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Brominated Flame Retardants (BFR) in the Nordic Environment

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TemaNord 2011:528

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TemaNord 2011:528

ISBN 978-92-893-2221-8

Printed on environmentally friendly paper
This publication can be ordered on www.norden.org/order. Other Nordic publications are available at www.norden.org/publications

Printed in Denmark

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Content

Foreword

by Mr John Johannessen, Minister of the Interior, Faroe Islands

As a representative of a society thriving on the North-East Atlantic Ocean resources, I am aware that the importance of having and maintaining a clean ocean is vital. Whether it is for ocean fishing or fish rearing in pens, access to clean water and feed is imperative. The work towards a healthy ocean is prioritized within the Nordic Council of Ministers.

The Joint Nordic Screening of Environmental Contaminants investigates the presence of brominated flame retardants and other related compounds in various parts of the environment.

Brominated flame retardants have been identified as pollutants occurring in the environment. Many of them share physic-chemical properties with polychlorinated biphenyls which makes them prone to accumulation and bio concentration particularly in the long and lipid-rich marine food chains. Societies in the western part of the Nordic countries are profoundly dependent upon an uncontaminated and healthy marine ecosystem. The marine ecosystems are vital for continuous sound food production and economic growth in the area.

The decisions in 2009 of the Conference of the Parties to the Stockholm Convention and the Executive Body of the Convention on Long-range Transboundary Air Pollution of the United Nations Economic Commission for Europe, to include some of these brominated flame retardants on the list of compounds for elimination and/or restriction, are important steps in the right direction to protect the livelihood of people and wildlife depending on the oceans. This Nordic report is therefore also a contribution to the global work.

The tracing of contaminants from their source either it being an industrial site or a city, via the recipients to the wildlife, is an important and necessary task that is a prerequisite for establishing the information that may eventually lead to regulatory measures being taken.

The tracing of new contaminants is a time-consuming task that is comparable with detective work. Sometimes new and unknown paths are pursued and the results may not be immediately evident or interpretable. The results may however provide an important piece of information to the large environmental puzzle that scientists around the world are engaged in. I hope the reader will read the results of the present study in the said context.

Preface

The aim of the Nordic environmental screening is to obtain a snapshot of the occurrence of potentially hazardous substances, both in regions most likely to be polluted as well as in some very pristine environments. The focus is on less known, anthropogenic substances and their derivatives, which are either used in high volumes or are likely to be persistent and hazardous to humans and other organisms. In this study the occurrence of "new" brominated flame retardants (BFRs) in environmental samples from the Nordic countries has been investigated. This was done to gain experience in environmental screening of this kind of substances and provide a better knowledge of the "new" BFRs in the environment. If the substances subjected for screening are found in significant amounts this may result in further investigations or monitoring on national level and measures to reduce contamination.

The Nordic screening project is run by a project group with representatives from the National Environmental Research Institute, Aarhus University, Denmark, the Finnish Environment Institute, the Icelandic Food and Biotech R&D, the Environment Agency of the Faroe Islands, the Climate and Pollution agency in Norway and the Swedish Environmental Protection Agency.

The project is financed and supported by the Nordic Council of Ministers through the Nordic Chemicals Group and the Aquatic Ecosystems Group as well as the participating institutions. The chemical analyses have been carried out jointly by the Norwegian Institute for Air Research (NILU) and the Swedish Environmental Research Institute (IVL).

The respective participating Nordic countries organised sample selection, collection and transport of samples based on a sample protocol and manuals provided by the analytical laboratories.

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Summary

The overall aim of this screening study was to investigate the occurrence of emerging brominated flame retardants (BFRs) in environmental samples from the Nordic countries.

Due to the phase out of polybrominated diphenyl ethers (PBDEs) an increasing number of alternative flame retardant chemicals have been introduced to comply with consumer product fire safety standards. Sixteen different brominated substances were included in this screening. In addition Dechlorane Plus™, a chlorinated flame retardant also of current environmental interest, was included in the analytical program. Selected PBDE congeners were also analyzed as reference compounds to facilitate the discussion of the results and to give more relevant conclusions. Several of the substances included in the screening have only been measured occasionally, and for some there was previously no information on environmental concentrations.

The overall results of this screening showed that, emerging brominated flame retardants, and dechlorane plus, were regularly found in all the sample matrices indicating a widespread distribution in the Nordic environment. However, there were geographic differences and differences in occurrence among substances and groups of substances.

Some flame retardants (FRs) were frequently found in air. The air concentrations varied for the different substances and among the different sampling sites. The presence of FRs in background air indicates that long range transport in the atmosphere of these substances may take place. The air concentrations were generally higher in urban areas compared to background areas and increased concentrations of some BFRs were measured in indoor air.

Some of the emerging FRs were like the reference substances (PBDEs) widespread in fish, mussels and guillemot eggs in the Nordic region and several of the FRs was present in all biota samples. The highest concentrations were found in fish liver samples collected in affected areas.

The detection frequency of FRs in sediments was high. Most of the sediment samples were, however, collected in urban areas where emissions from wastewater treatment plants (WWTP) and other diffuse sources may affect the concentrations. Increased concentrations of FRs were also found in sediment taken in harbours and marinas.

The FRs were present in sludge from WWTPs, storm water sludge, and sludge from landfills. The frequent occurrence in the different sludge samples indicates a widespread use of these substances in the Nordic countries.

To sum up, this screening has identified a widespread occurrence of some emerging BFRs in the Nordic environment. The measurements have been carried out in several media at several sites but with only a few samples from each site which gives a “snap shot” of the situation. Therefore, follow up studies for identification of emission sources and important pathways as well as investigations of the ecotoxicology and human effects are recommended.

1. Frame of the study

The occurrence and the environmental risk of chemicals are prioritized issues in several international legislative acts (*e.g.* the EUs Water framework directive, Registration Evaluation Authorisation of Chemicals (REACH), Stockholm Convention on Persistent Organic Pollutants (POPs) and the Convention on long-range trans-boundary air pollution – LRTAP) and there is a focus on emerging" chemicals in different research and monitoring programs.

The Climate and Pollution Agency (KLIF) has recently published a report on the current state of knowledge on emerging brominated flame retardants and the requirement for monitoring these compounds. The report identifies in total 14 brominated flame retardants as relevant for environmental screening (Harju *et al.* 2008). None of the selected compounds are part of regular environmental monitoring. Most of the compounds are only measured occasionally, and for some there is no information on environmental concentrations at all.

The overall aim of this screening study was to investigate the occurrence of emerging brominated flame retardants (BFR) in environmental samples from the Nordic countries.

The most relevant polybrominated diphenylether (PBDE) congeners were included as reference compounds to facilitate the discussion of the results and to give more relevant conclusions. Dechlorane Plus™, a chlorinated flame retardant also of current environmental interest, was included in the analytical program. The main reason for its concern is its similarity to other known chloro organic chemicals with adverse effects to the environment.

In this screening study the concentrations of the chemicals were determined in a variety of media, collected at different locations and representing different source characteristics, *e.g.* point sources and dispersed use related to many activities and products. Background samples were also taken. An additional aim was to highlight important transport pathways and to identify current emissions. The results of this screening project may be used to estimate the environmental risk posed by these chemicals to vulnerable Nordic ecosystems.

However, there are limitations and uncertainties in screening studies, *e.g.* measurements of a chemical are carried out in several media at several sites but only a few samples at each site which gives only a "snap shot" of the situation.

The substances included in the screening study are listed in Table 1. They are divided in three groups due to their functional group; Phenolic BFRs, BFR esters and ethers and Other BFRs. Abbreviations and CAS number are given for each compound.

Table 1. Name, abbreviation and CAS-number for the flame retardants included in this study.

Compound name	Abbreviation	CAS #
Phenolic BFRs		
2,4-Dibromophenol	24DBP	615-58-7
2,4,6-Tribromophenol	246TBP	118-79-6
Pentabromophenol	PBP	608-71-9
Tetrabromobisphenol-A	TBBPA	79-94-7
BFR ethers and esters		
2,4,6-Tribromophenyl allyl ether	ATE	3278-89-5
2,3-Dibromopropyl- 2,4,6- tribromophenyl ether	DPTE	35109-60-5
1,2-Bis (2,4,6-tribromophenoxy) ethane	BTBPE	37853-59-1
2-Bromoallyl-2,4,6-tribromophenyl ether	BATE	-
2,4,6-Tribromoanisol	TBA	607-99-8
Bis (2-ethylhexyl) tetrabromophthalate	BEHTBP	26040-51-7
2-Ethylhexyl- 2,3,4,5-tetrabromobenzoate	EHTeBB	183658-27-7
Other flame retardants		
Dechlorane Plus	DP	13560-89-9
Hexabromobenzene	HBB	87-82-1
Pentabromotoluene	PBT	87-83-2
Pentabromoethylbenzene	PBEB	85-22-3
Decabromodiphenylethane	DBDPE	84852-53-9
1,2-Dibromo-4-(1,2-dibromoethyl)cyclohexane	TBECH	3322-93-8
Reference compounds		
2,4,4’-Tribromobiphenyl ether	BDE-28	41318-75-6
2,2’,4,4’-Tetrabromodiphenyl ether	BDE-47	5436-43-1
2’,3,4,6’-Tetrabromodiphenyl ether/ 2,2’,4,5’-Tetrabromodiphenyl ether	BDE-71/49	189084-62-6/243982-82-3
2,3,4,4’-Tetrabromodiphenyl ether	BDE-66	189084-61-5
3,3’,4,4’-Tetrabromodiphenyl ether	BDE-77	40088-47-9
2,2’,4,4’,5-Pentabromodiphenyl ether	BDE-99	60348-60-6
2,2’,4,4’,6-Pentabromodiphenyl ether	BDE-100	189084-66-0
2,2’,3,4,4’-Pentabromodiphenyl ether	BDE-85	182346-21-0
2,3’,4,4’,6-Pentabromodiphenyl ether	BDE-119	189084-66-0
2,2’,4,4’,5,5’-Hexabromobiphenyl ether	BDB 153	68631-49-2
2,2’,3,4,4’,5’-Hexabromodiphenyl ether	BDE-138	182677-30-1
2,2’,4,4’,5,6’-Hexabromodiphenyl ether	BDE-154	207122-15-4
2,2’,3,4,4’,5’,6-Heptabromodiphenyl ether	BDE-183	207122-16-5
2,2’,3,3’,4,4’,5,6’-Octabromodiphenyl ether	BDE-196	446255-38-5
2,2’,3,3’,4,4’,5,5’,6-Nonabromodiphenyl ether	BDE-206	63387-28-0
2,2’,3,3’,4,4’,5,5’,6,6’-Decabromodiphenyl ether	BDE-209	1163-19-5

