

# Persistent organic pollutants in Swedish mosses



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This report has been reviewed and approved in accordance with IVL's audited and approved management system.

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## Summary

On behalf of the Swedish Environmental Protection Agency, IVL Swedish Environmental Research Institute led in 2015 a project aiming to examine the concentrations of persistent organic pollutants (POPs) in mosses.

Samples of red-stemmed feathermoss (*Pleurozium schreberi*) and glittering wood moss (*Hylocomium splendens*) were collected at 83 rural sampling sites. Of these, 20 samples were analysed for the following groups: polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), selected organochlorine pesticides, polybrominated diphenyl ethers (PBDEs), hexabromocyclododecane (HBCD), dioxins and furans (PCDD/PCDFs), dioxin-like PCBs and perfluorinated alkylated substances (PFAS).

The sampling sites were selected to cover the whole of Sweden, in both the north-south gradient and in the east-west gradient. The sites were also chosen to represent both eventually elevated concentrations as well as low concentrations of POPs. Information on locations of industrial activities, population density and monitoring stations for organic substances in air and precipitation (Swedish national monitoring programme) were also used for the selection of sampling sites.

Generally, the concentrations of the analysed substances were very low, often close to or below the quantification limits for the analyses.

Significant correlation was found between the concentrations of PAHs, dioxin/furans and dioxin like PCBs in the mosses and the distance to the closest industry, and also to the distance from the southernmost point in Sweden. p,p-DDE concentrations in mosses showed a correlation to the distance from the southernmost point in Sweden, with the highest concentrations in the south. No correlation was found between the concentrations of p,p-DDE (one of the DDTs) in mosses and distance to the closest industry.

The concentrations of PAHs in mosses collected at sites located in the vicinity of three air monitoring stations (Råö, Aspvreten and Pallas) were in agreement with the concentrations of PAHs in air, with the highest concentrations in mosses and in air found in the south and the lowest in the north. Comparison between the PAH profile in air and in mosses showed a higher percentage of heavier PAHs in the mosses. This indicates a larger proportion of particular bounded PAHs in mosses.

HBCDD and PFAS were not detected in any of the analysed moss samples, which is consistent with a similar study conducted in Norway.

## Sammanfattning

På uppdrag av Naturvårdsverket har IVL Svenska Miljöinstitutet under 2015 lett ett projekt som syftar till att undersöka koncentrationen av persistenta organiska föroreningar (POPs) i mossor.

Prov av väggmossa (*Pleurozium schreberi*) och husmossa (*Hylocomium splendens*) samlades in på 83 platser i bakgrundsmiljö. Av dessa har 20 mossprover analyserats med avseende på följande ämnesgrupper: polycykliska aromatiska kolväten (PAHer), polyklorerade bifenyler (PCBer), vissa klorerade pesticider, polybromerade difenyletrar (PBDEer), hexabromcyklododekan (HBCD), dioxiner och furaner (PCDD/PCDFs), dioxinlika PCBer och perfluorerade ämnen (PFAS).

Provtagningsplatserna valdes för att täcka hela Sverige, både i den nord-sydliga gradienten och i den öst-västliga gradienten. Platserna valdes också för att representera både områden med eventuellt förhöjda halter och områden med låga halter av POPs. Information om närhet till industriell verksamhet, befolkningstäthet och mätstationer inom svenska nationella övervakningsprogrammet för organiska ämnen i luft och nederbörd, användes också för urval av provtagningsplatser.

Koncentrationen av de undersökta ämnena i mossa var generellt mycket låg, inte sällan nära eller under kvantifieringsgränsen för analyserna.

Signifikant korrelation fanns mellan koncentrationen av PAHer, dioxiner/furaner och dioxinlika PCBer i mossorna och avstånd till närmaste industri samt även till avstånd från den sydligaste punkten i Sverige. Koncentrationen av p,p-DDE i mossor korrelerade signifikant mot avståndet från den sydligaste punkten i Sverige, med de högsta nivåerna i söder. Ingen signifikant korrelation fanns mellan koncentration av p,p-DDE i mossor och avstånd till närmaste industri.

Halter av PAHer i mossor från provtagningsplatser insamlade i närheten av tre nationella luftövervakningsstationer (Råö, Aspvreten och Pallas) överensstämde med motsvarande halter i bakgrundsluft, med de högsta halterna i mossor och luft i söder och de lägsta i norr. Jämförelse mellan profilen för enskilda PAH-komponenter i luft och i mossor visar på en större andel av tyngre PAHer i mossor. Detta tyder på en större andel av partikelbundna PAHer i mossor.

HBCDD och PFAS upptäcktes inte i något av de analyserade mossproverna, vilket är i överensstämmelse med en liknande studie utförd i Norge.

## 1 Introduction

In Sweden in the late 1960s a new and simple method to measure heavy metal load in the environment was introduced (Rühling & Tyler, 1968; Tyler, 1971). This method is based on the use of mosses as indicators for airborne heavy metals as their need of nutrition almost exclusively comes from the atmosphere. The dense carpets that *Hylocomium splendens*, *Pleurozium schreberi* and other pleurocarpous mosses form on the ground turned out to be effective traps of metals in precipitation and airborne particles. In order to identify the presence of heavy metals in the environment the method has been used in Sweden at five-year intervals since 1975. Since 1990, corresponding studies have been carried out in many other European countries, also with five-year intervals. The European work is conducted within the ICP Vegetation under the Convention on Long-range Transboundary Air Pollution (CLRTAP).

In the European moss survey 2010 a pilot project was performed aiming to investigate whether mosses also can be used as bio-indicators for airborne persistent organic pollutants (POPs). The study involved six European countries. For the 2015 survey it was suggested to extend the pilot study conducted in 2010 to other countries, and to focus on POPs such as PAHs, PCBs, PBDEs, dioxins, and PFAS.

On behalf of the Swedish Environmental Protection Agency, IVL Swedish Environmental Research Institute led in 2015 a project aiming to examine the concentrations of persistent organic pollutants (POPs) in mosses. In total 83 moss samples were collected for analyses of POPs. Of these, 20 samples were analysed for the following substance groups:

- Polycyclic aromatic hydrocarbons, PAHs
- Polychlorinated biphenyls, PCBs
- Hexachlorobenzene, HCB
- Hexachlorocyclohexanes, HCHs
- Chlordanes
- Dichlorodiphenyltrichloroethanes, DDTs
- Chlorinated dioxin and furans, PCDD/PCDFs including dioxin-like PCBs
- Polybrominated diphenyl ethers, PBDEs
- Hexabromocyclododecane, HBCD
- Perfluorinated alkylated substances, PFAS

## 2 Aim

The aim of this study was to analyse 20 of the 83 collected samples of the red-stemmed feathermoss (*Pleurozium schreberi*) and glittering wood moss (*Hylocomium splendens*) with regard to selected POPs in order to investigate the occurrence and concentrations of organic contaminants in mosses collected in Sweden.

## 3 Methodology

### 3.1 Sampling sites

The sampling sites were selected to cover the whole of Sweden, both in the South-North as in the East-West gradient. The sites were also chosen to represent both eventually elevated concentrations as well as low concentrations of POPs.

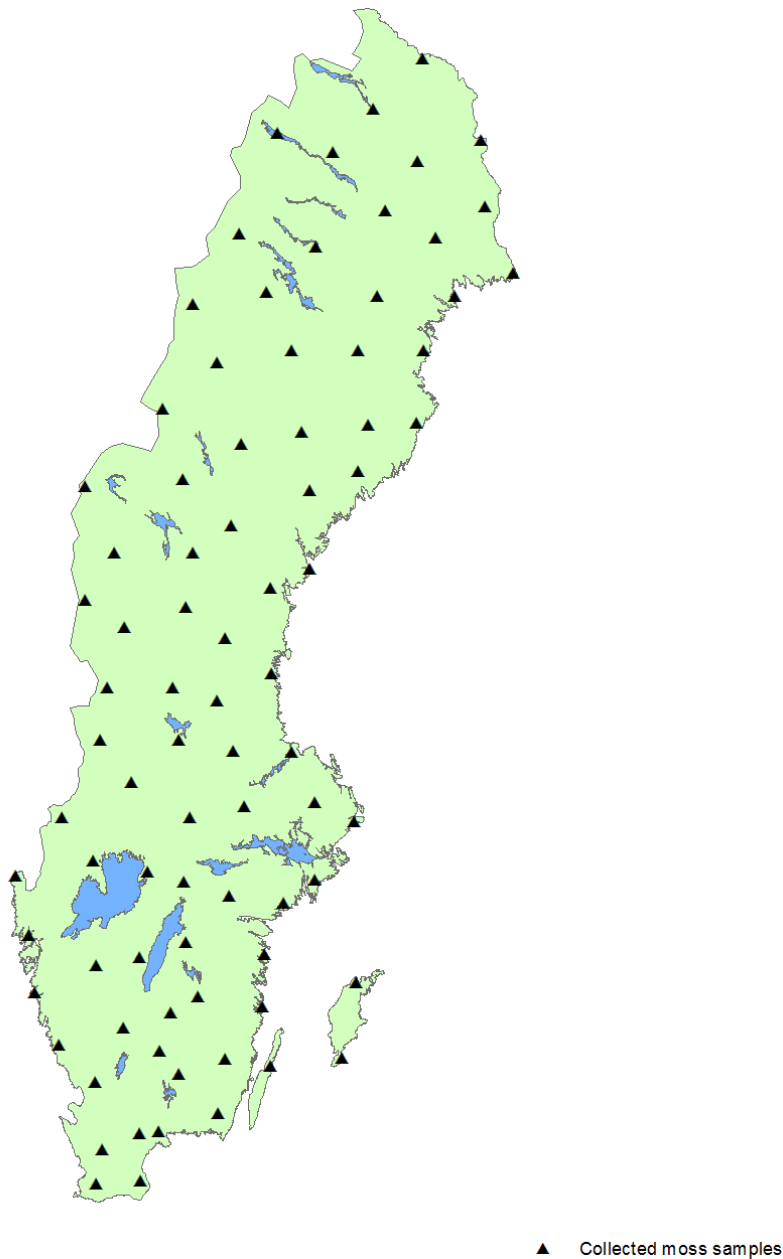


Figure 1. Map illustrating sampling sites for mosses collected in 2015.

Information on locations of industrial activities, population density and monitoring stations for organic substances in air and precipitation were used for the selection of moss samples for analyse in 2015 (Figure 2).

