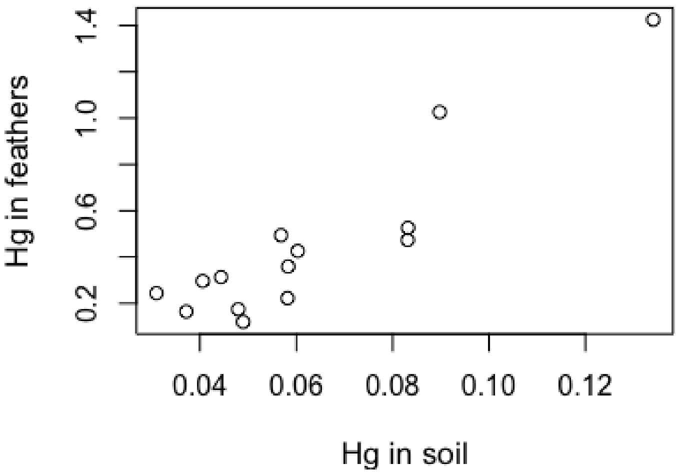


Figure 11. Correlation between Hg concentrations (µg/g dw) in feathers and soil. The relationship are statistical significant after Bonferroni correction (p = 0.0014) (Table 5, Appendix IV).

Appendix VI

Table 6. Concentrations (µg/g) of the 24 chemical elements analyzed in soil at the 18 stations. Distance (km) from Longyearbyen coal power plant is also given in the table.

Material of analysis	**Soil**																	
Station	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Distance (km) from coal power plant	**0.89**	**1.3**	**1.9**	**2.2**	**2.8**	**3.7**	**4**	**4.3**	**4.5**	**5.2**	**5.5**	**6.4**	**6.5**	**6.8**	**7.5**	**8.1**	**8.3**	**8.8**
Al (µg/g)	31998.53	56892.68	54172.62	54221.03	51337.36	42604.11	42741.06	40033.57	41493.07	39870.39	58690.29	27478.91	49083.51	34790.59	39469.41	34090.35	40864.84	49251.22
As (µg/g)	10.84	16.46	14.52	16.74	19.98	14.02	14.32	14.36	17.28	13.54	11.77	11.85	19.25	14.27	12.58	13.08	15.80	15.26
B (µg/g)	45.50	72.68	71.28	68.46	70.71	62.24	65.37	68.46	56.07	42.10	53.31	49.72	63.88	51.46	45.08	50.19	139.9	68.93
Be (µg/g)	1.01	1.73	1.60	1.59	1.80	1.28	1.39	1.31	1.41	1.32	1.86	1.01	1.35	1.15	1.28	1.11	1.67	1.51
Cd (µg/g)	0.13	0.09	0.09	0.07	0.10	0.15	0.12	0.14	0.08	0.08	0.16	0.33	0.10	0.23	0.15	0.14	0.87	0.16
Co (µg/g)	8.77	13.06	13.48	14.68	13.84	10.66	8.66	11.10	11.40	8.86	15.67	10.62	8.26	8.10	10.95	8.83	40.18	10.77
Cr (µg/g)	46.48	70.66	69.99	72.00	67.23	64.87	62.16	56.06	64.34	63.43	74.84	46.26	67.87	55.46	53.95	56.93	49.11	66.60
Fe (µg/g)	27003.08	41608.86	40249.80	44216.76	42282.39	31733.64	30997.43	31218.27	34986.73	33542.01	42626.03	22506.93	40599.15	27119.38	30570.37	26382.41	35479.42	33479.48