The BDEs are named according to Ballschmiter et al. 1980.

2. Background

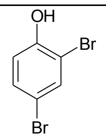
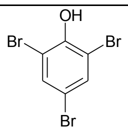
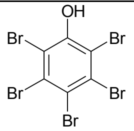
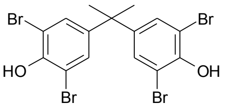
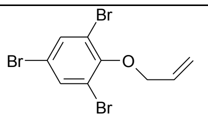
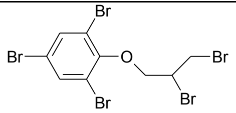
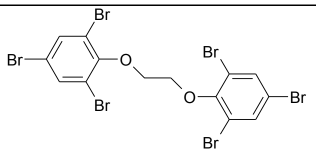
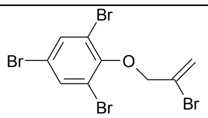
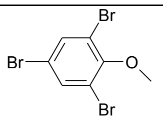
Brominated flame retardants (BFRs) are used to reduce the flammability of polymeric materials and have been utilized in commercial materials for several decades. BFRs can be either additive or reactive. Additive flame retardants are incorporated into the polymer prior to, during or more frequently after polymerization. They are used especially in thermoplastics. Additive BFRs are monomer molecules that are not chemically bound to the polymer, so that over time they may migrate out of the product into the environment. In contrast, reactive flame retardants are added during the polymerization process and are chemically bound to material in the product. The bound chemicals are not released from products, but residual, unreacted flame retardants present in the product can be released. Reactive flame retardants are mainly used in thermosets, especially polyester, epoxy resins and polyurethanes.

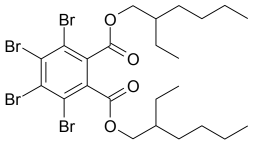
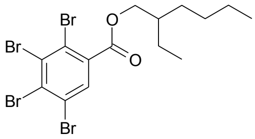
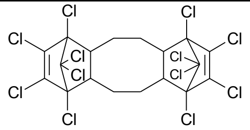
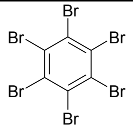
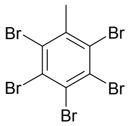
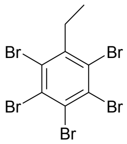
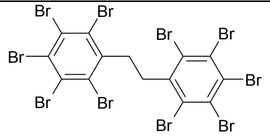
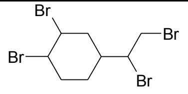
Historically, polybrominated diphenyl ethers (PBDEs) have been used in high volumes to reduce the flammability of numerous types of resins commonly found in furniture and electronic components. Over the last decade there has been a large focus on the prevalence and fate of the PBDEs and they are the most extensively studied class of additive BFRs in the environment. Two of the three commercial PBDE mixtures, PentaBDE and OctaBDE, have been banned from use in some parts of the world (*e.g.* within the EU) due to their ubiquitous environmental presence and potential toxicities associated with certain individual PBDE congeners (*e.g.* BDE 47 and BDE 99) (Gauthier *et al.* 2009). The third and last commercial mixture, DecaBDE continues to be used. However, many countries are currently considering bans or phase-outs of DecaBDE .

Due to the phase out of PentaBDE and OctaBDE, it is expected that an increasing number of alternative flame retardant chemicals will be introduced to comply with consumer product fire safety standards. Examples of potential replacement include tetrabromobisphenol-A (TBBPA), hexabromocyclododecane (HBCD), bis (2, 4, 6-tribromophenoxy) ethane (BTBPE) and decabromdiphenylethane (DBDPE). Given that these alternate flame retardants share properties similar to those of the PBDE mixtures (*e.g.* aromatic moieties, high bromination, and low aqueous solubility) and that most are used as additive flame retardants, as opposed by reactive, an environmental fate similar to the PBDEs may be expected. For example BTBPE and DBDPE have been detected in the environments of Sweden and the U.S. (Kirkegaard *et al.* 2004; Hoh *et al.* 2005; Stapleton *et al.* 2008; Venier *et al.* 2008) showing that these emerging flame retardants are leaching out into the environment. However, little is known about their potential for bioaccumulation and toxicity.

In Table 2.1 the BFRs selected for this study are presented (structure, type of BFR and log Kow). In the report by Harju *et al.* (2008) most of these BFRs have been reviewed thoroughly. The report contains information about toxicity, exposure, distribution etc.

Table 2.1 Substances selected for the study (structure, type of BFR, log Kow). If no reference is given, the information is gathered from ChemIDPlus Lite. [a] Harju et al. 2008, [b] Tomy et al. 2008.

Compound name **CAS #** **Abbreviation**	**Structure**	**Type of BFR**	**Log Kow**
Phenolic BFRs			
2,4-Dibromophenol 615-58-7 24DBP			3.22
2,4,6- tribromophenol 118-79-6 246TBP		Reactive	4.13
Pentabromophenol 608-71-9 PBP			5.96
Tetrabromobisphenol A 79-94-7 TBBPA		Additive/ Reactive	7.20
BFR ethers and esters			
2,4,6-Tribromophenyl allyl ether 3278-89-5 ATE		Reactive	4.98a
2,3-Dibromopropyl-2,4,6- tribromophenyl ether 35109-60-5 DPTE			
1,2-Bis(2,4,6-tribromo-phenoxy) ethane 37853-59-1 BTBPE		Additive	9.15
2-Bromoallyl-2,4,6-tri-bromophenyl ether BATE			
2,4,6-Tribromoanisol 607-99-8 TBA		Not a BFR. Natural product	4.48

Compound name **CAS #** **Abbreviation**	**Structure**	**Type of BFR**	**Log Kow**
Bis(2-ethylhexyl) - tetrabromophthalate 26040-51-7 BEHTBP		Additive	10.08
2-Ethylhexyl-2,3,4,5-tetrabromobenzoate 183658-27-7 EHTeBB			
Other BFRs			
Dechlorane Plus 13560-89-9 DP			11.27
Hexabromobenzene 87-82-1 HBB			6.07
Pentabromotoluene 87-83-2 PBT			6.99
Pentabromoethylbenzene 85-22-3 PBEB		Additive	7.48
Decabromodiphenylethane 84852-53-9 DBDPE		Additive	
1,2-Dibromo-4-(1,2-dibromoethyl)cyclohexane 3322-93-8 TBECH		Additive	5.2b

2.1 Environmental concentrations, applications and uses

Concentration levels in the environment of emerging brominated flame retardants have previously been measured in Norway by Møskeland (2010), who also reviewed the literature. The data in the Tables 2.2–2.15 below are cited from Møskeland (2010) and include the results from an earlier Norwegian screening study (Harju *et al.* 2008). Environmental concentrations from other literature are indicated by a reference. For some compounds no information has been found.

2.1.1 Phenolic BFRs

2, 4-Dibromophenol (24DBP)

24DBP is an industrial BFR (JIG, 2007) but also naturally formed in the marine environment (Vetter, 2005; Sim, 2009). Concentrations measured in fresh water from an Indian river was 540–40000 ng/l (Nomani *et al.* 1996). Fielman *et al.* (2001) reported 2 µg/kg d.w. of 24DBP in marine sediments from a background area. In a Swedish screening study 24DBP was not detected in air samples (Remberger *et al.* 2002). Concentrations in other matrices analysed in the Swedish study are summarized in the Table 2.2.

Table 2.2: Environmental concentration of 24DBP in different matrices.

Sample	Concentration	Reference
Water, brackish Sweden	<5–35 ng/l	Remberger et al. 2002
Water, fresh Indian river	540–40000 ng/l	Nomani et al. 199
Sediment, brackish, Sweden	<5–13 ng/g d.w.	Remberger et al. 2002
Sediment, marine sediment background	2 µg/g d.w.	
Soil background, Sweden	<3–15 µg/kg d.w.	Remberger et al. 2002
Sludge	<3–11 µg/kg d.w.	Remberger et al. 2002

d.w. = dry weight.