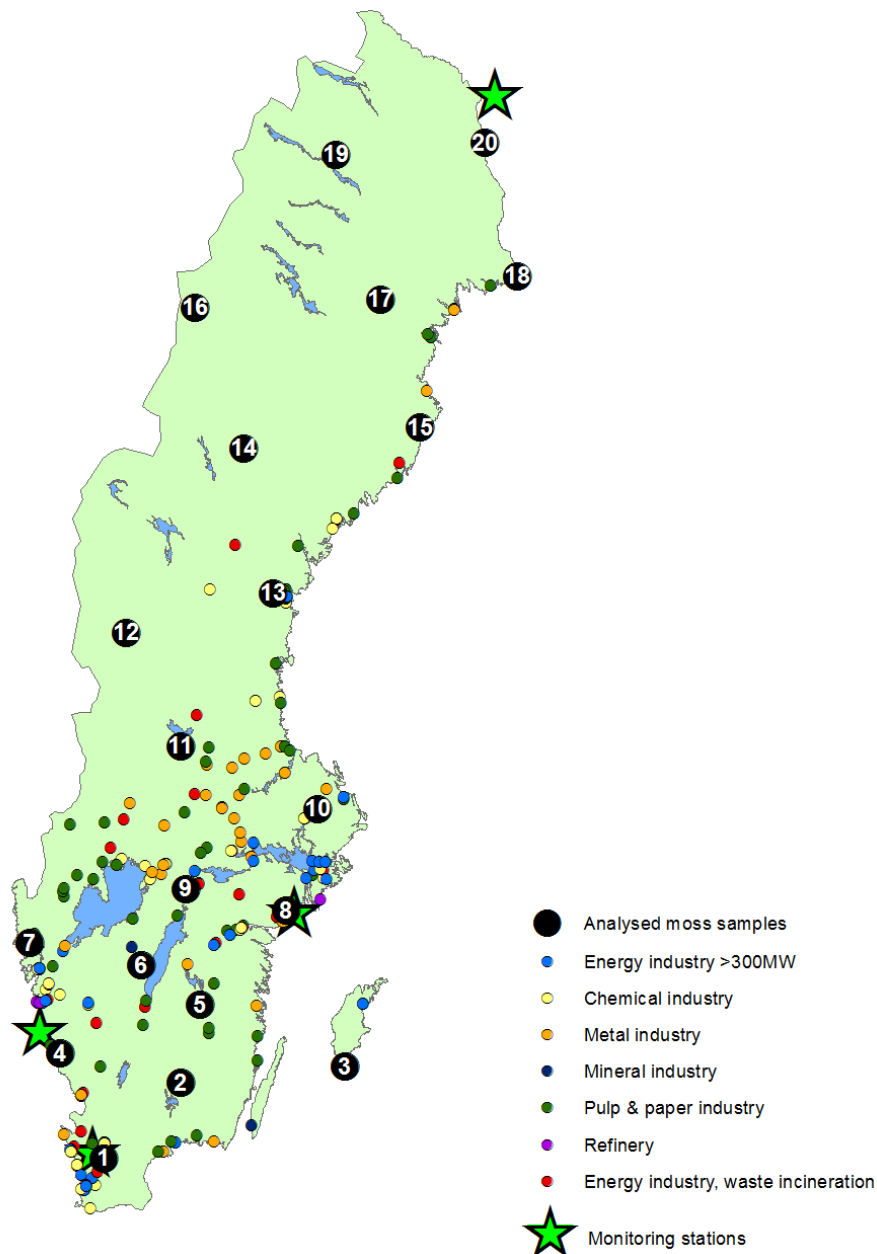


Figure 2. Map illustrating moss samples chosen for analyses in 2015. Location of facilities with industrial activities and monitoring stations for organic pollutants in air and precipitation are also included.

In Table 1 the distances between each moss sampling plot and closest industrial facility as well as the distance northwardly from Sweden's southernmost point are listed. The



moss sampling plots located closest to the atmospheric monitoring stations Råö, Aspvreten and Pallas (EMEP stations) are also indicated.

**Table 1. Distances between moss sampling plots and closest industrial facility as well as the distance northwardly from the southernmost point in Sweden. The moss sampling plots located closest to the monitoring stations Råö, Aspvreten and Pallas are indicated.**

Moss sampling plot	Distance to closest industry, km	Distance to the southernmost point in Sweden, km	Moss sampling plots closest to monitoring stations
1	19	7	
2	6	16	
3	84	18	
4	16	20	Råö
5	31	26	
6	27	31	
7	11	34	
8	14	38	Aspvreten
9	18	41	
10	20	51	
11	36	59	
12	121	74	
13	15	79	
14	124	97	
15	48	100	
16	300	115	
17	75	116	
18	36	119	
19	249	135	
20	182	136	Pallas

### 3.2 Sampling procedure

The collection of moss samples were carried out by staff from the Swedish National Forest Inventory at the Swedish University of Agricultural Sciences (SLU). The collection of mosses followed the sampling instruction given below:

- The sampling plot should be at least 300 m from national or county roads and settlements (three or more houses for permanent living).
- The sampling plot should be at least 100 m from any other regularly busy road and houses for permanent living.
- The moss sample should consist of five to ten (5-10) subsamples. The subsamples shall be collected 5-10 m from each other and taken in closed forest (not below or at the edge of tree crowns).
- The moss sample volume should be about 3 l.
- Bare hands should be used, but washed thoroughly with copious amounts of *Sphagnum* (peat moss) or any other moist moss before sampling
- Smoking is not allowed during sampling or other handling of the moss samples.

- Clear the moss sample from pine needles, soil and debris.
- Enclose the moss sample in a large sheet of aluminium foil. Seal the foil package carefully. Before putting the foil package in a plastic bag, wrap in two more layers of aluminium foil. It is very important that the moss sample does not come in contact with the plastic bag.
- On the tag, specify date, sampler, coordinates, species and the number of sub samples.
- The sample shall consist of either *Pleurocium screberi* or *Hylocomium splendens*.
- After sampling the samples should be kept cold in a cooler bag with ice blocks until put in mobile freezer.
- The samples should be kept cold with ice blocks when sent to the laboratory

### 3.3 Analysis

#### 3.3.1 Storing and preparation of moss samples

At the laboratory the samples were stored in the dark at -20 °C and before analyses the samples were thawed in a clean refrigerator overnight. The following day the thawing continued in room temperature and the moss was carefully rinsed from all dead material and attached litter until only the green and green-brown shoots from the last three years of growth remained. During the sample preparation the moss was handled in a room separated from the actual laboratory in order to avoid exposure to chemicals.

The samples were dried at room temperature for about one day before analysis. The dry weight was determined after drying in 105° C for 24 hours.

#### 3.3.2 Analytical work

##### 3.3.2.1 PAHs, PCBs, HCHs, chlordanes, PBDE and HCBd

The extraction of PAHs, PCBs and other organochlorines and PBDEs were performed according to IVL Swedish Environmental Research Institutes accredited methods for PAHs and PCBs. A schematic chart flow of the analysis work is shown in Figure 3.

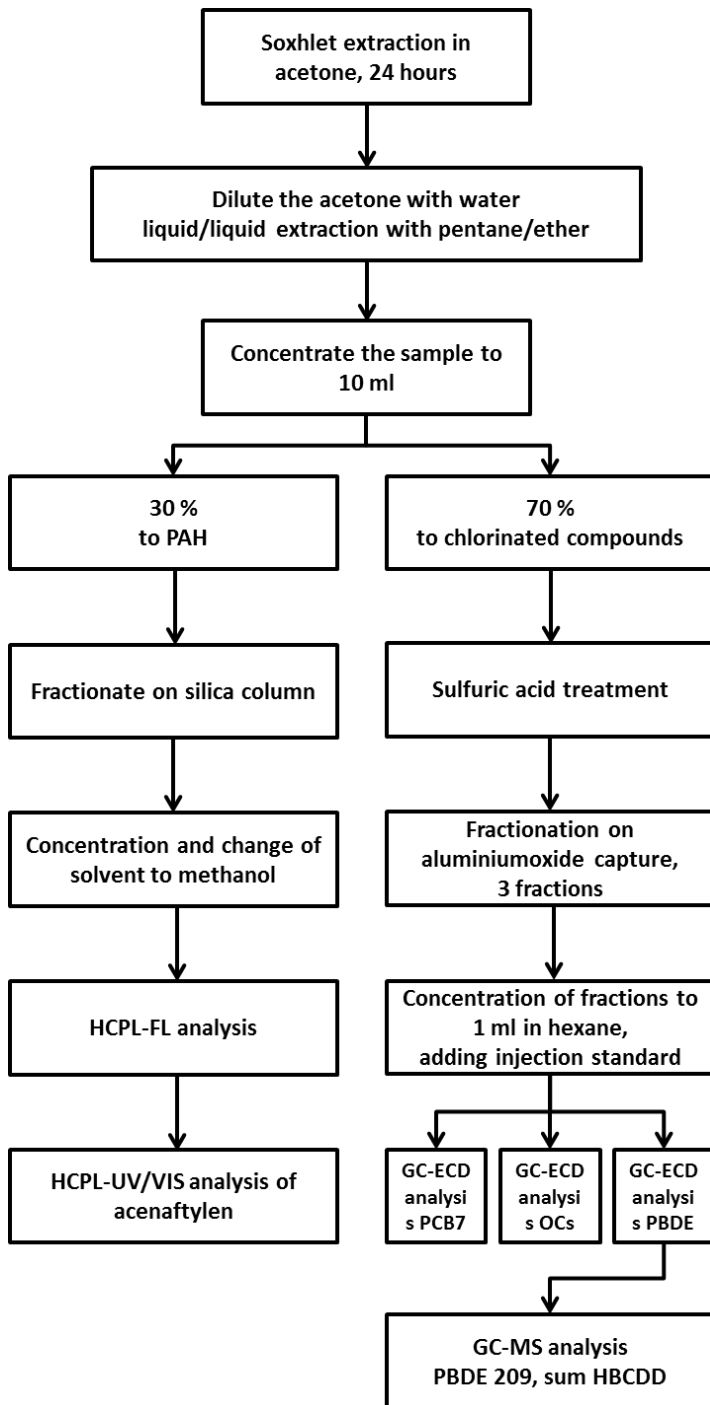


Figure 3. Schematic flow chart of the analysis

The moss samples were Soxhlet extracted in acetone for 24 hours and then spiked with recovery standard. The organic compounds were extracted to an organic phase by liquid/liquid extraction with water and pentane and then concentrated under nitrogen to 10 ml. The extracts were divided in two parts; 30 % for PAH-analysis and 70 % for organochlorides and PBDEs.

The part of the samples intended for PAH-analysis were further concentrated under nitrogen and fractionated on silica gel column as an additional "clean-up" procedure. The PAH-fraction of the sample was concentrated and solvent exchanged to methanol.

Determination of the PAH components was carried out using a high performance liquid chromatograph (HPLC), type Varian Prostar 240, M410 with a 5 µm C18-column (Chromosphere PAH 100\* 3 mm, Chrompack). A linear gradient elution program was used and a fluorescence detector (Varian Prostar 363) with a wavelength program optimised for each PAH was used for identification and quantification. The samples were also analysed on a UV/VIS-detector where acenaphthylene was detected.

Before determination of the chlorinated and brominated substances, the samples were treated with concentrated sulfuric acid and a fractionation on an alumina column with a controlled polarity was performed. The PCBs were eluted in fraction 1, the PBDEs in fraction 2 and the chlorinated pesticides in fractions 1, 2 and 3. The three fractions of each sample were concentrated and injection standard was added before analysis. The analyses were performed on a gas chromatograph with electron capture detector (GC-ECD, type Varian 3800). The analysis column was a 50 m capillary column with stationary CP-Sil 8CB from Chrompack. The different PCBs, PBDEs and chlorinated pesticides were identified and quantified using internal standard and external certified standard mixtures. The yield was calculated by the recovery standard.

In order to determine deca BDE (BDE209) and sum of HBCD, two of the sample fractions (2 and 3) were also analysed with gas chromatography coupled with mass spectrometry (GC-MS) using negative chemical ionization (CI) Quality control.

The methods used for analysis of PAHs and PCBs in biota are accredited by SWEDAC. The analysis of PBDEs and chlorinated pesticides comply with the control procedures included in the accredited methods. The possible contamination of the samples at extraction and clean-up procedures as well as during analysis is checked by laboratory blank samples processed together with each batch of samples. Loss of components during extraction and clean-up procedures is checked and corrected using internal standards.