Hg (µg/g)	0.05	0.05	0.04	0.06	0.05	0.05	0.06	0.08	0.04	0.03	0.04	0.13	0.06	0.09	0.03	0.08	0.15	0.06
La (µg/g)	27.89	31.14	29.20	31.18	29.10	29.39	28.06	28.11	29.15	31.99	36.33	21.60	28.92	26.59	31.24	27.80	20.67	29.95
Mn (µg/g)	340.52	335.77	336.67	353.60	353.56	306.84	198.66	379.28	255.98	253.03	533.95	560.66	192.49	243.66	391.60	314.62	2455.52	377.93
Mo (µg/g)	0.74	0.62	0.52	0.59	0.71	0.77	0.75	0.76	0.62	0.84	0.74	1.12	0.91	0.95	0.80	1.04	1.06	0.94
Ni (µg/g)	19.94	31.62	32.52	35.03	32.30	27.22	25.69	28.41	25.91	21.10	37.18	27.28	24.31	24.59	25.21	23.61	59.39	29.94
Pb (µg/g)	11.64	16.30	15.54	16.42	16.10	13.57	13.48	13.69	11.90	12.74	20.66	12.57	13.96	12.34	14.30	12.10	15.75	13.71
S (µg/g)	904.17	1935.83	1532.98	907.41	2648.12	1927.84	1701.99	2595.33	1668.08	855.37	702.04	2474.94	1286.44	1348.66	815.84	1224.37	6104.87	1552.45
Sb (µg/g)	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.01	0.07	0.02	0.03	0.02	0.02	0.02	0.02
Se (µg/g)	0.62	0.74	0.63	0.60	0.65	0.81	1.02	0.93	0.85	0.82	0.85	1.15	0.88	0.71	0.81	0.82	1.91	0.74
Sm (µg/g)	4.77	5.80	5.40	5.33	5.51	5.14	5.23	5.25	5.35	5.08	6.31	3.93	4.80	4.36	5.14	4.72	4.23	5.65
Th (µg/g)	5.67	7.54	7.11	6.53	7.08	6.64	6.33	6.30	6.63	7.48	9.51	5.14	7.18	6.06	8.19	6.27	5.23	6.72
U (µg/g)	0.91	0.86	0.81	0.68	0.94	0.83	0.85	0.78	0.80	0.87	1.02	0.72	0.98	0.79	0.84	0.82	1.07	0.81
V (µg/g)	77.98	146.04	136.51	133.86	140.60	106.01	108.40	109.90	132.67	102.49	114.62	65.09	126.31	83.44	86.16	81.83	113.56	119.72
Y (µg/g)	12.74	13.11	11.80	13.02	13.03	11.56	12.54	12.61	11.23	10.20	15.91	10.17	12.35	10.58	11.40	11.96	11.21	12.86
Yb (µg/g)	0.92	0.89	0.82	0.84	0.93	0.79	0.83	0.85	0.81	0.73	0.98	0.70	0.79	0.73	0.71	0.72	0.78	0.83
Zn (µg/g)	49.79	80.69	75.95	87.89	81.50	78.16	63.31	71.11	66.16	62.78	85.74	87.28	71.01	70.06	59.94	59.67	176.2	84.53