2, 4, 6-Tribromophenol (246TBP)

The flame retardant 246TBP (JIG, 2007) has been detected throughout the environment, for example in fish, sediment, water, sewage sludge and indoor air (Møskeland, 2010). The reason for 246TBP prevalence in the environment is that 246TBP is an important industrial chemical but is also naturally produced by marine organisms (Vetter, 2005; Sim, 2009). Concentrations in different matrices analysed are summarized in the Table 2.3 below.

Table 2.3: Environmental concentration of 246TBP in different matrices.

Sample	Concentration	Reference
Air	n.d.	Møskeland, 2010
Air, indoor, gas phase Hokkaido, Japan, 2009	220–690 pg/m3	Ref in Møskeland, 2010
Moss	n.d.	Møskeland, 2010
Air, outdoor, gas phase Hokkaido, Japan, 2009	49 and 73 pg/m3	Ref in Møskeland, 2010
Water	n.d.	Møskeland, 2010
Water German Bight, Germany, 2006	n.d.-6 ng/l	Ref in Møskeland, 2010
Sediment Osaka Prefectrue, Japan, 1985	<0.–35 ng/g d.w.	Ref in Møskeland, 2010
Sediment	n.d. – 3.3 ng/g d.w.	Møskeland, 2010
Sediment marine	4–30 µg/kg d.w.	Fieldman et al. 2001
Sewage sludge	n.d.	Møskeland, 2010
Cod liver	n.d. – 55.8 ng/g f.w.	Møskeland, 2010
Trout liver	n.d.	Møskeland, 2010
Blue mussel	n.d. – 1.1 ng/g f.w.	Møskeland, 2010
Workers, electronic dismantling plant Norway, 2001	0.17–81 ng/g l.w.	Ref in Møskeland, 2010

n.d = not detected; d.w. = dry weight; f.w. = fresh weight; l.w. = lipid weight.

Pentabromophenol (PBP)

No information found.

Tetrabromobisphenol A (TBBPA)

TBBPA is the most widely used brominated flame retardant worldwide. It is primarily used as a reactive flame retardant in printed circuit boards. Alternatives to TBBPA have been developed and are increasingly being used for this application. TBBPA is also used as an additive flame retardant in plastics and resins.

In a screening study of phenolic substances in the Nordic environment, TBBA was found in WWT sewage sludge but not in any of the other investigated matrices (fish liver, mussels, marine mammals, sediment and different types of water), see the Table 2.4 (Hansen *et al.* 2008).

Table 2.4: Environmental concentration of TBBPA in different matrices.

Sample	Concentration	Reference
Human adipose tissue New York, U.S., 2008	0,05–0,10 ng/g l.w.	Johnson-Restrepo et al. 2008
Bottlenose dolphin, blubber Florida, U.S., 2008	0,06–8,48 ng/g l.w.	Johnson-Restrepo et al. 2008
Bull shark Florida, U.S., 2008	0,035–36 ng/g l.w.	Johnson-Restrepo et al. 2008
Bird China, 2010	9–1482 ng/g l.w.	He et al. 2010
Fish China, 2010	0,23–1,7 ng/g l.w.	He et al. 2010
Water China, 2010	0.068 ng/l	He et al. 2010
Cod liver North Sea	<0,3–1,8 ng/g l.w.	Morris et al. 2004
Cormorant tern eggs Western Scheldt	2,5–14 ng/g l.w.	Morris et al. 2004
Harbor porpoise N. Sea-E. England blubber	0,1–418 ng/g l.w.	Morris et al. 2004
Sediment Sweden	19–491 ng/g d.w.	Asplund et al.
Sediment Sweden	< 2–25 ng/g d.w.	Remberger et al 2002
WWTP sewage sludge Sweden	< 3–180 ng/g d.w.	Asplund et al.
WWTP sewage sludge Sweden	< 1–38 ng/g d.w.	Remberger et al. 2002
Air Sweden	< 0.001–0.03 ng/m3	Remberger et al. 2002
Water Sweden	< 2–9 ng/l	Remberger et al. 2002
Herring Sweden	0.5–4.5 ng/g f.w.	Remberger et al. 2002
WWTP sewage sludge Nordic countries	< 5–1138 ng/g d.w.	Hansen et al. 2008

d.w. = dry weight; f.w. = fresh weight; l.w. = lipid weight.

2.1.2 BFR ethers and esters

2, 4, 6-Tribromophenyl allyl ether (ATE)

ATE was proposed to be one of 120 high production chemicals which are structurally similar to known arctic contaminants and/or have partitioning properties that suggests that they are potential arctic contaminants (Brown and Wania, 2008 cited in Møskeland, 2010).

Concentrations in different matrices analysed are summarized in the Table 2.5 below.

Table 2.5: Environmental concentration of ATE in different matrices.

Sample	Concentration	Reference
Air	n.d.	Møskeland, 2010
Water	n.d.	Møskeland, 2010
Sediment	n.d.	Møskeland, 2010
Sewage sludge	n.d.	Møskeland, 2010
Hooded seal, blubber and brain Barents Sea	5,4–9,1 ng/g f.w.	Von Der Recke, 2007
Harp seal, blubber and brain Barents Sea	3,1–10 ng/g f.w.	Von Der Recke, 2007
Cod liver	n.d.	Møskeland, 2010
Trout liver	n.d.	Møskeland, 2010
Blue mussel	n.d.	Møskeland, 2010
Moss	n.d.	Møskeland, 2010

n.d. = not detected.

2,3-Dibromopropyl-2,4,6-tribromophenyl ether (DPTE)

Concentrations in different matrices analysed are summarized in the Table 2.6.

Table 2.6: Environmental concentration of DPTE in different matrices.

Sample	Concentration	Reference
Air	n.d.	Møskeland, 2010
Water	n.d.	Møskeland, 2010
Sediment	n.d.	Møskeland, 2010
Sewage sludge	n.d.	Møskeland, 2010
Sewage sludge Germany	Up to 1,9 mg/ kg d.w.	Ref. in von der Recke, 2007
Snoek fillet South Atlantic	detected	Ref. in von der Recke, 2007
Harp seal, blubber and brain Barents and Greenland Seas, 2007	322–470 g/ kg f.w.	Von Der Recke, 2007
Cod liver	n.d.	Møskeland, 2010
Trout liver	n.d.	Møskeland, 2010
Blue mussel	n.d.	Møskeland, 2010
Moss	n.d.	Møskeland, 2010

d.w. = dry weight; f.w. = fresh weight;

1,2-Bis(2,4,6-tribromophenoxy)ethane (BTBPE)

BTBPE is an additive flame retardant in thermoplastics and thermosetting plastics and may be used as a replacement for octaBDE mixtures.

Concentrations in different matrices analysed are summarized in the Table 2.7 below.

Table 2.7: Environmental concentration of BTBPE in different matrices.

Sample	Concentration	Reference
Air	n.d.	Møskeland, 2010
Air Pearl River Delta, China, 2009	0,3–1,66 pg/m3	Ref in Møskeland, 2010
Air, particle phase Great Lakes, U.S, 2008	0,5–1,2 pg/m^3	Ref in Møskeland, 2010
Water Lake Winnipeg, Canada, 2006–2007	1,96 pg/l	Ref in Møskeland, 2010
Water	0,5–107,0 ng/l	Møskeland, 2010
Surface sediment Lake Ontario, U.S, 2007	6,7 ng/g d.w.	Ref in Møskeland, 2010
Sediment Pearl River Delta, China, 2009	0,3–22 ng/g d.w.	Ref in Møskeland, 2010
Sediment	n.d. – 4,5 ng/g d.w.	Møskeland, 2010
Sewage sludge	n.d. – 2,08 ng/g d.w.	Møskeland, 2010
Dust Boston, U.S.	1,6–789 ng/g d.w.	Stapleton et al. 2008
Dust, houses Birmingham, U.K., 2008	Mean 120 ng/g	Ref in Møskeland, 2010
Dust, offices Birmingham, U.K., 2008	Mean 7,2 ng/g	Ref in Møskeland, 2010
Dust, cars Birmingham, U.K., 2008	Mean 7,7 ng/g	Ref in Møskeland, 2010
Mussels Lake Winnipeg, Canada,2006–2007	Mean 1,29 ng/ g l.w.	Ref in Møskeland, 2010
Lake trout Great lakes, U.S., 1979–93	0,6–2,6 ng/g l.w.	Ref in Møskeland, 2010
Herring gull eggs Great lakes, U.S.	<0.06–0.20 ng/g f.w.	Gauthier et al. 2009
Fulmar eggs Faroe Islands, 2006	0,11 ng/g l.w.	Ref in Møskeland, 2010
Cod liver	n.d.	Møskeland, 2010
Trout liver	n.d.	Møskeland, 2010
Blue mussel	n.d.	Møskeland, 2010
Moss	n.d.	Møskeland, 2010

n.d = not detected; d.w. = dry weight; f.w. = fresh weight; l.w. = lipid weight.

2-Bromoallyl-2,4,6-tribromophenyl ether (BATE)

No information found.

2,4,6-Tribromoanisol (TBA)

TBA is not used as a flame retardant but is frequently detected in environmental samples. TBA was included as an extra compound since the compound is closely related to 246TBF.

TBA is naturally produced in sponges and is therefore frequently detected in the marine environment (Sim, 2009; Gribble, 2000). TBA as well as 2,4-dibromoanisol (not measured in this study) have also been identified in human blood but no concentration was indicated (Hovander, 2002).