The concentrations of the various components were quantified by calibration with certified calibration standards. The calibration was checked at each batch with analysis of a certified reference solution. Duplicate samples were extracted and analysed regularly and at least one sample of each batch were analysed several times and the results were monitored with control cards. IVLs annual quality work also includes participation in inter laboratory comparisons and analysis of certified reference materials.

### **3.3.2.2 Dioxins and furans**

The analyses were performed according to Swedish and European Standards SS-EN 1948:2-4 at the Umeå University. The samples were freeze dried and then <sup>13</sup>C-labeled standards were added to the sample before extraction. These standards consist of isotopically labelled substances with the same characteristics as the subjects analysed, but with different molecular weight. The sample was then Soxhlet extracted with toluene for 16 hours.

The clean-up of polychlorinated dibenzo-p-dioxins (PCDD), polychlorinated dibenzofurans (PCDF) was performed, first by a multistep silica column followed by a Carbon column. To the final extract, a keeper solvent (tetradecane) and  $^{13}\text{C}$  labelled recovery standards was added, before the evaporation to the final volume.

Isomer specific analysis was performed using gas chromatography (GC) coupled with mass spectrometry (MS). The separation of substances occurs on the GC and the detection on the mass spectrometer. In MS analysis, the substances with different atomic masses are detected selectively. This enables the use of synthetic  $^{13}\text{C}$ -isotopically enriched compounds ( $^{13}\text{C}$ -congeners), which were used as internal standards, the so-called isotope dilution methodology. Accordingly, a comparison of the response ratio between natural congeners and  $^{13}\text{C}$  congeners in the sample with the corresponding ratio in a quantification standard, containing both known amounts of natural and added  $^{13}\text{C}$ -congeners, was performed. This procedure meant that the results were automatically compensated for potential losses during clean-up. An MS (Waters Autospec Ultima) with high mass resolution have been used. It used electron impact ionization (EI), and then specific ions were selected and recorded (SIR).

Concentration determination was carried out following the standard EN 1948: 3. Recovery rates of the sampling standard (PS) and internal standard (IS), added to the samples, were calculated and expressed as a percentage of the original amount. The calculation of the TCDD equivalents (TEQ) and information about LOD/LOQ is given in Appendix 1.

### **3.3.2.3 Perfluorinated alkylated substances**

Moss samples were dried overnight and 1 g dry sample was rinsed and extracted by solid-liquid extraction. The samples were spiked with 25 ng of each of the internal standards  $^{13}\text{C}$ -PFOS and  $^{13}\text{C}$ -PFOA and 2 mL 0.2 M sodiumhydroxide was added. The samples were then extracted twice with 20 mL methanol in an ultrasonic bath for 30 min and transferred to a 50 ml PP-test tube. After centrifugation, the extracts were combined and 200  $\mu\text{l}$  hydrochloric acid (2 M) was added for neutralization. The extract was concentrated to 1 mL and cleaned using a dispersive clean up with ENVI-Carb (100 mg, 1 mL, 100–400 mesh, Supelco, USA) and glacial acetic acid. A volume of 0.5 mL of the supernatant was transferred to a vial and 0.5 mL of 4 mM ammonium acetate in Millipore water was added. The extract was stored in a freezer until instrumental analysis before analysis.

The separation and detection of PFASs were performed by high-performance liquid chromatography (HPLC, UFLC Shimadzu, model CBN-20A, Japan) coupled to a mass spectrometer interfaced with an electrospray ionization source in a negative-ion mode (ESI-MS/MS, API 4000, AB Sciex, Foster City, CA, USA). The analytical column was a C8 column (50 mm x 3 mm, 5  $\mu\text{m}$  particle size, Thermo Scientific, Dalco Chromtech) using a gradient of 400  $\mu\text{L min}^{-1}$  methanol and water (both with 2 mM  $\text{NH}_4\text{OAc}$ ). The MS/MS was operated at the most sensitive transition from precursor ion to product ions in the multiple-reaction monitoring (MRM) mode.

## 4 Results and discussion

In the figures below, the concentrations of the different POPs found in the moss samples from the 20 sampling sites are presented in a gradient from south to north (see Figure 2). The individual concentrations of all substances are presented in Appendix 2.

### 4.1 Polycyclic aromatic hydrocarbons (PAHs)

The concentrations of the PAH16 (Naphthalene to Indeno (1,2,3-cd)pyrene) in mosses from rural areas in Sweden are presented in Figure 4. The PAH concentrations varied between 15 and 120 ng/g DW (sum of the PAH16). The highest concentrations were measured in the southwest and southeast of Sweden and the lowest in the north. This geographical distribution is in agreement with the concentrations of PAHs in air as the highest concentrations are found in south and the lowest in north (Sjöberg et al., 2014). The average yearly atmospheric concentrations of PAH12 (Phenanthrene-Indeno (1,2,3-cd)pyrene) in air 2014 at the background sites Råö, Aspveten and Pallas were 1.6, 2.1 and 0.5 ng/m<sup>3</sup>, respectively. At these sites the corresponding concentrations of PAH12 in mosses were 102, 110 and 19 ng/g DW.

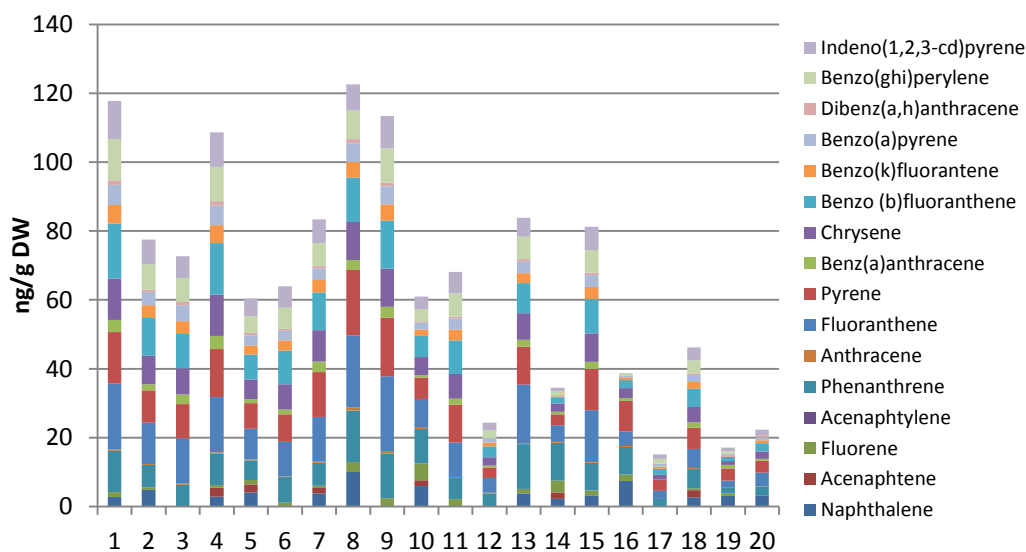


Figure 4. Concentrations of PAH16 in mosses. The southern sampling sites are presented to the left and the northern to the right.

The concentrations of PAH16 are significantly correlated to both the distance to the closest industry and to the distance northwardly from the southernmost point in Sweden (Figure 5, Figure 6). The concentrations of PAH16 in mosses seem thus to be a result of both emissions from nearby industrial activities and to long-range transport.

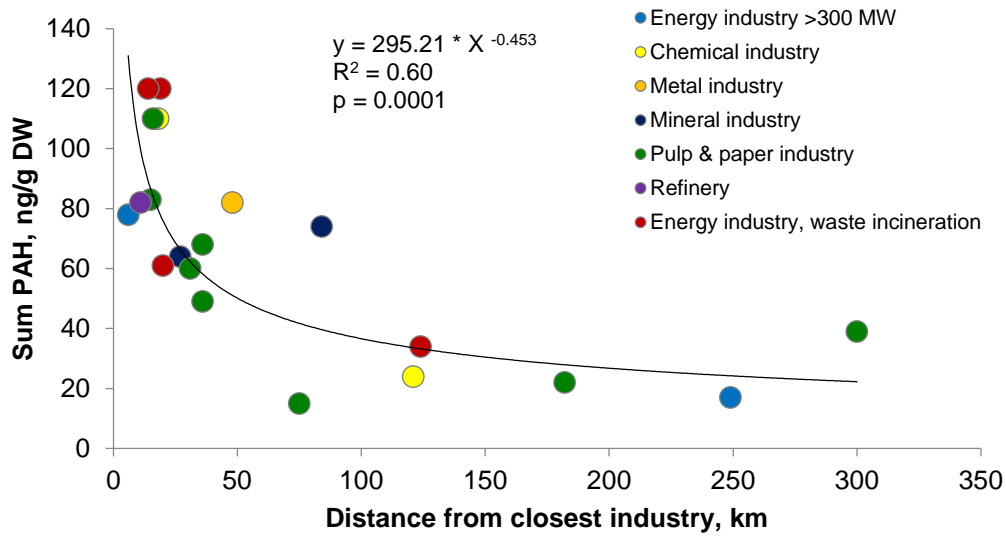


Figure 5. Correlation between PAH16 in mosses and distance to closest industrial facility.