Table 7. Concentrations (µg/g) of the 24 chemical elements analyzed in mosses at the 18 stations. Distance (km) from Longyearbyen coal power plant is also given in the table.

Material of analysis	**Mosses**																	
Station	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Distance (km) from coal power plant	**0.89**	**1.3**	**1.9**	**2.2**	**2.8**	**3.7**	**4**	**4.3**	**4.5**	**5.2**	**5.5**	**6.4**	**6.5**	**6.8**	**7.5**	**8.1**	**8.3**	**8.8**
Al (µg/g)	15371.90	8077.69	12257.91	7552.57	3626.20	3095.31	5090.02	3698.64	3959.08	7252.27	8003.64	2832.72	2458.70	4097.36	20266.79	3382.52	5341.09	3841.35
As (µg/g)	6.51	3.39	4.44	3.35	1.65	1.33	2.33	1.67	2.03	3.41	2.19	1.38	1.01	1.66	4.98	1.49	2.41	2.18
B (µg/g)	134.48	51.29	116.09	22.15	86.95	115.04	90.94	63.04	53.85	26.29	20.79	92.92	22.93	82.08	49.85	42.59	35.48	149.44
Be (µg/g)	0.53	0.30	0.44	0.27	0.13	0.11	0.19	0.14	0.15	0.37	0.28	0.12	0.16	0.15	0.75	0.15	0.25	0.31
Cd (µg/g)	0.43	0.11	0.17	0.26	0.13	0.15	0.27	0.16	0.18	0.53	0.24	0.55	0.35	0.15	0.16	0.28	0.10	0.45
Co (µg/g)	8.07	2.15	3.66	2.52	1.15	1.60	1.85	1.29	1.39	5.41	2.41	10.14	2.34	1.62	7.24	2.45	2.00	2.17
Cr (µg/g)	23.03	11.29	16.92	10.23	5.63	4.73	7.80	5.78	6.19	9.54	10.14	4.27	3.56	6.46	26.45	5.51	7.91	6.07
Fe (µg/g)	13392.62	6222.50	9113.93	6121.82	3005.18	2465.72	4202.68	3121.39	3366.78	6506.47	5469.88	2776.50	2005.74	3450.25	14494.53	2976.77	5105.02	4654.11
Hg (µg/g)	0.04	0.04	0.05	0.05	0.03	0.03	0.04	0.03	0.03	0.04	0.04	0.03	0.03	0.04	0.03	0.03	0.03	0.04
La (µg/g)	9.68	5.36	7.49	5.08	2.73	2.41	3.86	2.79	3.29	6.18	5.22	1.91	1.58	2.95	13.45	2.50	3.95	3.15
Mn (µg/g)	334.65	62.64	111.03	107.30	42.49	83.98	69.50	75.57	62.28	381.59	119.34	2310.38	170.04	93.81	331.41	307.11	195.30	187.46
Mo (µg/g)	0.56	0.24	0.36	0.22	0.14	0.20	0.25	0.17	0.21	0.30	0.21	0.29	0.18	0.32	0.39	0.19	0.46	0.20
Ni (µg/g)	16.22	6.28	11.08	6.98	3.64	5.01	5.93	3.34	3.83	15.30	8.51	15.42	8.79	6.55	19.49	7.52	6.51	13.11
Pb (µg/g)	6.58	3.02	4.10	3.19	1.46	1.22	2.06	1.49	1.52	3.20	2.89	1.21	1.09	2.98	7.38	1.36	1.98	1.63
S (µg/g)	1811.72	948.13	1383.51	882.69	2870.04	3164.62	1338.69	1551.83	1975.81	3144.12	1571.00	3888.54	2264.98	1339.21	1728.41	1418.85	1987.95	2132.64
Sb (µg/g)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.04	0.02	0.02	0.01	0.02	0.01	0.01
Se (µg/g)	0.55	0.38	0.39	0.32	0.24	0.22	0.29	0.20	0.21	0.40	0.27	0.21	0.15	0.29	0.55	0.22	0.30	0.42
Sm (µg/g)	1.81	1.00	1.59	1.01	0.52	0.53	0.77	0.54	0.60	1.75	1.01	0.41	0.38	0.60	2.90	0.49	0.81	0.77
Th (µg/g)	2.66	1.26	1.70	1.19	0.67	0.57	0.90	0.70	0.81	1.23	1.41	0.46	0.37	0.71	4.11	0.62	0.96	0.68
U (µg/g)	0.35	0.15	0.20	0.14	0.08	0.08	0.11	0.08	0.09	0.29	0.13	0.08	0.06	0.09	0.39	0.08	0.12	0.14
V (µg/g)	45.23	23.81	35.23	21.39	10.45	8.81	14.97	10.18	11.57	19.38	19.30	8.46	6.82	11.95	49.49	10.77	18.36	14.13
Y (µg/g)	5.18	2.33	4.66	2.50	1.32	1.44	2.03	1.31	1.38	4.41	2.34	1.23	1.40	1.57	7.54	1.40	2.03	3.37
Yb (µg/g)	0.34	0.15	0.25	0.15	0.08	0.08	0.12	0.08	0.08	0.26	0.14	0.07	0.08	0.09	0.43	0.08	0.13	0.21
Zn (µg/g)	109.21	29.27	32.46	41.17	23.09	19.33	29.36	31.45	26.93	55.18	36.77	91.92	54.94	31.85	42.26	39.12	35.10	44.29

Table 8. Concentrations (µg/g) of the 24 chemical elements analyzed in insects/spiders at the 18 stations. Distance (km) from Longyearbyen coal power plant is also given in the table.