It has been proven that aerobic bacteria in the environment may *O*-methylate 246TBP to the corresponding *O*-methyl ether, TBA (Allard, 1987; Neilson, 1988). The opposite reaction, the de-*O*-methylation of TBA to the phenol 246TBP may occur by bacteria in anaerobe environments such as sediments and sludge (Neilson, 1987; Remberger *et al.* 1986). De-*O*-methylation of TBA to 246TBP, also occurs in biota *e.g.* fish liver (Neilson, 1991).

Bis(2-ethylhexyl)tetrabromophtalate (BEHTBP)

BEHTBP is an additive flame retardant and one of the two brominated chemicals in Firemaster 550, the primary replacement for PentaBDE ("pentablend") in polyurethane foam. Firemaster 550 was introduced to the market in 2003. It is also used as a plasticizer for flexible polyvinylchloride and in wire and cable insulation, film and sheeting, carpet backing, coated fabrics, wall covering and adhesives.

Concentrations in different matrices analysed are summarized in the Table 2.8.

Table 2.8: Environmental concentration of BEHTBP in different matrices.

Sample	Concentration	Reference
Household dust	1,5–10600 ng/g d.w.	Stapleton et al. 2008
Biosolids (WWTP)	40–1421 ng/g d.w.	Ref in Møskeland, 2010
Dolphin blubber	0,04–5,3 ng/g l.w.	Lam et al. 2008
Porpoise blubber	0,04–3589 ng/g l.w.	Lam et al. 2008
Sediment	n.d.	Møskeland, 2010
Water	n.d.	Møskeland, 2010
Sewage sludge	n.d.	Møskeland, 2010
Cod liver	n.d.	Møskeland, 2010
Trout liver	n.d.	Møskeland, 2010
Blue mussel	n.d.	Møskeland, 2010
Moss	n.d.	Møskeland, 2010
Air	n.d.	Møskeland, 2010

n.d = not detected; d.w. = dry weight; l.w. = lipid weight.

2-Ethylhexyl- 2,3,4,5-tetrabromobenzoate (EHTeBB)

EHTeBB is the second brominated compound in Firemaster 550 besides BEHTBP.

Concentrations in different matrices analysed are summarized in the Table 2.9.

Table 2.9: Environmental concentration of EHTeBB in different matrices.

Sample	Concentration	Reference
Household dust Boston, U.S.,	1,5–15030 ng/g d.w.	Stapleton et al. 2008
Biosolids (WWTP) San Francisco, U.S.,	57–515 ng/g d.w.	Ref in Møskeland, 2010
Porpoise Hong Kong, China,	<0,04–70 ng/g l.w.	Lam et al. 2008

d.w. = dry weight; l.w. = lipid weight.

2.1.3 Other FRs

Bis(hexachlorocyclopentadieno)cyclooctane, Dechlorane Plus (DP)

DP is used as an additive flame retardant in coatings for electrical wires and cables and in computer connectors and plastic roofing materials (Betts, 2006). The content of DP in commercial polymer products range between 10–35% (Sverko, 2008). It can be assumed that DP is no longer on the Swedish (or Nordic) chemical product market, but it can still be imported in goods from other regions (Kaj, 2010).

Concentrations in different matrices analysed are summarized in the Table 2.10.

Table 2.10: Environmental concentration of DP in different matrices.

Concentration	Sample	Reference
Air 0.41 – 490, average 34, median 2.4 pg/m3, n=21	50 km from production site for DP, New York, USA	Hoh, 2006
Air 0.31 – 134, average 9.2, median 1.9 pg/m3, n=22	urban area, Chicago, USA	Hoh, 2006
Air 0.25 – 21, average 3.4, median 0.83 pg/m3, n=12	lightly populated rural area, Ontario, USA	Hoh, 2006
Air 0.04 – 0.99, average 0.16, median 0.075 pg/m3, n=18	rural area, Michigan, USA	Hoh, 2006
Air 0.016 – 0.047, average 0.032, median 0.032 pg/m3, n=2	rural area, Pallas, N Finland	Kaj, 2010
Air 0.18 – 0.52, average 0.29, median 0.24 pg/m3, n=4	rural area, Råö, Sweden	Kaj, 2010
Air 0.12 – 0.32, average 0.22, median 0.23 pg/m3, n=3	rural area, Aspvreten, Sweden	Kaj, 2010
Air 1.4 – 1.5, average 1.5, median 1.5 pg/m3, n=4	urban area, Stockholm	Kaj, 2010
Fish 0.14 – 0.91 ng/g l.w. walleye (Sander vitreus,)	Lake Erie, USA	Hoh, 2006
Fish 0.12 ng/g l.w., alewife (Alosa pseudoharengus)	Toronto Harbour, Canada	Tomy, 2007
Fish 36.1±35.3 ng/g l.w., fish muscle	rivers, 15 urban sites, South Korea	Kang, 2010
Fish 1.4±1.0 ng/g l.w., fish muscle	rivers, 7 rural sites, South Korea	Kang, 2010
Birds eggs 2 – 6 ng/g f w, herring gull (Laurus argentatus) mean values for seven colonies for the years 1982–2006, highest individual value 18 ng/g f. w.	Great Lakes, USA, Canada	Gauthier, 2009
Sediment 0.061 – 8.6 ng/g d.w.	Lake Erie, USA	Sverko, 2008
Sediment 2.2 – 586 ng/g d.w.	Lake Ontario, Canada	Sverko, 2008
Sediment 2 – 5 ng/g d.w.	Lake Michigan, USA	Hoh, 2006
Sediment 0.033 ng/g d.w., average, n=4	Lake Winnipeg, Canada	Tomy 2007
Sediment 0.21 ng/g d.w., average n=3	Lake Ontario, Canada	Tomy, 2007
Sediment 0.11±0.05 ng/g d.w., average, n=6	Songhua River, within the city of Harbin, NE China	Qi, 2010
Sediment 0.04±0.05 ng/g d.w., average, n=18	Songhua River, rural area, NE China	Qi 2010
Water <0.1 – 0.83 ng/l, n=4	Four WWTPs, effluent water, Sweden	Kaj, 2010
Sludge 6.9 – 21, average 11, median 7.4 ng/g d.w., n=4	Four WWTPs, Sweden	Kaj, 2010

d.w. = dry weight; f.w. = fresh weight; l.w. = lipid weight.

Hexabromobenzene (HBB)

HBB is one of the BFRs found in polymeric materials that can be released at room temperature. However, preliminary modelling results indicate that the substance is used as an additive itself (Gouteux *et al.* 2008).

Concentrations in different matrices analysed are summarized in the Table 2.11.

Table 2.11: Environmental concentration of HBB in different matrices.

Sample	Concentration	Reference
Air Egbert, Ontario, U.S	0,02–0,09 pg/m^3	Gouteax et al. 2008
Air	0,0013–0,0102 ng/m^3	Møskeland, 2010
Water	0,5–19,1 ng/l	Møskeland, 2010
Sediment	n.d. – 1,8 ng/g d.w.	Møskeland, 2010
Herring Gull eggs Great Lakes, U.S.	0,27–0,66 ng/g l.w.	Gauthier et al. 2009
Human serum Tianjin, China,	0,11–1,5 ng/g l.w.	Ref in Møskeland, 2010
Glaucous Gull eggs	0,1–2,6 ng/g l.w.	Sagerud et al. 20010
Sewage sludge	0,12–0,42 ng/g d.w.	Møskeland, 2010
Cod liver	n.d.	Møskeland, 2010
Trout liver	n.d.	Møskeland, 2010
Blue mussel	n.d.	Møskeland, 2010
Herring Gull eggs Great Lakes, U.S	0,24–0,53 ng/g l.w.	Ref in Møskeland, 2010
Moss	0,05–0,1 ng/g d.w.	Møskeland, 2010

n.d = not detected; d.w. = dry weight; l.w. = lipid weight.

Pentabromotoluene (PBT)

PBT can itself be released to the environment but is also an environmental transformation product of TBBPA (Arbeli *et al.* 2006, cited in Møskeland, 2010) and other BFRs, such as DBDPE (Møskeland, 2010).

Concentrations in different matrices analysed are summarized in the Table 2.12.

Table 2.12: Environmental concentration of TBT in different matrices.

Sample	Concentration	Reference
Air	n.d.	Møskeland, 2010
Water	n.d. – 7,51 ng/l	Møskeland, 2010
Sediment	n.d. – 0,3 ng/g d.w.	Ref in Møskeland, 2010
Sewage sludge	n.d.	Møskeland, 2010
Herring Gull eggs Great Lakes, U.S.	0,004–0,02 ng/g f.w.	Ref in Møskeland, 2010
Glaucous Gull eggs	< LOQ-0,12 ng/g f.w.	Sagerud et al. 2010
Glaucous Gull plasma	< LOQ-0,15 ng/g f.w.	Sagerud et al. 2010
Cod liver	n.d.	Møskeland, 2010
Trout liver	n.d.	Møskeland, 2010
Blue mussel	n.d.	Møskeland, 2010
Moss	n.d.	Møskeland, 2010

n.d = not detected; d.w. = dry weight; f.w. = fresh weight.

Pentabromoethyl benzene (PBEB)

PBEB is known to have been produced in the 1970’s and 1980’s (Møskeland, 2010). Concentrations in different matrices are summarized in Table 2.13.