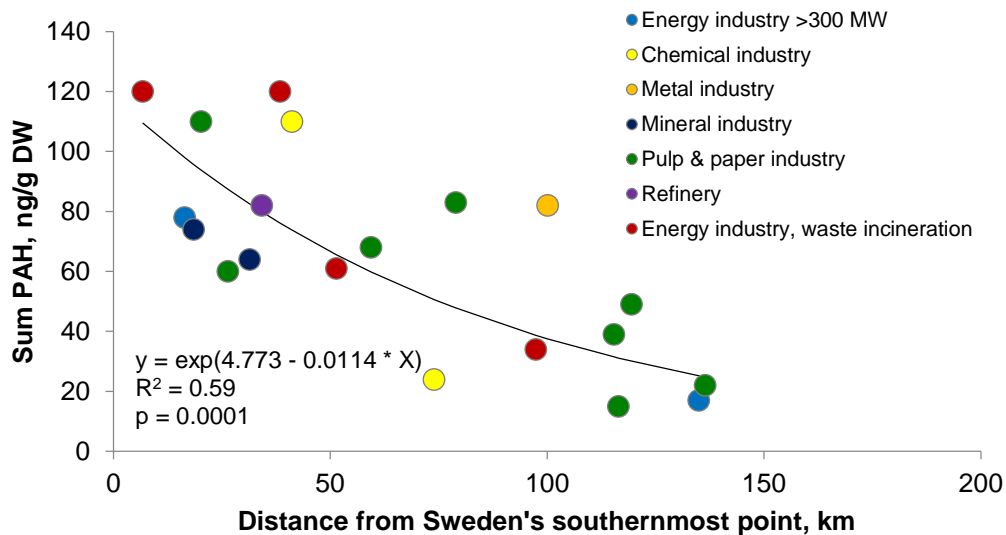
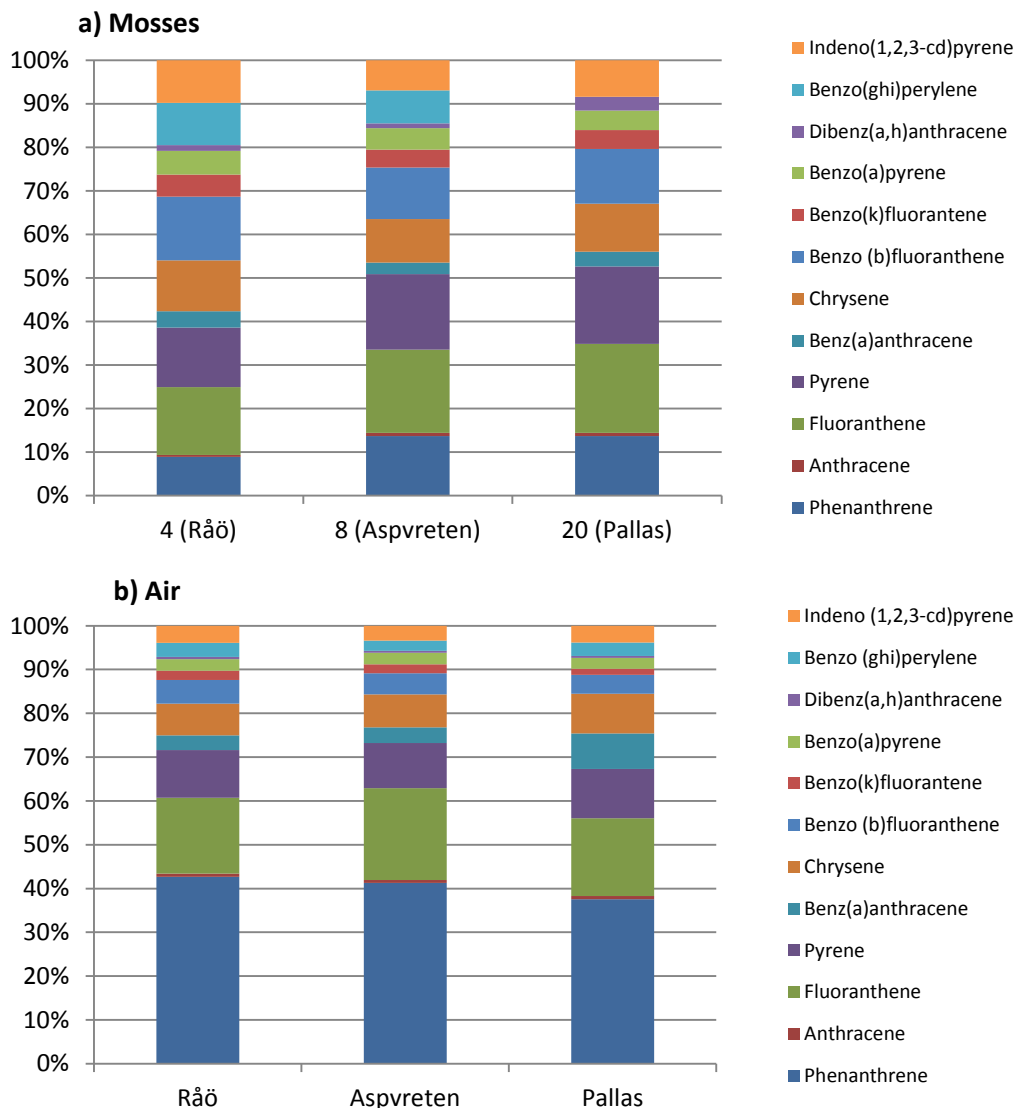


Figure 6. Correlation between PAH16 in mosses and distance northwardly from Sweden's southernmost point.

The relative distribution of the individual PAHs (sum 12, phenanthrene-indeno (1,2,3-cd)pyrene) in mosses from three sites located in the vicinity of Råö, Aspvreten and Pallas is shown in Figure 7. Compared to the PAH profile in air, the percentage of heavier PAHs are higher in the mosses, which indicates a greater share of particular bounded PAHs.



**Figure 7. PAH profiles in a) mosses and b) air (average 2014), at the sites 4, 8 and 20 located closest to the monitoring background stations, Råö, Aspvreten and Pallas.**

In Harmens et al., (2013) averages and ranges of PAH concentrations in mosses from rural areas from Poland, Spain, Austria and Czech Republic are presented. The average concentrations measured in this study were in the same concentration range as measured in Austria (2 studies) and Spain (120, 140 and 170 ng/g DW). The average concentrations of PAHs in Czech Republic and Poland (2 studies) were approximately four times higher (610, 600 and 510 ng/g DW, respectively).

In Foan et al., (2014) PAH13 were analysed in totally 61 moss samples from France, Spain and Switzerland. The results varied between 150-360 ng/g DW (n=20) in samples from France, 100-360 ng/g DW (n=23) in Spain and 100-700 ng/g DW (n=18) in Switzerland. Compared to PAH concentrations in this study, these European concentrations are approximately three to six times higher. Steinnes and Schlabach,



(2012) measured PAH16 in mosses from 20 rural sites in Norway. In this study, the concentrations varied between 19 and 220 ng/g DW, which is in the same order as the Swedish results found in this study.

## 4.2 Polychlorinated biphenyls (PCBs)

The sum of PCB7 (CB-28, 52, 101, 118, 153, 138 and 180) was measured in concentrations close to or below the limit of quantification for the analysis (0.19-0.84 ng/g DW). PCB101 and 153 occurred most frequently. No clear geographic distribution pattern was obtained.

In mosses collected in Norway, PCB7 varied between 0.06 and 0.52 ng/g DW (Steinnes and Schlabach, 2012) and the concentrations were somewhat higher in the southern part of Norway.

## 4.3 Hexachlorobenzene (HCB)

The concentrations of HCB in the mosses are shown in Figure 8. Concentrations varied only slightly, between 0.18 and 0.50 ng/g DW. No concentration gradient between the southern and northern sites was seen. The HCB concentrations in this study are slightly higher compared to the Norwegian study (Steinnes and Schlabach, 2012) in which concentrations varied between 0.05 and 0.20 ng/g DW (n=20).

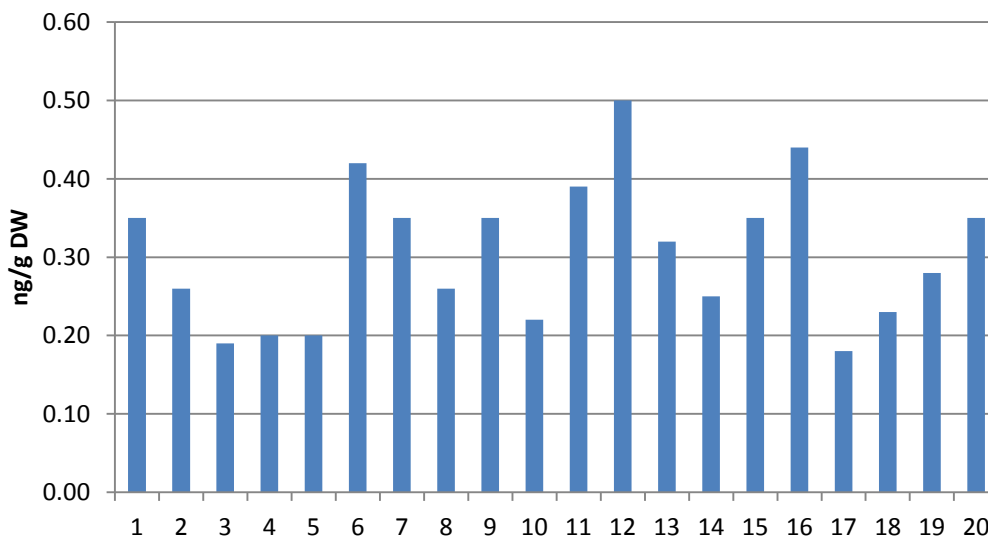


Figure 8. The concentrations of HCB in mosses. The southern sampling sites are presented to the left and the northern to the right.

#### 4.4 Hexachlorocyclohexanes (HCHs)

$\alpha$ -HCH was detected in mosses from three sites (sites 4, 8 and 11) in concentrations slightly above the quantification limit (0.026, 0.062 and 0.071 ng/g DW). No geographical pattern in concentrations was seen.

$\beta$ - and  $\gamma$ -HCH were not detected in any of the 20 samples (<0.06, <0.03 ng/g DW, respectively).

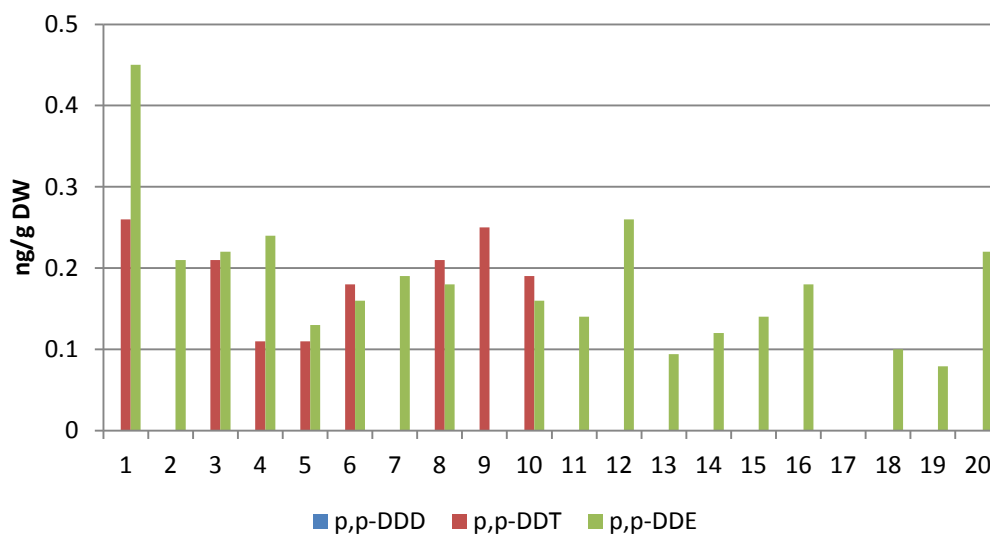
The concentrations of HCHs in mosses from Norway were somewhat higher compared to the present study. The concentrations of  $\alpha$ -,  $\beta$ - and  $\gamma$ -HCH were between 0.015-0.14, 0.005-0.031 and 0.022-0.12 ng/g DW, respectively (Steinnes and Schlabach, 2012).

#### 4.5 Chlordanes

The concentrations of  $\alpha$ -chlordane,  $\gamma$ -chlordane and transnonachlor were measured in mosses.  $\gamma$ -chlordane was only detected in one out of the 20 samples, site 4 at the Swedish west coast, in a low concentration of 0.071 ng/g DW. The concentrations of  $\alpha$ -chlordane and transnonachlor were below the quantification limit in all moss samples (<0.03-<0.08 ng/g DW).