Material of analysis	**Insects/spiders**																	
Station	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Distance (km) from coal power plant	**0.89**	**1.3**	**1.9**	**2.2**	**2.8**	**3.7**	**4**	**4.3**	**4.5**	**5.2**	**5.5**	**6.4**	**6.5**	**6.8**	**7.5**	**8.1**	**8.3**	**8.8**
Al (µg/g)	2203.05	380.23	480.49	421.33	107.98	530.54	1297.26	764.50	616.60	4697.07	636.98	2366.37	8685.54	228.22	2692.84	339.30	131.89	949.82
As (µg/g)	0.90	0.42	0.40	0.34	0.51	0.50	2.53	0.52	0.49	4.12	0.39	1.58	2.76	0.34	0.88	0.41	0.17	0.52
B (µg/g)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Be (µg/g)	0.06	0.01	0.04	0.02	0.04	0.04	0.13	0.13	0.04	0.10	0.13	0.13	0.26	0.04	0.14	0.03	0.02	0.13
Cd (µg/g)	1.13	0.57	0.45	0.73	1.91	2.70	1.74	2.34	2.53	9.25	2.57	3.70	17.60	1.70	4.62	2.23	4.04	4.83
Co (µg/g)	0.73	0.19	0.23	0.21	0.22	0.31	0.88	0.76	0.69	260.43	1.52	5.03	4.28	0.35	1.31	0.36	0.18	0.59
Cr (µg/g)	2.85	0.53	0.89	0.57	0.22	0.87	1.59	1.16	0.77	6.26	0.99	4.36	11.85	0.49	3.92	0.53	0.22	2.36
Fe (µg/g)	1891.34	419.57	378.69	493.54	182.08	625.82	1141.74	829.21	817.89	4647.54	665.58	2593.84	6871.11	381.29	2134.36	446.05	278.12	1111.46
Hg (µg/g)	0.14	0.23	0.18	0.17	0.20	0.11	0.47	0.45	0.34	0.80	0.19	1.10	1.35	0.27	0.12	0.25	0.12	0.14
La (µg/g)	1.23	0.17	0.19	0.22	0.06	0.38	0.60	0.26	0.27	2.38	0.26	0.99	6.10	0.11	1.59	0.18	0.07	0.42
Mn (µg/g)	84.70	28.49	17.48	48.11	15.86	34.50	62.00	58.78	47.03	436.66	96.88	333.37	559.75	56.08	171.85	62.56	271.16	332.61
Mo (µg/g)	0.55	0.33	0.45	0.34	0.48	0.48	1.64	0.88	0.71	2.20	0.60	0.99	4.31	0.48	1.56	0.49	0.41	0.96
Ni (µg/g)	1.89	0.39	0.58	0.47	0.49	1.17	2.03	1.19	0.93	8.58	2.27	3.14	14.53	0.62	3.94	1.07	0.85	1.51
Pb (µg/g)	1.28	0.17	0.54	0.22	0.09	0.30	0.63	0.38	0.37	2.45	0.28	0.81	4.19	0.37	1.10	0.17	0.09	0.29
S (µg/g)	5888.61	7763.01	3716.87	7593.73	6231.72	8703.21	13547.17	14796.51	10227.78	25801.53	11738.04	20214.67	51278.72	9453.09	13800.13	7903.11	7264.98	14029.37
Sb (µg/g)	0.23	0.02	0.06	0.04	0.04	0.07	0.13	0.13	0.18	0.20	0.18	0.29	0.62	0.12	0.51	0.04	0.07	0.11
Se (µg/g)	1.74	2.89	1.26	2.02	1.96	2.88	4.69	4.24	3.95	10.19	4.12	4.52	10.44	2.74	5.01	2.62	4.30	8.67
Sm (µg/g)	0.31	0.04	0.04	0.06	0.01	0.10	0.12	0.05	0.08	0.65	0.07	0.22	2.32	0.03	0.36	0.04	0.02	0.08
Th (µg/g)	0.28	0.05	0.05	0.06	0.05	0.05	0.10	0.16	0.05	0.50	0.16	0.18	1.07	0.05	0.49	0.04	0.01	0.16
U (µg/g)	0.07	0.01	0.01	0.01	0.01	0.02	0.05	0.02	0.02	0.13	0.02	0.05	0.41	0.01	0.09	0.01	0.00	0.02
V (µg/g)	4.80	0.86	2.17	1.00	0.84	1.27	2.63	1.64	1.28	9.56	1.27	7.10	16.64	0.55	5.79	0.85	0.34	2.36
Y (µg/g)	0.89	0.32	0.11	0.16	0.04	0.39	0.34	0.20	0.21	1.72	0.28	0.49	6.60	0.15	1.21	0.11	0.06	0.29
Yb (µg/g)	0.07	0.02	0.01	0.01	0.00	0.02	0.03	0.02	0.02	0.12	0.02	0.04	0.47	0.01	0.08	0.01	0.00	0.03
Zn (µg/g)	263.71	344.98	170.22	385.41	280.33	297.63	573.32	741.38	469.88	1070.30	522.45	848.76	1976.02	473.93	347.19	311.00	414.89	614.73

Red: the concentration is < 50 % below LOD.