Table 2.13: Environmental concentration of PBEB in different matrices.

Sample	Concentration	Reference
Air, Chicago, U.S.	4.0–9.2 pg/m^3	Hoh et al. 2005
Air, particle phase Chicago, U.S.	29 pg/m^3	Ref in Møskeland, 2010
Air Egbert, Ontario U.S.	<0.01–0.01 pg/m^3	Gouteux, et al. 2008
Air	n.d.	Ref in Møskeland, 2010
Water	n.d. – 1,3 ng/l	Ref in Møskeland, 2010
Sediment	n.d. – 0,1 ng/g d.w.	Møskeland, 2010
Sewage sludge	n.d.	Møskeland, 2010
Herring Gull eggs Great Lakes, U.S	0,03–1,4 ng/g f.w.	Ref in Møskeland, 2010
Lake trout, Lake Ontario, Canada,	17–320 ng/g l.w. time series 1979–2004, no relationship between concentration and time	Ref in Møskeland, 2010
Glaucous Gull eggs	0,03–0,23 ng/g f.w.	Sagerud et al. 2010
Cod liver	n.d.	Møskeland, 2010
Trout liver	n.d.	Møskeland, 2010
Blue mussel	n.d.	Møskeland, 2010
Moss	n.d.	Møskeland, 2010

n.d = not detected; d.w. = dry weight; f.w. = fresh weight; l.w. = lipid weight.

Decabromodiphenylethane (DBDPE)

DBDPE is an additive flame retardant that has similar applications to those of decaBDE and has been marketed as general purpose substitute for decaBDE.

Concentrations in different matrices analysed are summarized in the Table 2.14.

Table 2.14: Environmental concentration of DBDPE in different matrices.

Sample	Concentration	Reference
Air, particle phase Great lakes, U.S.	1–22 pg/m^3	Venier and Hites 2008
Air, gas and particle phase Pearl River Delta, China,	402–3578 pg/m^3	Ref in Møskeland, 2010
Water	n.d. – 185,7 ng/l	Møskeland, 2010
Sediment Pearl River Delta, China,	39–364 ng/g d.w.,	Ref in Møskeland, 2010
Sediment	n.d. – 1,8 ng/g d.w.	Møskeland, 2010
Sediment, lake Sweden	<0.01–1.6 ng/g d.w.	Ricklund et al. 2009
Sediment, marine Sweden	0.28–11 ng/g d.w.	Ricklund et al. 2009
Sewage sludge Pearl River Delta, China	266–1464 ng/g d.w.	Ref in Møskeland, 2010
Sewage sludge	n.d. – 8,7 ng/g d.w.	Møskeland, 2010
Sewage sludge	32–52 ng/g d.w.	Kierkegaard et al. 2004
Sewage sludge Sween	<–160 ng/g d.w	Ricklund et al.2008
Fish Lake Winnipeg, Canada	1,0 ± 0,5 ng/g l.w.	Ref in Møskeland, 2010
Herring gull egg Great Lakes, U.S.	1,3–288 ng/g f.w.	Gauthier et al. 2009
Giant red Panda China	n.d.-41 ng/g l.w.	Ref in Møskeland, 2010
House hold dust U.S.	< 10–11070 ng/g dust	Stapleton et al. 2009
Dust, houses Birmingham, U.K., 2008	270 ng/g	Ref in Møskeland, 2010
Dust, office Birmingham, U.K., 2008es	170 ng/g	Ref in Møskeland, 2010
Dust, cars Birmingham, U.K., 2008	400 ng/g	Ref in Møskeland, 2010
Dust, electronic recycling plants Sweden	< 0,02–0,79 ng/m^3	Ref in Møskeland, 2010
Cod liver	n.d.	Møskeland, 2010
Trout liver	n.d.	Møskeland, 2010
Blue mussel	n.d.	Møskeland, 2010
Moss	n.d.	Møskeland, 2010

n.d = not detected; d.w. = dry weight; f.w. = fresh weight; l.w. = lipid weight.

1,2-Dibromo-4-(1,2-dibromoethyl)-cyclohexane (TBECH)

TBECH is marketed as Saytex BCL-462. This material is primarily used as an additive flame retardant in expandable polystyrene beads, which are largely used to produce thermal insulation for housing. Concentrations of TBECH in these products are about 1% (Tomy *et al.* 2008). TBECH is also used in polystyrene foam, in adhesive in fabric and vinyl lamination, electric cable coatings etc.

TBECH can exist as four pairs of enantiomers. Technical TBECH has a near 1:1 relationship between the α- and β- diastereomers (Tomy *et al.* 2008). At temperatures above 120 ºC, some thermal conversion of the α- and the β- isomers can occur, resulting in formation of γ- and δ-isomers.

Concentrations in different matrices analysed are summarized in the Table 2.15.

Table 2.15: Environmental concentration of TBECH in different matrices.

Sample	Concentration	Reference
Arctic beluga blubber Canada	0,9–11,3 ng/g l.w.	Tomy et al. 2008
Herring gull egg Great Lakes	0.16–0.54 mg/g f.w.	Gauthier et al. 2009

f.w. = fresh weight; l.w. = lipid weight.

3. Methodology

3.1 Sampling sites and sample selection

One of the purposes of a screening investigation is to sample several environmental matrices with a wide geographical distribution and at locations where it's expected to find the compounds investigated.

All samples collected in this screening study are listed in Appendix 1, where also the sampling characteristics are given in detail.

Each country made their own selection of sample sites and matrices according to the strategy previously agreed upon in the steering group. Samples were chosen to represent point sources as well as diffuse sources and in some cases also background areas. When possible, samples were chosen so as to facilitate comparisons between areas/regions.

The goal was also to cover the matrices air, sediment, sludge and biota. The samples selected in the different countries are described in the following sections.

Below the different sampling sites from each country are presented and they are also shown in maps, Figures 3.1–3.3.

3.1.1 Denmark

Air

Two air samples were collected, one at a rural location (Lille Valby) and one at an urban location (Copenhagen).

Sediment

Sediment samples were collected from two marine areas, Roskilde Marina and Fornæs. The sample from Roskilde Marina was taken by diver. Roskilde Marina is situated in the inner Roskilde Fjord, close to Bjergmarken sludge treatment outlet. The sample from Fornæs was taken using HAPS bottom sampler at 10.6 meters depth outside Fornæs Fyr, just north of Grenå city and harbour.

Sludge

Samples of sludge from two waste water treatment plants (WWTP), Søholt and Bjergmarken, were included in the programme. Both receive wastewater from households as well as industry. Søholt is in Silkeborg, which is a town in Jutland with about 42 000 inhabitants. The loading of the plant in 2008 was 63 400 person equivalents (PE). Bjergmarken is situated in Roskilde, which is a town in Sealand with about 47 000 inhabitants. The loading of the plant in 2008 was 84 400 PE.

3.1.2 Faroe Islands

Sediments

Marine sediments were sampled at three presumed hotspots: Tórshavn harbour (station BÁ), Klaksvík harbour (station á Stongum, grabb), and in Skálafjord (station SK09, Haps) which is one of the most densely populated areas in the Faroe Islands.

Sludge

Sludge from two WWTP in Tórshavn was analysed. One sample was taken at the municipal sewage treatment plant Sersjanvíkin, and one was taken at the Central Hospital of the Faroe Islands.

Moss

Moss (*Hylocomium splendens*) were sampled around the incineration facilities in Tórshavn and Leirvík.

Egg

Black guillemot (*Cepphus grylle*) eggs were sampled from two locations; 9 eggs were sampled from the island Skúvoy, and 10 eggs from the island Koltur. The eggs were analysed as one pooled sample from each sampling site. These locations are background areas, and will typically represent possible long-range transported contaminants.

Fish, freshwater

Samples of Arctic char (*Salvelinus alpinus*) were taken from the dammed lake á Mýranar. Mixed muscle samples were dissected from 12 fish (average length 32.5 cm, average weight 357 g) and analysed as a pooled sample. These samples are taken at what is regarded as a background station which is mainly exposed to long-range transported contaminants.

Fish, marine

Samples of Atlantic cod (*Gadus morhua*) were taken from the sampling station Mýlingsgrunnur. The station is used as a reference station for cod from the Faroe Island shelf. 20 cod with a mean fork length 50.2 cm and mean weight of 1485 g were sampled, and analysed as one pooled sample. The analyses were done on liver tissue.

3.1.3 Finland

All Finnish samples were collected from urban environments; no samples were collected from background locations.

Sediments

Sediment samples were collected by Ekman-Birge grab samplers from three locations; two from coastal, estuary type bays (Helsinki and Pori) of major multi-affected rivers. The third sample was taken in Lake Pyhäjärvi downstream the city of Tampere.

Sludge samples

Sludge samples from three municipal WWTPs were included. One single dewatered sample was collected from Helsinki (Viikinmäki, population equivalent, pe 780 000), Espoo (Suomenoja, pe 240 000) and Hyvinkää (Kalteva, pe 40 000). All plants included in this investigation collected small or medium enterprise (SME) industrial wastewaters as well.

From the central waste deposit of Helsinki metropolitan area (Ämmässuo), one sample of sedimenting sludge material from storm water collection point was collected with an Ekman-Birge sediment sampler. Another smaller waste deposit was sampled with a plexi-tube in Hyvinkää. A third sedimenting material sample was collected in a storm water ditch below an industrial area in Helsinki (Herttoniemi).