#### 4.6 Dichlorodiphenyltrichloroethanes (DDTs)

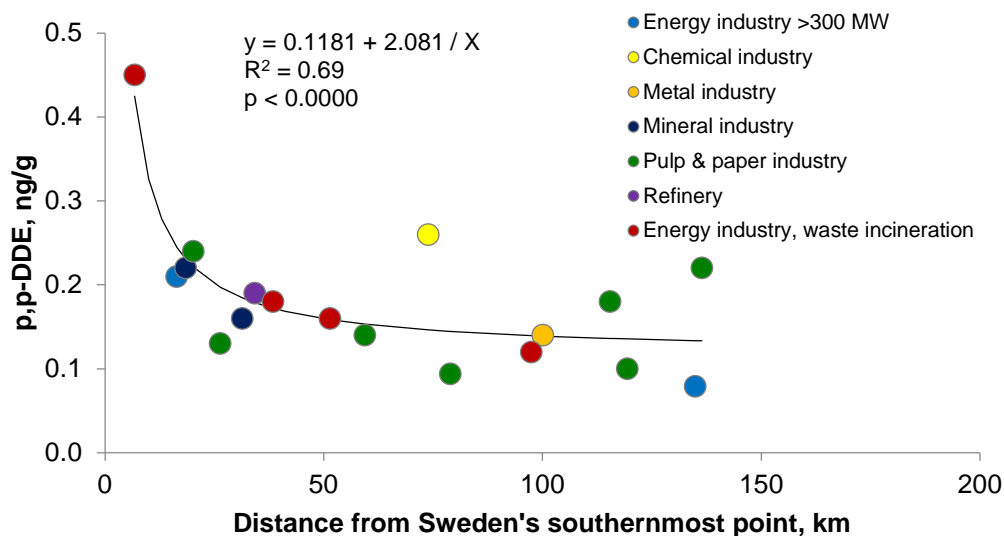
The analysis included determination of p,p-DDD, p,p-DDT and p,p-DDE in mosses. p,p-DDD was not detected in any of the samples (<0.06-<0.17 ng/g DW). p,p-DDT varied between <0.06 and 0.25 ng/g DW, with the highest concentrations in the south parts of Sweden. The concentrations of p,p-DDE varied between <0.07 and 0.45 ng/g DW and the highest concentrations were found in mosses from the southern areas, see Figure 9.



**Figure 9. The concentrations of p,p-DDD, p,p-DDT and p,p-DDE in mosses. The southern sampling sites are presented to the left and the northern to the right.**

Both the concentrations and the geographical distribution are similar to what was found in the Norwegian study (Steinnes and Schlabach, 2012) in which the concentrations of p,p-DDD, p,p-DDT and p,p-DDE were in the range between 0.05 and 0.95 ng/g DW. The highest concentrations were, as in the present study, found at the southernmost sites.

The concentrations of p,p-DDE is significantly correlated to the distance from the southernmost point in Sweden (Figure 10). The concentrations of p,p-DDE in mosses reflects long-range transport.



**Figure 10. Correlation between p,p-DDE in mosses and distance northwardly from Sweden's southernmost point.**

#### 4.7 Polybrominated diphenyl ethers (PBDEs) and hexabromocyclododecane (HBCD)

The concentrations of BDE 28, 47, 99, 100, 85, 153, 154 and 209 were generally low or below the quantification limit for the analysis, see Figure 11. BDE-47 was most frequently found in concentrations between <0.06 – 0.46 ng/g DW.

In the Norwegian study (Steinnes and Schlabach, 2012), BDE-209 was the most dominant compound of all BDEs with highest concentrations the south. In an another study from Norway (Mariussen et al., 2008), the sum of BDE 28, 47, 99, 100, 85, 153, 154 and 183 varied between 0.012-0.34 ng/g DW (n=18) and BDE-209 was detected between 0.05-1.6 ng/g DW.

HBCD was not detected in any of the 20 moss samples from Sweden. HBCD was neither detected in the mosses in the Norwegian study (Steinnes and Schlabach, 2012).

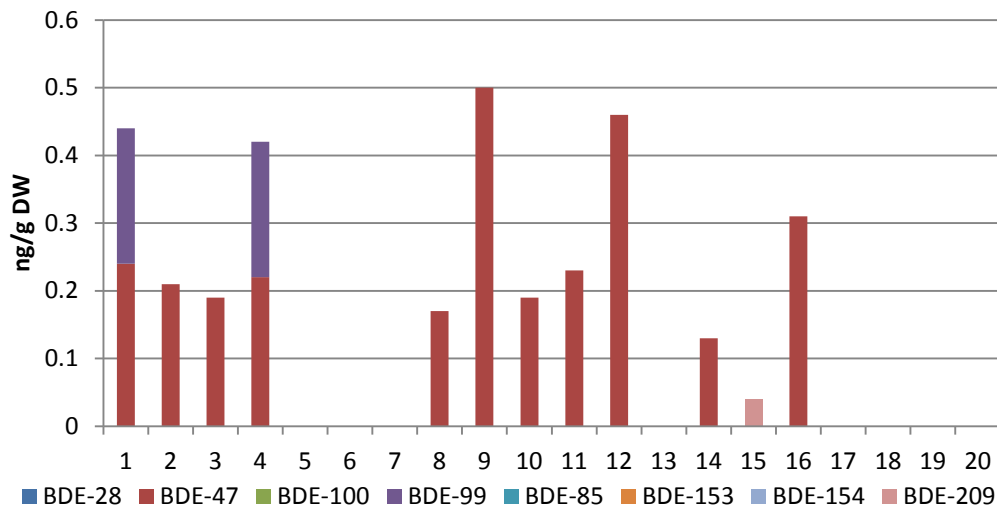


Figure 11. The concentrations of PBDEs in mosses. The southern sampling sites are presented to the left and the northern to the right.

#### 4.8 Dioxin and furans (PCDD/PCDFs) and dioxin-like PCBs

The concentrations of PCDD/PCDFs (sum of 17, TEQ values) are presented in Figure 12. The results are presented as lower limit in WHO 2005 TEQ, which means that the sum of PCDD/PCDFs only includes the values above the quantification limit for the different congeners. The concentrations varied between 0.0001 and 0.57 pg/g DW WHO 2005 TEQ. The highest concentrations were detected in mosses from southern Sweden.

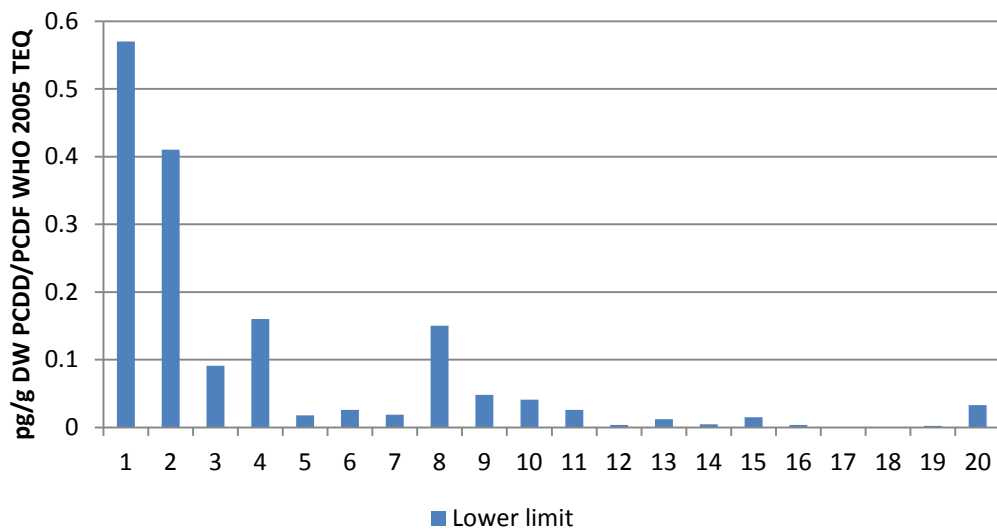
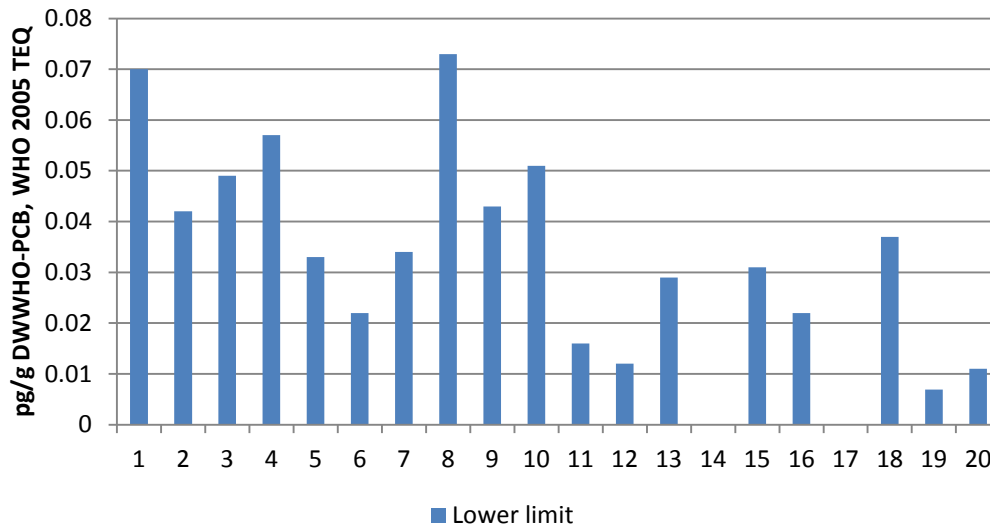


Figure 12. The concentrations of sum of PCDD/PCDFs (lower limit, values below the quantification limit are not included in the sum) in mosses. The southern sampling sites are presented to the left and the northern to the right.

The concentrations of dioxin-like PCBs (sum of 12 WHO-PCBs, 77, 81, 105, 118, 123, 126, 156, 157, 167, 169 and 189) are shown in Figure 13. The highest concentrations were found in the mosses from southern Sweden and the concentrations varied between 0.00003 and 0.073 pg/g DW WHO 2005 TEQ.



**Figure 13. Sum of dioxin-like PCBs in Swedish mosses (lower limit, values below the quantification limit are not included in the sum). The southern sampling sites are presented to the left and the northern to the right.**

As for PAH16 and PCDD/PCDFs, dioxin-like PCBs are significantly correlated to both the distance to the closest industry and to the distance from the southernmost point in Sweden (Figure 14, Figure 15, Figure 16 and Figure 17). The concentrations of PAH16, PCDD/PCDFs and dioxin-like PCBs in mosses could thus be influenced by emissions from nearby industries and of long range transport.

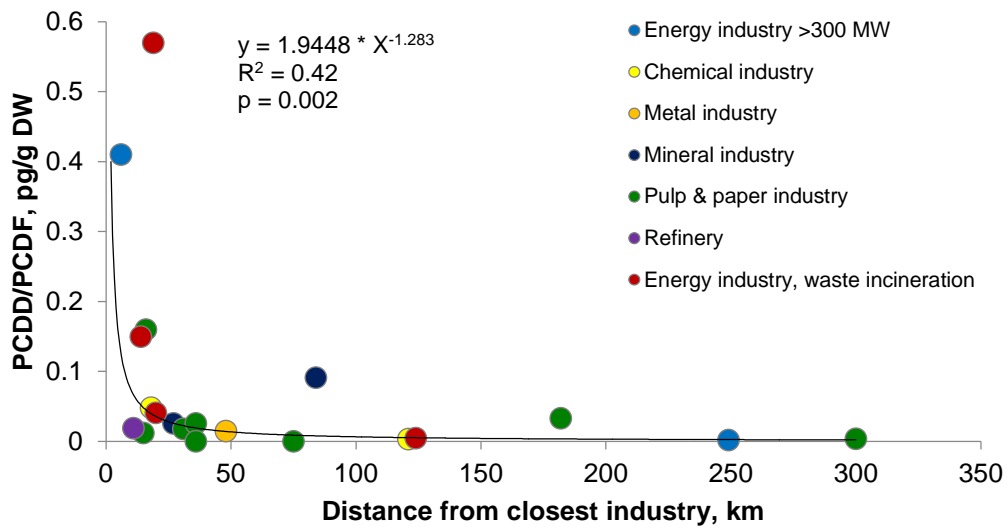


Figure 14. Correlation between sum of PCDD/PCDFs in mosses and distance to closest industrial facility.