Blue: the concentration is below LOD, but > 50 % below LOD

Table 9. Concentrations (µg/g) of the 24 chemical elements analyzed in feathers from snow bunting nestlings at the 14 stations. Distance (km) from Longyearbyen coal power plant is also given in the table.

Material of analysis	**Feathers**														
Station	**3**	**4**	**5**	**6**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**16**	**18**
Distance (km) from coal power plant	**1.9**	**2.2**	**2.8**	**3.7**	**3.7**	**4**	**4.3**	**4.5**	**5.2**	**5.5**	**6.4**	**6.5**	**6.8**	**8.1**	**8.8**
Al (µg/g)	57.23	459.56	9.95	29.07	28.66	45.67	72.36	27.09	54.66	61.08	296.48	37.69	114.88	55.88	100.88
As (µg/g)	0.20	0.23	0.20	0.06	0.08	0.12	0.07	0.12	0.05	0.05	0.17	0.44	0.20	0.20	0.09
B (µg/g)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Be (µg/g)	0.06	0.14	0.07	0.04	0.04	0.04	0.04	0.04	0.02	0.02	0.06	0.14	0.06	0.06	0.03
Cd (µg/g)	0.08	0.18	0.08	0.05	0.05	0.05	0.05	0.05	0.02	0.02	0.08	0.18	0.08	0.08	0.03
Co (µg/g)	0.15	0.44	0.15	4.36	4.33	0.72	0.09	26.01	0.03	55.79	0.15	0.44	0.09	0.15	0.06
Cr (µg/g)	0.59	1.05	0.59	0.35	0.35	0.26	0.35	0.35	0.15	0.11	0.63	1.76	0.41	0.68	0.65
Fe (µg/g)	58.28	387.94	21.64	36.29	36.13	64.65	73.73	37.18	56.82	60.98	292.16	47.72	117.46	75.56	117.23
Hg (µg/g)	0.30	0.49	0.12	0.17	0.16	0.22	0.53	0.16	0.24	0.31	1.42	0.43	1.03	0.47	0.36
La (µg/g)	0.06	0.24	0.02	0.02	0.02	0.02	0.04	0.01	0.03	0.04	0.11	0.04	0.04	0.03	0.04
Mn (µg/g)	0.79	4.15	0.54	1.55	1.55	1.04	1.12	21.25	0.84	14.39	4.76	0.98	2.19	1.53	1.86
Mo (µg/g)	0.16	0.23	0.11	0.05	0.07	0.08	0.07	0.08	0.07	0.07	0.24	0.35	0.15	0.10	0.11
Ni (µg/g)	0.13	0.49	0.13	0.05	0.05	0.20	0.17	0.09	0.19	0.16	0.49	0.38	0.20	0.28	0.16
Pb (µg/g)	0.02	0.26	0.03	0.05	0.06	0.06	0.17	0.02	0.28	0.05	0.19	0.08	0.34	0.06	0.12
S (µg/g)	18827.89	55115.99	18176.23	20634.96	20560.01	19782.22	22636.79	20188.17	19330.41	18376.96	56754.47	27522.66	34403.85	27674.08	26794.00
Sb (µg/g)	0.09	0.08	0.04	0.02	0.01	0.01	0.04	0.01	0.01	0.01	0.04	0.07	0.02	0.05	0.01
Se (µg/g)	3.50	8.65	2.86	3.11	3.14	4.29	2.86	3.06	2.24	2.72	5.34	1.60	4.50	3.33	2.41
Sm (µg/g)	0.01	0.06	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.02	0.01	0.01	0.01	0.01
Th (µg/g)	0.08	0.24	0.08	0.05	0.05	0.05	0.05	0.05	0.02	0.02	0.08	0.24	0.08	0.08	0.03
U (µg/g)	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00
V (µg/g)	0.09	1.12	0.06	0.04	0.05	0.09	0.15	0.04	0.12	0.11	0.75	0.18	0.25	0.11	0.26
Y (µg/g)	0.02	0.11	0.01	0.01	0.01	0.02	0.03	0.01	0.02	0.02	0.07	0.01	0.04	0.03	0.04
Yb (µg/g)	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00
Zn (µg/g)	176.53	380.09	148.45	159.87	160.10	163.82	191.02	179.69	160.89	155.54	422.54	225.18	299.91	223.20	222.00

Red: the concentration is < 50 % below LOD.

Blue: the concentration is below LOD, but > 50 % below LOD.