Fish

Six composite samples (6–10 individuals in each pool) of Perch (*Perca fluviatilis*) were included; one from Helsinki (Old City Bay, same area as sediment) and five from Pyhäjärvi, Tampere (same area as sediment).

3.1.4 Iceland

Sludge

A total of four samples (KLF1, KLF2, KLS1, KLS2) were collected from Klettagarðar, one of two WWTPs in Reykjavik. KLF1 and KLF2 were analysed as one sample and KLS1 and KLS2 as one.

Sewage from Reykjavik and its neighbourhood is separated into solid and liquid parts in the WWTP. The solid part is buried at Alfsnes, a landfill site near Reykjavik while the liquid is pumped 3–5 kilometres off shore. All samples collected at the WWTP are non-processed, non-dehydrated sludge. Two samples (KLF1 & KLF2) were collected in a step screen which separates solid matter from the sludge. After leaving the step screen the sludge enters a screw conveyor which transfers the sludge to a temporary storage location. In the screw conveyor the sludge is sprinkled with a preparation of enzymes and microbes called Odorite which breaks down fats and other chemicals to reduce smell, however the exact preparation and composition of “Odorite” is not known. Two samples (KLS1 & KLS2) were collected from the screw conveyor.

Three stormwater sludge samples (ALF1, ALF2 & ALF3) were collected from the effluent of Alfsnes, a landfill site used by Reykjavik and its neighbourhood. Waste from Reykjavik and its neighbourhood is buried at Alfsnes including the solid part of the sludge from the WWTPs.

Fish

Samples (25 cods; 30–45 cm) were taken as the part of the Icelandic environmental monitoring program. The samples were collected by the Icelandic Marine Research institute from the same fishing area. Whole fish were frozen until they were treated at the laboratory at Matis. There the fish was thawed up, and biological parameters registered. Both filets were separated as well as the livers. Livers were weighed and homogenised and moved to a clean glass jar that had previously been heated to 400°C. Precautions were taken in order to avoid contamination and cross contamination. Liver homogenate samples were frozen for shipment.

Blue mussel

Specimens of Blue mussel (*Mytilus edulis*) for the Nordic Screening project were collected 30.11.2009 in the Fossá river estuary during low tide in Hvalfjörður. The specimens were collected early in the morning as soon as both tide and daylight permitted. The collection was done by turning over Bladder-wreck (*Fucus vesiculosus*) onto which the Blue mussel attached itself as well as underlying stones, and then picked loose. Temperature during collection was around -10°C. The specimens were subsequently kept frozen.

3.1.5 Norway

Samples have been collected from wastewater treatment plants, waste disposal sites, recycling plants, receiving water, biota and air. Samples related to Åse WWTP in Ålesund (sludge, sediment, fish, mussel) were collected as an example of environmental influence from a municipal and industrial area.

Air

Ambient air in Oslo (Alna) and indoor air in KLIFs building in Oslo were collected. The outdoor samples were collected 1.5 m above ground level and indoor 1.5 m above floor level.

Sediment

Sediments influenced by recycling facilities were collected. Hellik Teigen AS in Losmoen in Hoksund is an example of a car demolishing site and electronic waste recycling facility. Grønmo is a municipal recycling and landfill facility. The sediment samples from the two recycling plants were collected from leachate basin. Sediment from the receiving water to Åse WWTP, Åsefjorden, was collected. The sediments were stored in glass bottles wrapped in aluminium foil.

Sludge

Two sludge samples from Åse WWTP were included. Sludge samples were stored in glass bottles wrapped in aluminium foil.

Fish

Three fish (*Gadus morhua*; cod) samples from the receiving water to Åse WWTP, Åsefjorden, were collected. The fish was caught by local fishermen after instruction from DNV (Det NorskeVeritas AS). Sampled material was worked up at DNV's Biology laboratory and stored in glass bottles wrapped in aluminium foil. Three samples with 5 individuals in each were prepared.

Blue mussel

Composite sample of Blue mussel (*Mytilus edulis*) from two stations from receiving water were sampled by local fishermen. Sampled material was worked up at DNV's Biology laboratory and stored in glass bottles wrapped in aluminium foil.

3.1.6 Sweden

Air

Air samples were collected from two stations, one in Stockholm at the KTH Royal Institute of Technology campus, representing an urban situation, and one at the Råö station (at the Swedish west coast) representing the long range transport of studied compounds. The sampling station Råö is operating within The Swedish national monitoring program for air and is an official EMEP station. The air samples were collected using a high volume air sampler (HVS) with a flow of approximately 1 m^3/h.

Sediment

Sediment was collected from recipients influenced by the WWTP Henriksdal in Stockholm and other sources. Samples were taken near the effluent point, at Biskopsudden and in Torsbyfärden. Biskopsudden is 1 km and Torsbyfärden 20 km away from the effluent point in the main direction of flow.

Sludge

Henriksdal and Käppala WWTPs are located in Stockholm and nearby Lidingö and receive mixed sewage water from many communities. Digested dewaterised sludge was collected from these two sewage treatment plants.

Sludge from two landfills, one 40 km North of Stockholm, and one South of Stockholm was included.

Egg

Egg samples (mixture of 5 eggs) of Guillemot (*Uria aalge*) were received from the Swedish Environmental Specimen Bank. These samples (first laid egg) were collected at Stora Karlsö 2009.

Fish

Fish samples were collected at two locations in Lake Mälaren in the urban area Stockholm; Riddarfjärden and Stora Essingen.

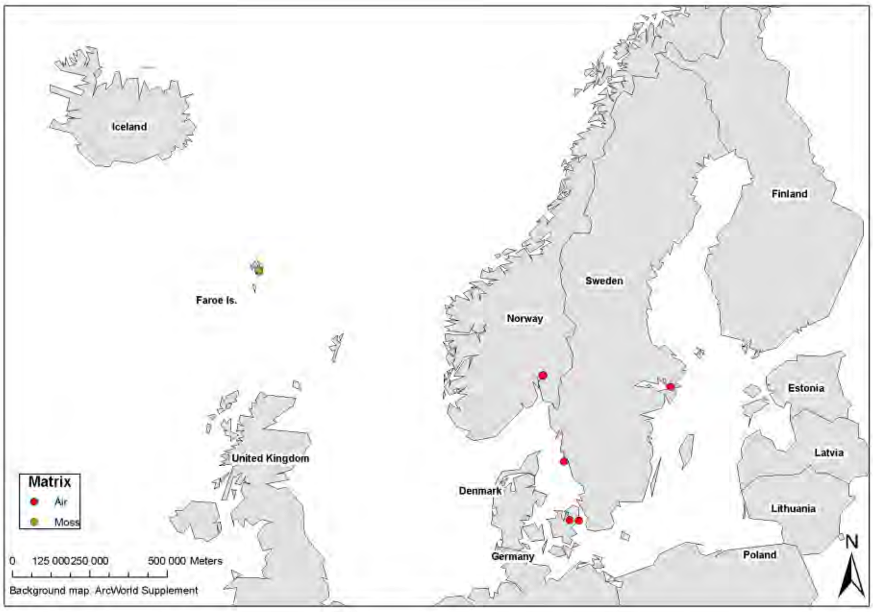


Figure 3.1 Nordic sampling sites for air and mosses.

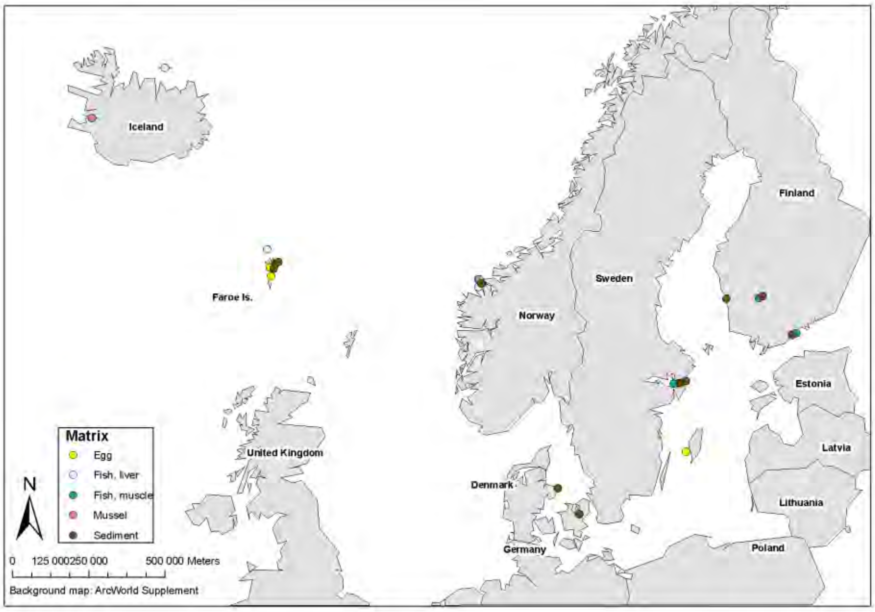


Figure 3.2 Nordic sampling sites for sediment & biota. (The circles are not placed at the exact sampling location as they would overlap).