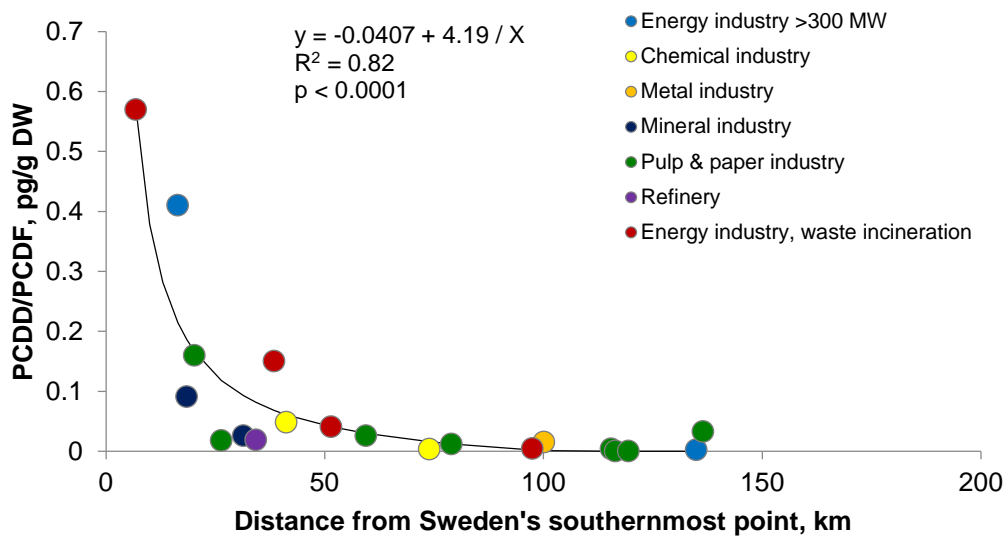


Figure 15. Correlation between sum of PCDD/PCDF in mosses and distance northwardly from Sweden's southernmost point.

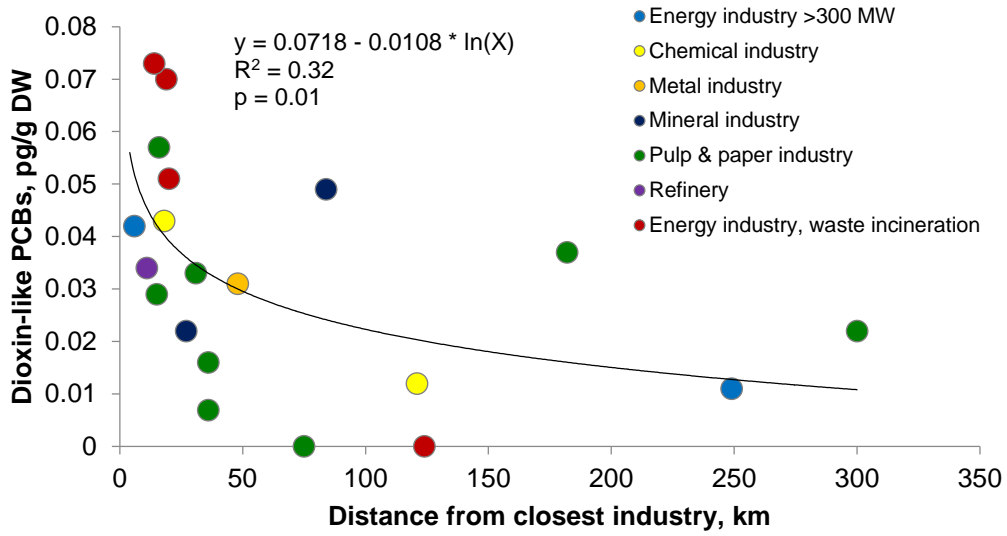


Figure 16. Correlation between sum of dioxin-like PCBs in mosses and distance to closest industrial facility.

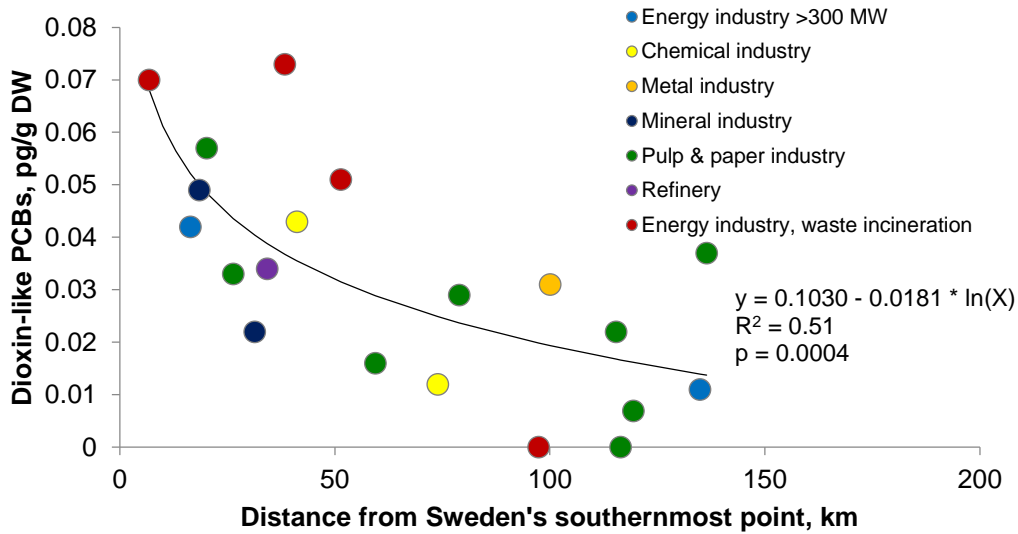


Figure 17. Correlation between sum of dioxin-like PCBs in mosses and distance northwardly from Sweden's southernmost point.

## 4.9 Perfluorinated alkylated substances (PFAS)

The concentrations of 10 perfluorinated alkylated substances<sup>1</sup> were measured in mosses. The concentrations were below the quantification limit (<0.6 ng/g dw) for every compound and moss sample.

These compounds were also not found in the Norwegian study (Steinnes and Schlabach, 2012).

## 5 Conclusions

Selected organic pollutants (PAHs, PCBs, HCB, HCHs, chlordanes, DDTs, PBDEs, HBCD, PCDD/PCDFs and dioxin-like PCBs and PFAS) were analysed in 20 moss samples evenly distributed over Sweden.

For many of the substances a geographic pattern with highest concentrations in the south was found.

Significant correlation was found between the concentrations of PAHs, dioxin/furans and dioxin like PCBs in the mosses and the distance to the closest industry, and also to the distance from the southernmost point in Sweden. p,p-DDE concentrations in mosses showed a correlation to the distance from the southernmost point in Sweden, with the highest concentrations in the south. No correlation was found between the concentrations of p,p-DDE (one of the DDTs) in mosses and distance to the closest industry.

The concentrations of PAHs in mosses collected at sites located in the vicinity of three air monitoring stations (Råö, Aspvreten and Pallas) were in agreement with the concentrations of PAHs in air, with the highest concentrations in mosses and in air found in the south and the lowest in the north. Comparison between the PAH profile in air and in mosses showed a higher percentage of heavier PAHs in the mosses. This indicates a larger proportion of particular bounded PAHs in mosses.

Generally, the concentrations of PCBs, pesticides, PBDEs, HBCD and PFAS were very low, close to or below the quantification limits for the analyses. HBCD and PFAS were not detected in any of the samples in the study, which is in agreement with a similar study in Norway (Steinnes and Schlabach, 2012).

The amount of moss material for the analysis is important for the quantification limits. In this study the moss material were used for a large number of analysis. For eventually coming analysis, some of the pollutant groups could be prioritized in order to increase the moss sample size and thereby possibly lower the quantification limits.

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<sup>1</sup> perfluorohexanoic acid, perfluoroheptanoic acid, perfluorooctanoic acid, perfluorononanoic acid, perfluorodecanoic acid, perfluoroundecanoic acid, perfluorobutane sulfonate, perfluorohexane sulfonate, perfluorooctanoic acid and perfluorooctane sulfonamide



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## Appendix 1 Extended methodology-dioxin and furans

When a congener can't be detected, the limit of detection (LOD) is calculated. It corresponds to a signal from the analyzer which is three times higher than the noise level and is assigned a less than value. LOD depends on a number of factors and therefore vary somewhat from sample to sample, between different congeners and from one analysis to another. The measurement uncertainly given in the analysis report is valid at the limit of quantification (LOQ), defined as signals exceeding ten times the noise level, and above. In the analysis report, the value for congeners where this criterion is not met is given in italics. In the interval between three and ten times the noise level measurement uncertainty is elevated but the values still provide valuable contributions to the results and the TEQ calculations.

### Calculation of the TCDD equivalents (TEQ)

Based on the individual concentrations of the congeners, the TCDD equivalents (TEQ) were calculated. TCDD equivalents relate the dioxin like toxicity of the congeners to the most toxic one, 2,3,7,8-TeCDD, by giving them different weight using toxic equivalency factors (TEF's):

$$\text{TEQ} = \text{concentration} \times \text{TEF}$$

A number of different TEF scales have been used over the years. Today, the WHO-TEF scale, last updated 2005, is the established one but the results can be converted according to the tables as desired (Table 1).

In many cases not all congeners can be detected and TCDD equivalents are normally calculated at three levels. A lower concentration limit (lower bound) where LOD is replaced with zero for all non-detected congeners, a mean concentration (medium bound) where LOD is replaced with  $\frac{1}{2}$  LOD and an upper concentration limit (upper bound) where LOD is directly used in the calculation of TEQ. In cases where all congeners are detected the TEQ values from the three calculations coincide.

In the analysis report column called "WHO-TEQ", the percentage contribution to the total TEQ was calculated using the upper bound.

Table 1. Factors for calculating toxic equivalents (TEQ).