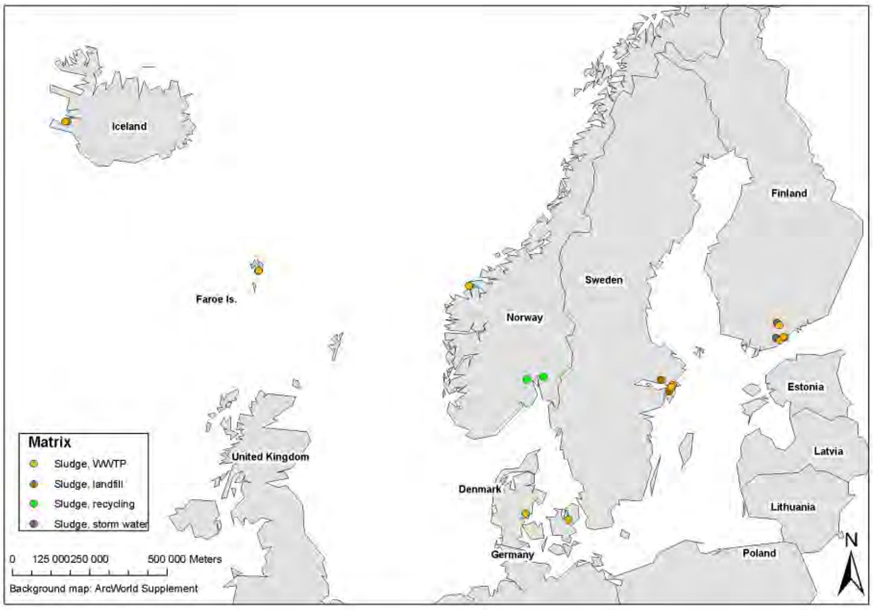


Figure 3.3 Nordic sampling sites for sludge.

3.2 Sampling methods

3.2.1 Air

The outdoor air samples were collected by passing the air through a glass fibre filter where particles were collected and then through a glass column packed with polyurethane foam (PUF). Note that the Norwegian samples were collected on solely glass fibre filters, *i.e.* only particle bound compounds were sampled.

Prior to sampling, glass fibre filters were heated to 400°C, and the adsorbent columns (PUF) were cleaned by Soxhlet extraction with acetone. The volume of the outdoor samples ranged between 160 and 2512 m^3 and the indoor sampling volumes were about 5 m^3. The sampling duration for outdoor sampling ranged from 3 to 7 days (Oslo) and 4 weeks (change of filter and PUF after seven days) (Stockholm, Råö) (Appendix 1). The sampling time for indoor air was one week (Appendix 1).

After sampling, the filter and columns were wrapped in aluminium foil and sent to the laboratory, where they were stored in a freezer (-18°C) until analysis. Additional filters and columns used as field blanks were sent back to the laboratory unexposed.

3.2.2 Biota

The fish samples were collected by means of suitable fishing-gear. From the total catch approximately 6–20 individuals were selected. The fish samples were individually wrapped in cleaned aluminium foil and stored in a freezer (-18°C) until analysed. Fish muscle or liver was dissected for analysis by means of solvent cleaned scalpels.

A homogenised mixture of 5–10 eggs were stored in pre-cleaned glass jars at –18°C.

Composite sample of Blue mussel from two stations from receiving water (Norway) were sampled by local fishermen. The animals were dissected for analysis and the shell discarded. These samples were stored at –18°C in pre-cleaned glass jars.

3.2.3 Sediment

Surface sediment (0–2 cm) samples were collected by means of a sampler or diver (Denmark). The sediment was transferred into muffled (400°C) glass jars and stored in a freezer (-18°C) until analysed.

3.2.4 Sludge

The sewage treatment plants sludge samples were collected by trained personell or the staff at the different plants. The sludge samples from landfills/waste deposit were collected from the leachate water settling basin.

Sludge from storm water was collected from the storm water settling basin using a grab, an Ekman-Birge or a plexi-glas sampler. The different sludge samples were transferred into glass jars and stored in a freezer (-18°C) until analysed.

3.2.5 Moss

The uppermost part of the plant *Hylocomium splendens*, representing approx. 2–3 years of growth, was used. Both samples consisted of several subsamples. The samples were collected in plastic bags (PE, Minigrip ®) and were stored at –18°C.

3.3 Analysis methods

3.3.1 Chemicals

Unlabeled reference standards HBB, PBT, PBEB, ATE, DPTE, BEHTBP, EHTeBB, and DBDPE were bought from Wellington Laboratories (Guelph, ON, Canada). BTBPE was bought from Cambridge Isotope Laboratories (Andover. MA, USA). TBBPA-DBPE was delivered from Aldrich. These where all standards of high purity (>98%).

^{13}C-Labeled internal standards of HBB, and BTBPE were bought from Wellington Laboratories (Guelph, ON, Canada) and ^{13}C-labeled BDE 28, 47, 99, 153, 183, and 209 were bought from Cambridge Isotope Laboratories (Andover, MA, USA). Unlabeled 1,2,3,4-TCN was used as recovery standard for the neutral brominated flame retardants and was bought from Cambridge Isotope Laboratories (Andover, MA, USA).

The internal standard ^{13}C-Dechlorane Plus syn was from Cambridge Isotope Laboratories (Andover, MA, USA) and Dechlorane plus, technical mixture, used for quantification was from Wellington Laboratories (Guelph, ON, Canada).

24DBP; (97%), TBBPA; (97%) were bought from Sigma-Aldrich. 246TBP was received from Hopkin and Williams LTD (London, England), and PBP; 98% from Lancaster (Morecambe, England).

Three internal standards were used for quantification of the Phenolic BFRs: tetrabromo-o-cresol (97%; Ralube TL, Rasching GmbH), tetrachlorobisphenol-A (98%; Sigma-Aldrich) and 4,5,6-tribromoguaiacol (>96%, synthesized at IVLs laboratory; Neilson et al. 1988).

3.3.2 Equipment

All equipment made of Teflon and metal was washed by solvent before use. Solvents used for extraction were delivered from Rathburn (Chemical Ltd., Peeblesshire, Scotland). The silica gel (Merck) was muffled prior to use. PUF-columns were pre-extracted in a Soxhlet apparatus before use.

3.3.3 Phenolic brominated flame retardants and Dechlorane Plus; sample preparation and analysis

Air

Filter and PUF-columns were extracted with n-hexane/diethylether (9/1) in a Soxhlet apparatus. The extract was concentrated and divided into to equivalent aliquots. One aliquot were used for the analysis of the neutral compounds and the other for the phenolic compounds. The aliquot was spiked with internal standards. The solvent was exchanged to hexane. The extract was stored in a freezer (-18°C) until derivatisation with diazomethan and clean-up (se below).

Sludge and sediment

The sample was fortified with an internal standard and, acidified and extracted with acetone. The extraction was repeated twice with a mixture of acetone: MTBE. The pooled extract was washed with diluted acid to remove the acetone. The organic extract was dried over sodium sulphate, transferred and concentrated by the aid of a stream of nitrogen gas. The extract was stored in a freezer (-18°C) until derivatisation with diazomethan and clean-up (se below).

Egg and liver

The sample was fortified with an internal standard and, acidified and extracted with acetone. The extraction was repeated twice with a mixture of acetone: MTBE. The pooled extract was washed with diluted acid to remove the acetone. The organic extract was dried over sodium sulphate, transferred and concentrated by the aid of a stream of nitrogen gas. The extract was stored in a freezer (-18°C) until derivatisation with diazomethan and clean-up (se below).

Fish and mussel samples

The sample was fortified with an internal standard, acidified, homogenized and extracted according to Jensen *et al.* (2003). The extract was dried and stored in a freezer (-18°C) until derivatisation with diazomethane and clean-up (se below).

Moss samples

The moss sample was placed in a glass fibre thimble and extracted in a Soxhlet apparatus with acetone containing acetic acid. The extract was dried over sodium sulphate and concentrated using a rotary evaporator. The solvent was exchanged to hexane, and the extract stored in a freezer (-18°C) until derivatisation with diazomethane and clean-up (se below).

Derivatisation of the phenols with diazometane

The phenols, dissolved in diethyl ether, were converted to the corresponding *O*-methyl ethers by reacting the samples for four hours at 4°C with ethereal diazomethane in the presence of methanol.

Clean-up of derivatised extract

The extract of the different samples, dissolved in hexane, was first treated with concentrated sulfuric acid to remove the main part of matrix molecules followed by chromatography on a silica-H_2SO_4 column using dichloromethane as mobile phase (Hovander *et al.* 2000; Hovander *et al.* 2002). Finally, the extract was chromatographed on a silica gel column. Before instrumental analysis an injection standard was added.

Instrumental analysis, phenolic compounds

The extracts were analyzed on a 7890A gas chromatograph coupled to a 7000A Triple Quad MS (Agilent Technologies, Inc. Santa Clara, CA, USA). The injection was made pulsed splitless at 250°C. The fused silica capillary column (VF-5MS 30 m x 0.25 mm i.d. x 0.25 µm film thickness, Varian) was held at 45°C for 1 min, ramped 15°C/min to 200°C, then 10°C/min to 300 °C and isothermal for 5 min. The transfer line was held at 290°C. Helium was used as carrier gas. The detector was used in MRM mode with electron ionisation at energy of 70 eV. The analytes were identified by their characteristic retention times and two daughter ions. Quantification was based on comparison of peak abundance to the known response of the internal standard (biphenyl). The reported analyte concentrations were calculated according to the determined surrogate standard.