Congener:	PCDD/ PCDF	Weight factor (TEF):				
		WHO 2005	WHO 1998	International	Nordic	Eadon
2,3,7,8	-TeCDD	1	1	1	1	1
1,2,3,7,8	-PeCDD	1	1	0.5	0.5	1
1,2,3,4,7,8	-HxCDD	0.1	0.1	0.1	0.1	0.033
1,2,3,6,7,8	-HxCDD	0.1	0.1	0.1	0.1	0.033
1,2,3,7,8,9	-HxCDD	0.1	0.1	0.1	0.1	0.033
1,2,3,4,6,7,8	-HpCDD	0.01	0.01	0.01	0.01	
	OCDD	0.0003	0.0001	0.001	0.001	
2,3,7,8	-TeCDF	0.1	0.1	0.1	0.1	0.33
1,2,3,7,8	-PeCDF	0.03	0.05	0.05	0.01	0.33
2,3,4,7,8	-PeCDF	0.3	0.5	0.5	0.5	0.33
1,2,3,4,7,8	-HxCDF	0.1	0.1	0.1	0.1	0.01
1,2,3,6,7,8	-HxCDF	0.1	0.1	0.1	0.1	0.01
1,2,3,7,8,9	-HxCDF	0.1	0.1	0.1	0.1	0.01
2,3,4,6,7,8	-HxCDF	0.1	0.1	0.1	0.1	0.01
1,2,3,4,6,7,8	-HpCDF	0.01	0.01	0.01	0.01	
1,2,3,4,7,8,9	-HpCDF	0.01	0.01	0.01	0.01	
	OCDF	0.0003	0.0001	0.001	0.001	

## Appendix 2 Results

Table 1. Sampling sites, sampling date and dry weight (DW)

Sample ID	LAB ID	Specie	County	Municipality	Sampling date	DW %
1	6484-2	<i>Pleurozium schreberi</i>	Skåne	Höör	2015-07-08	39 %
2	6484-4	<i>Pleurozium schreberi</i>	Kronoberg	Växjö	2015-07-17	76 %
3	6484-16	<i>Pleurozium schreberi</i>	Gotland	Gotland	2015-07-30	72 %
4	6484-1	<i>Hylocomium splendens</i>	Halland	Varberg	2015-07-07	83 %
5	6484-8	<i>Pleurozium schreberi</i>	Östergötland	Ydre	2015-06-30	90 %
6	6484-17	<i>Pleurozium schreberi</i>	Västra Götaland	Tidaholm	2015-07-06	24 %
7	6484-10	<i>Pleurozium schreberi</i>	Västra Götaland	Uddevalla	2015-07-06	34 %
8	6484-15	<i>Pleurozium schreberi</i>	Södermanland	Nyköping	2015-07-26	28 %
9	6484-18	<i>Pleurozium schreberi</i>	Örebro	Hallsberg	2015-06-22	17 %
10	6484-14	<i>Pleurozium schreberi</i>	Uppsala	Uppsala	2015-07-24	27 %
11	6484-19	<i>Pleurozium schreberi</i>	Dalarnas	Leksand	2015-06-17	22 %
12	6484-3	<i>Pleurozium schreberi</i>	Jämtlands	Härjedalen	2015-08-03	23 %
13	6484-12	<i>Pleurozium schreberi</i>	Västernorrland	Sundsvall	2015-06-17	69 %
14	6484-6	<i>Pleurozium schreberi</i>	Jämtland	Strömsund	2015-06-16	98 %
15	6484-13	<i>Pleurozium schreberi</i>	Västerbotten	Robertsfors	2015-06-15	73 %
16	6484-5	<i>Hylocomium splendens</i>	Västerbotten	Storuman	2015-08-12	15 %
17	6484-20	<i>Pleurozium schreberi</i>	Norrbotten	Älvsbyn	2015-08-22	68 %
18	6484-9	<i>Pleurozium schreberi</i>	Norrbotten	Haparanda	2015-08-15	81 %
19	6484-7	<i>Hylocomium splendens</i>	Norrbotten	Gällivare	2015-08-13	68 %
20	6484-11	<i>Pleurozium schreberi</i>	Norrbotten	Pajala	2015-08-14	28 %

Table 2. Polycyclic aromatic hydrocarbons (PAHs) in ng/g DW.

Sample ID	Naphthalene	Acenaphthene	Acenaphthylene	Fluorene	Phenanthrene	Anthracene	Fluoranthene	Pyrene	Benz(a)anthracene	Chrysene	Benzo (b)fluoranthene	Benzo(k)fluorantene	Benzo(a) pyrene	Dibenz(a,h)anthracene	Benzo(ghi)perylene	Indeno(1,2,3-cd)pyrene
1	2.8	<0.85	<6.4	1.4	12	0.46	19	15	3.5	12	16	5.4	5.9	1.3	12	11
2	4.8	<0.76	<5.8	0.79	6.5	0.28	12	9.4	1.7	8.3	11	3.7	3.8	0.79	7.3	7.2
3	<2.3	<0.94	<7.0	<0.47	6.4	0.34	13	10	2.8	7.6	10	3.7	4.6	0.94	7	6.3
4	2.9	2.6	<4.5	0.68	9.1	0.46	16	14	3.8	12	15	5.2	5.6	1.3	10	10
5	4.1	2.3	<6.2	1.3	5.7	0.22	9	7.4	1.1	5.8	7.2	2.6	3	0.62	5	5.1
6	<2.5	<1.0	<7.6	1.1	7.4	0.22	10	8	1.4	7.4	9.7	3	2.8	0.59	6.1	6.2
7	3.8	1.6	<7.8	0.66	6.7	0.23	13	13	3.1	9.1	11	3.6	3.3	0.73	6.7	6.9
8	10	<0.85	<6.4	2.9	15	0.8	21	19	2.9	11	13	4.5	5.4	1.2	8.3	7.6
9	<4.2	<1.7	<13	2.4	13	0.44	22	17	3.2	11	14	4.7	5.2	1.1	10	9.4
10	5.9	1.7	<6.7	4.9	10	0.33	8.4	6.2	0.7	5.3	6.1	1.9	2	0.34	3.5	3.7
11	<2.6	<1.0	<7.8	2.1	6.2	0.26	10	11	1.8	7.1	9.8	3.1	3.2	0.6	6.7	6.3
12	<3.1	<1.2	<9.2	<0.61	3.8	0.14	4.3	3.1	0.54	2.4	3.2	1.1	1.2	<0.31	2.3	2.3
13	3.8	<0.74	<5.6	1.3	13	0.32	17	11	2	7.7	8.8	2.8	3.4	0.7	6.5	5.5
14	2.2	1.9	<5.1	3.4	11	0.23	4.9	3.1	0.75	2.4	1.6	0.48	0.49	<0.17	1	1
15	3.2	<0.78	<5.9	1.4	8.1	0.24	15	12	2.1	8.2	10	3.5	3.5	0.7	6.5	6.8
16	7.4	<1.2	<8.9	1.9	8	0.29	4.2	8.9	0.85	2.8	2.4	0.65	0.52	<0.30	0.83	<1.2
17	<1.7	<0.70	<5.2	<0.35	2.2	0.049	2.3	3.2	<0.21	1.4	1.8	0.66	0.81	<0.17	1.4	1.3
18	2.7	2.0	<4.5	0.54	5.6	0.28	5.6	6.1	1.6	4.5	5.3	1.9	2.1	0.45	3.8	3.7
19	3.2	<0.73	<5.4	0.62	1.7	0.065	1.9	3.6	1	1.1	1.3	0.41	0.43	<0.18	0.76	1
20	3.2	<1.1	<8.3	<0.55	2.6	0.14	3.9	3.4	0.64	2.1	2.4	0.83	0.86	0.6	<0.55	1.6

Table 3. Polychlorinated biphenyls (PCBs), hexachlorobenzene (HCB), hexachlorocyclohexanes (HCHs), chlordanes and dichlorodiphenyltrichloroethanes (DDTs) in ng/g DW.

Sample ID	PCB 28	PCB 52	PCB 101	PCB 118	PCB 153	PCB 138	PCB180	HCB	a-HCH	b-HCH	g-HCH	a-chlordane	g-chlordane	trans-nonachlor	p,p-DDD	p,p-DDT	p,p-DDE
1	<0.17	<0.21	0.40	<0.13	0.18	<0.13	<0.13	0.35	<0.043	<0.085	<0.043	<0.043	<0.043	<0.043	<0.085	0.26	0.45
2	<0.16	<0.19	0.22	<0.12	0.21	<0.12	<0.12	0.26	<0.039	<0.078	<0.039	<0.039	<0.039	<0.039	<0.078	<0.078	0.21
3	<0.19	<0.23	0.31	<0.14	<0.14	<0.14	<0.14	0.19	<0.047	<0.094	<0.047	<0.047	<0.047	<0.047	<0.094	0.21	0.22
4	<0.12	<0.15	0.17	<0.090	0.12	<0.090	<0.090	0.20	0.026	<0.060	<0.030	<0.030	0.071	<0.030	<0.060	0.11	0.24
5	<0.16	<0.21	0.18	<0.12	0.14	<0.12	<0.12	0.20	<0.041	<0.082	<0.041	<0.041	<0.041	<0.041	<0.082	0.11	0.13
6	<0.20	<0.25	0.39	<0.15	<0.15	<0.15	<0.15	0.42	<0.050	<0.10	<0.050	<0.050	<0.050	<0.050	<0.10	0.18	0.16
7	<0.21	<0.26	0.40	<0.16	0.24	<0.16	<0.16	0.35	<0.052	<0.10	<0.052	<0.052	<0.052	<0.052	<0.10	<0.10	0.19
8	<0.17	<0.21	0.30	<0.13	0.15	<0.13	<0.13	0.26	0.062	<0.085	<0.043	<0.043	<0.043	<0.043	<0.085	0.21	0.18
9	<0.34	<0.42	0.39	<0.25	<0.25	<0.25	<0.25	0.35	<0.084	<0.17	<0.084	<0.084	<0.084	<0.084	<0.17	0.25	<0.17
10	<0.18	<0.22	0.34	<0.13	<0.13	<0.13	<0.13	0.22	<0.045	<0.089	<0.045	<0.045	<0.045	<0.045	<0.089	0.19	0.16
11	<0.21	<0.26	0.32	<0.16	<0.16	<0.16	<0.16	0.39	0.071	<0.10	<0.052	<0.052	<0.052	<0.052	<0.10	<0.10	0.14
12	<0.25	<0.31	0.50	<0.18	0.34	<0.18	<0.18	0.50	<0.061	<0.12	<0.061	<0.061	<0.061	<0.061	<0.12	<0.12	0.26
13	<0.15	<0.19	0.30	<0.11	0.19	<0.11	<0.11	0.32	<0.037	<0.074	<0.037	<0.037	<0.037	<0.037	<0.074	<0.074	0.094
14	<0.14	<0.17	0.21	<0.10	0.17	<0.10	<0.10	0.25	<0.034	<0.068	<0.034	<0.034	<0.034	<0.034	<0.068	<0.068	0.12
15	<0.16	<0.20	0.39	<0.12	0.23	0.15	<0.12	0.35	<0.039	<0.078	<0.039	<0.039	<0.039	<0.039	<0.078	<0.078	0.14
16	<0.24	<0.30	0.28	<0.18	0.49	<0.18	<0.18	0.44	<0.060	<0.12	<0.060	<0.060	<0.060	<0.060	<0.12	<0.12	0.18
17	<0.14	<0.17	0.19	<0.10	<0.10	<0.10	<0.10	0.18	<0.035	<0.070	<0.035	<0.035	<0.035	<0.035	<0.070	<0.070	<0.07
18	<0.12	<0.15	0.32	<0.09	0.17	<0.09	<0.09	0.23	<0.030	<0.060	<0.030	<0.030	<0.030	<0.030	<0.060	<0.060	0.10
19	<0.15	<0.18	0.24	<0.11	0.11	<0.11	<0.11	0.28	<0.030	<0.060	<0.030	<0.030	<0.030	<0.030	<0.060	<0.060	0.079
20	<0.22	<0.28	0.60	<0.17	0.23	<0.17	<0.17	0.35	<0.055	<0.11	<0.055	<0.055	<0.055	<0.055	<0.11	<0.11	0.22

Table 4. Polybrominated diphenyl ethers (PBDEs) and hexabromocyclododecane (HBCD) in ng/g DW.

Sample ID	DDE	BDE-28	BDE-47	BDE 85	BDE-100	BDE-99	BDE-153	BDE-154	BDE-209	HBCD
1	0.55	<0.11	0.24	<0.11	<0.085	0.2	<0.11	<0.11	<0.02	<1
2	0.23	<0.097	0.21	<0.097	<0.078	<0.078	<0.097	<0.097	<0.02	<1
3	0.15	<0.12	0.19	<0.12	<0.094	<0.094	<0.12	<0.12	<0.02	<1
4	0.21	<0.075	0.22	<0.075	<0.060	0.2	<0.075	<0.075	<0.02	<1
5	<0.08	<0.10	<0.082	<0.10	<0.082	<0.082	<0.10	<0.10	<0.02	<1
6	0.19	<0.13	<0.10	<0.13	<0.10	<0.10	<0.13	<0.13	<0.01	<0.5
7	0.23	<0.13	<0.10	<0.13	<0.10	<0.10	<0.13	<0.13	<0.02	<0.5
8	0.2	<0.11	0.17	<0.11	<0.085	<0.085	<0.11	<0.11	<0.01	<0.5
9	0.32	<0.21	0.5	<0.21	<0.17	<0.17	<0.21	<0.21	<0.01	<0.5
10	0.14	<0.11	0.19	<0.11	<0.089	<0.089	<0.11	<0.11	<0.02	<0.5
11	0.15	<0.13	0.23	<0.13	<0.10	<0.10	<0.13	<0.13	<0.02	<0.5
12	<0.12	<0.15	0.46	<0.15	<0.12	<0.12	<0.15	<0.15	<0.01	<0.5
13	0.11	<0.093	<0.074	<0.093	<0.074	<0.074	<0.093	<0.093	<0.02	<1
14	<0.07	<0.085	0.13	<0.085	<0.068	<0.068	<0.085	<0.085	<0.02	<1
15	0.12	<0.098	<0.078	<0.098	<0.078	<0.078	<0.098	<0.098	0.04	<1
16	<0.12	<0.15	0.31	<0.15	<0.12	<0.12	<0.15	<0.15	<0.02	<0.5
17	<0.07	<0.087	<0.070	<0.087	<0.070	<0.070	<0.087	<0.087	<0.02	<1
18	0.11	<0.074	<0.060	<0.074	<0.060	<0.060	<0.074	<0.074	<0.02	<1
19	0.092	<0.075	<0.060	<0.075	<0.060	<0.060	<0.075	<0.075	<0.02	<1
20	<0.11	<0.14	<0.11	<0.14	<0.11	<0.11	<0.14	<0.14	<0.01	<0.5

Table 5. Dioxin and furans (PCDD/PCDFs) in pg/g DW and upper and lower limit Sum WHO 2005 TEQ.

Sample ID	2378 TeCDD	12378 PeCDD	123478 HxCDD	123678 HxCDD	123789 HxCDD	1234678 HpCDD	OCDD	2378 TeCDF	12378 PeCDFa	23478 PeCDF	123478 HxCDFb	123678 HxCDF	234678 HxCDF	123789 HxCDF	1234678 HpCDF	1234789 HpCDF	OCDF	Upper limit, PCDD/PCDF	Lower limit, PCDD/PCDF
1	<0.073	<0.21	0.18	0.3	0.13	2.9	15	0.76	0.6	0.89	0.32	0.21	0.26	0.27	0.92	<0.23	2.7	0.85	0.57
2	<0.089	0.18	0.33	0.47	0.44	3.6	8.9	<0.089	<0.13	0.14	<0.15	0.18	<0.16	<0.21	0.72	0.27	1.3	0.57	0.41
3	<0.098	<0.28	<0.22	<0.2	<0.22	0.73	1.8	0.13	<0.2	<0.2	0.16	0.14	0.22	0.12	0.6	<0.31	0.45	0.6	0.091
4	<0.1	<0.28	<0.23	0.18	<0.22	2.5	9.1	<0.12	<0.21	0.24	<0.24	<0.22	0.33	<0.33	1.1	<0.31	1	0.69	0.16
5	<0.21	<0.58	<0.47	<0.42	<0.46	0.87	2.2	<0.25	<0.43	<0.43	<0.49	<0.45	<0.53	<0.68	0.84	<0.65	2.1	1.3	0.018
6	<0.096	<0.27	<0.22	<0.19	<0.21	0.85	3.5	<0.11	<0.2	<0.2	<0.23	<0.21	0.12	<0.32	0.4	<0.3	0.32	0.61	0.026
7	<0.087	<0.24	<0.2	<0.17	<0.19	1.2	4.3	<0.1	<0.18	<0.18	<0.21	<0.19	<0.22	<0.29	0.55	<0.27	0.52	0.57	0.019
8	<0.08	<0.23	<0.18	<0.16	<0.18	0.98	2.7	0.13	<0.17	0.2	0.14	0.16	0.19	0.096	0.73	<0.25	0.74	0.51	0.15
9	<0.2	<0.55	<0.45	<0.39	<0.43	1.1	4	<0.23	<0.4	<0.41	<0.46	<0.42	0.26	<0.64	1	<0.61	1.4	1.2	0.048
10	<0.075	<0.21	<0.17	<0.15	<0.17	0.42	1.6	<0.089	<0.16	<0.16	0.084	0.085	0.073	0.084	0.37	<0.24	0.31	0.44	0.041
11	<0.11	<0.3	<0.24	<0.21	<0.23	0.67	1.9	<0.13	<0.22	<0.22	<0.25	<0.23	0.15	<0.35	0.38	<0.33	0.32	0.67	0.026
12	<0.067	<0.19	<0.15	<0.13	<0.15	0.19	0.52	<0.079	<0.14	<0.14	<0.16	<0.15	<0.17	<0.22	0.15	<0.21	<0.14	0.43	0.004
13	<0.14	<0.39	<0.32	<0.28	<0.31	0.63	1.5	<0.16	<0.29	<0.29	<0.33	<0.3	<0.36	<0.46	0.5	<0.43	0.33	0.89	0.012
14	<0.15	<0.42	<0.34	<0.3	<0.33	0.27	0.46	<0.18	<0.31	<0.31	<0.36	<0.33	<0.38	<0.49	0.19	<0.47	<0.31	0.95	0.005
15	<0.15	<0.43	<0.35	<0.3	<0.33	0.74	2.1	<0.18	<0.31	<0.32	<0.36	<0.33	<0.39	<0.5	0.71	<0.48	0.54	0.98	0.015
16	<0.07	<0.2	<0.16	<0.14	<0.16	0.17	0.56	<0.083	<0.15	<0.15	<0.17	<0.15	<0.18	<0.23	0.2	<0.22	0.24	0.45	0.004
17	<0.099	<0.28	<0.23	<0.2	<0.22	<0.14	0.69	<0.12	<0.21	<0.21	<0.24	<0.22	<0.26	<0.33	<0.2	<0.31	<0.2	0.63	0.0002
18	<0.099	<0.28	<0.23	<0.2	<0.22	0.19	0.57	<0.12	<0.21	<0.21	<0.24	<0.22	<0.25	<0.33	<0.2	<0.31	<0.2	0.63	0.002
19	<0.06	<0.17	<0.14	<0.12	<0.13	<0.088	0.26	<0.071	<0.12	<0.13	<0.14	<0.13	<0.15	<0.2	<0.12	<0.19	0.17	0.38	0.0001
20	<0.097	<0.27	<0.22	<0.19	<0.21	0.51	1.6	<0.11	<0.2	<0.2	<0.23	<0.21	0.098	0.11	0.61	<0.3	0.48	0.59	0.033



Table 6. Dioxin-like PCBs in pg/g DW and upper and lower limit Sum WHO 2005 TEQ .

Sample ID	#77 TeCB	#81 TeCB	#126 PeCB	#169 HxCB	#105 PeCB	#114 PeCB	#118 PeCB	#123 PeCB	#156 HxCB	#157 HxCB	#167 HxCB	#189 HpCB	Upper limit, WHO PCB	Lower limit, WHO PCB
1	2.1	0.11	0.66	0.14	8.3	<0.025	17	<0.025	5.6	1.2	2.6	<0.025	<b>0.07</b>	<b>0.07</b>
2	2.9	0.19	0.42	<0.15	5.4	<0.022	7.6	1.1	2.4	<0.022	1.4	<0.022	<b>0.046</b>	<b>0.042</b>
3	1.1	<0.058	0.45	0.13	5	<0.034	11	<0.034	3.3	0.71	1.6	<0.034	<b>0.049</b>	<b>0.049</b>
4	1.4	0.066	0.57	<0.075	6.2	0.3	15	0.72	4.9	0.91	2.2	0.99	<b>0.059</b>	<b>0.057</b>
5	0.96	<0.12	0.32	<0.12	3.7	<0.072	8.4	<0.072	2.3	0.48	<0.072	<0.072	<b>0.036</b>	<b>0.033</b>
6	0.77	<0.057	0.22	<0.072	2.4	<0.033	5.1	<0.033	1.5	0.44	0.44	<0.033	<b>0.025</b>	<b>0.022</b>
7	1.1	<0.052	0.34	<0.081	9.5	<0.03	31	<0.03	6	0.98	2	<0.03	<b>0.036</b>	<b>0.034</b>
8	1.9	0.11	0.69	0.14	6.5	<0.028	16	<0.028	5.1	<0.028	3.1	<0.028	<b>0.073</b>	<b>0.073</b>
9	1.6	<0.12	0.43	<0.12	7.2	<0.067	18	<0.067	4.8	1.1	2.6	<0.067	<b>0.046</b>	<b>0.043</b>
10	1.1	<0.045	0.48	0.095	5.1	<0.026	12	<0.026	3.3	<0.026	1.9	<0.026	<b>0.051</b>	<b>0.051</b>
11	0.67	<0.063	0.16	<0.063	2.5	<0.037	8.1	<0.037	1.5	<0.037	<0.037	<0.037	<b>0.018</b>	<b>0.016</b>
12	0.41	<0.04	0.12	<0.04	2.4	<0.023	4.7	<0.023	0.92	0.31	0.63	<0.023	<b>0.014</b>	<b>0.012</b>
13	0.46	<0.083	0.29	<0.13	3.2	<0.048	10	<0.048	2.4	0.44	1.5	<0.048	<b>0.033</b>	<b>0.029</b>
14	0.33	<0.089	<0.089	<0.089	1.7	<0.052	6.8	<0.052	1.3	<0.052	0.91	<0.052	<b>0.012</b>	<b>0.00003</b>
15	1.3	<0.091	0.31	<0.091	6.4	<0.052	14	<0.052	3.2	0.73	1.2	<0.052	<b>0.034</b>	<b>0.031</b>
16	0.77	<0.042	0.21	0.046	<0.025	<0.025	8.9	<0.025	1.5	<0.025	<0.025	<0.025	<b>0.022</b>	<b>0.022</b>
17	0.32	<0.059	<0.059	<0.059	1.3	<0.034	4.3	<0.034	0.5	<0.034	0.33	<0.034	<b>0.008</b>	<b>0.00003</b>
18	1.4	0.067	0.37	<0.058	6.6	<0.033	18	<0.033	3.5	0.53	2.2	<0.033	<b>0.039</b>	<b>0.037</b>
19	0.4	<0.036	0.069	<0.036	1.2	<0.028	3.5	<0.028	<0.028	<0.028	0.21	<0.028	<b>0.008</b>	<b>0.007</b>
20	0.38	<0.059	0.11	<0.059	1.8	<0.034	4.3	<0.034	0.78	0.25	0.37	<0.034	<b>0.013</b>	<b>0.011</b>

Table 7. Perfluorinated alkylated substances (PFAS) in ng/g DW.

Sample ID	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnDA	PFBS	PFHxS	PFOS	PFOSA
1	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6
2	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6
3	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6
4	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6
5	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6
6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6
7	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6
8	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6
9	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6
10	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6
11	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6
12	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6
13	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6
14	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6
15	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6
16	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6
17	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6
18	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6
19	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6
20	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6



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