Instrumental analysis, Dechlorane Plus

The same instrument and column as for "Phenolic compounds" was used but the column temperature was held at 50°C for 1 min, increased to 325°C at 20°C /min and held at 325°C for 10 min. The mass spectrometer was used in SIM mode using CI ionization with methane as reaction gas. DP was monitored at m/z 653.8 with m/z 651.8 as a qualifier. $^{13}C_{10}$-DP was monitored at m/z 663.8.

3.3.4 Compounds in addition to Phenolic BFRs and DP; sample preparation and analysis

Air

Filter and PUF-columns were extracted with n-hexane/diethylether (9/1) in a Soxhlet apparatus. The extract was concentrated and divided into two equivalent aliquots. One aliquot were used for the analysis of the neutral compounds and the other for the phenolic compounds. The aliquot was spiked with an internal standard mixture. The solvent was exchanged to hexane.

Sludge and sediment

Samples of sediment and sludge were dried at 30°C and soxhlet extracted with n-hexane/diethylether (9/1) for 8 hours. Internal standards were added before extraction.

Biological tissue

Fish, egg and mussel samples were homogenized in Na_2SO_4, and extracted on an open column with cyclohexane/ethyl acetate. Internal standards were added before extraction.

Moss

Moss samples were air dried in an ultra clean-room facility and Soxhlet extracted with n-hexane/diethylether (9/1) for 8 hours.

Clean-up of extract

For all samples the extract, dissolved in hexane, was first treated between one and four times with concentrated sulfuric acid to remove the main part of matrix molecules followed by chromatography on a silica column using n-hexane/diethylether (9/1) as mobile phase. Before instrumental analysis the extract was concentrated to between 100 and 1000 µl and recovery standards was added.

Instrumental analysis, neutral compounds

The extracts were analyzed on a 7890A gas chromatograph (Agilent Technologies, Inc. Santa Clara, CA, USA) coupled to an AutoSpec high resolution mass spectrometer (Waters, Milford, MA, USA). The injection was made pulsed splitless at 300°C. The fused silica capillary column (DB-5HT 15 m x 0.25 mm i.d. x 0.10 µm film thickness, Agilent) was held at 100°C for 2.5 min, ramped 13.2°C/min to 220°C, then 7°C/min to 280°C, 50°C/min to 320°C and isothermal for 10 min. The transfer line was held at 290°C. Helium was used as carrier gas. The detector was used in SIM mode with electron ionisation at energy of 35 eV. The analytes were identified by their characteristic retention times and two doughter ions. The reported analyte concentrations were calculated according to the determined internal standard.

Special care was given to the unequivocal identification and quantification of TBECH.

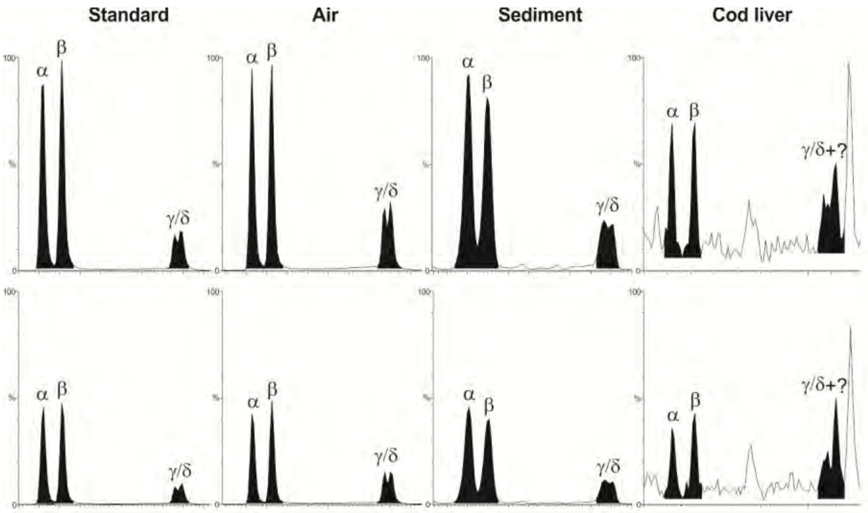


Figure 3.3: Massfragmentograms of the [M-HBr₂]⁺ ion of TBECH in a standard, an air sample from Copenhagen, a sediment sample from Åsefjorden, and a cod liver sample from Åsefjorden. (264.9227 upper trace, 266. 9207 lower trace)

For an unequivocal identification and quantification both retention time and isotope ratio must be correct. As visible in figure 3.3 these parameters are true for nearly all samples. However, in biota for the γ/δ-TBECH isomers the isotope ratio is not correct and within 20% of the theoretical ratio. A visual examination of the signal measured at the retention time of γ/δ-TBECH suggests that this signal is not only caused by γ/δ-TBECH but also by an interfering compound which cannot be separated with the GC-parameters available in this project. Due to the shape of the signal which is quite similar to the signal measured in the standard, it is very likely that a significant part of the signal is made up by γ/δ-TBECH. The exact proportion can, however, not be quantified exactly. On the other hand it would not be correct to mark these results as non-detects and report levels "<" (less) than this value. Therefore, we have chosen to mark the results of γ/δ-TBECH in biota samples with "i" for interference in the results table.

3.3.5 Quality control

The following quality criteria were used to ensure correct identification and quantification of the target compound: (a) the retention time should match those of the standard compounds within ± 0.05 min., (b) the intensity ratios of the selected ions (target- and qualifier-ions) are within ± 15% of expected/theoretical value (c) the signal-to-noise ratios are greater than 3:1.

Field blanks were collected at several sampling stations. An analytical method blank was included for each sample batch analysed to assess background interferences and possible contamination of the samples. Concentrations below field blank levels were treated as not detected.

Possible background levels of analytes were subtracted from measured sample values.

In this investigation limit of quantification (LOQ) was used and is defined as a signal 10 times the standard deviation of the blank values.

Internal standard was added to the sample at the start of the working-up procedure of the sample. The internal standard has similar chemical and physical properties to the compounds to be analyzed. If available, isotopes labelled internal standards were used.

Uncertainties

When performing environmental screening or monitoring all steps in the study starting with the design of the study, selection of sampling sites and sampling frequency, time of sampling, performing of sampling, transport and storage of samples, chemical analysis and data treatment are generating some degree of uncertainty. To quantitatively estimate the contribution of all steps is an extreme difficult task or not possible at all. However, we will discuss the relevance of the different contributors in a qualitative way.

One important question is whether a sample is representative for a given time period or a given region. Many of the selected compounds are intermittently emitted to the environment and a constant concentration of these compounds in the environment is not expected. In this screening, the samples were collected within a narrow time frame and at only a few different geographical locations. The results obtained here are therefore only a snapshot of the reality at those places at the given time.

Factors with influence on sampling uncertainty are analyte loss due to adsorption to sample containers, wastewater flow and particle content, tidal water current, contamination (for some compounds), selection of sample type (water with or without particle phase), and degradation during transport and storage.

The uncertainty of the chemical analysis is governed by loss during extraction and clean-up, interference from other compounds, trueness of analytical standards, instrumental parameters, and contamination. A normal approach to estimate and quantify these factors is the participation in a laboratory intercalibration. However, at this stage the analysis of these compounds in environmental samples is not done routinely and intercalibration studies have not been available. The uncertainty is expected to be larger for compounds which are analysed the first time than for compounds which previously have been analysed or where similar compounds have been analysed earlier. That means that most compounds will probably have analytical uncertainties in the range of 20 to 40%. For all analytes we consider the analytical uncertainty as fit-for-purpose (that means adequate for a first screening study), however, the results cannot be implemented uncritically in time-trend studies.

4. Results and discussion

All measured concentrations of individual substances are tabulated in Appendix 2. An overview of the detection frequencies, *i.e.* the fraction of samples where a substance was found in a concentration above the detection limit for different sample matrices, is given in Table 4.1. The detection limits varies as a consequence of variations in analytical methods, sample volumes/amounts and varying interferences in individual samples. As Table 4.1 is intended only as an overview, this variation is not taken into account here.

In general, the emerging brominated flame retardants, as well as the reference compounds (BDEs) and the chlorinated substance, dechlorane plus, were regularly found in all the sample matrices indicating a widespread distribution in the environment. However, there were differences between different groups as well as for individual substances.

In the following, the concentrations found are presented in more detail. The results from the present study are compared to concentrations found in other investigations (reference data have been taken from 2.1. as well as from other studies).

Table 4.1 Detection frequency (%) of the individual substances for the different sample matrices.

Matrix	Air	Sediment	Sludge	Biota
Number of samples	12	15	16	21
	%	%	%	%
Phenolic BFRs				
24DBP	58	78	8	39
246TBP	50	92	23	91
PBP	8	8	15	17
TBBPA	17	8	15	0
BFR esters & ethers				
ATE	33	8	31	4
DPTE	67	8	31	17
BTBPE	92	50	100	91
BATE	25	0	31	4
TBA	100	100	100	100
BEHTBP	75	17	100	70
EHTeBB	92	25	77	57
Others flame retardants				
DP	75	100	100	52
HBB	92	50	31	100
PBT	92	92	100	100
PBEB	67	58	69	43
DBDPE	100	50	100	70
TBECH, sum	92	50	46	81

Matrix	Air	Sediment	Sludge	Biota
Reference BFR				
BDE-28	100	94	75	100
BDE-47	100	100	83	100
BDE-71/49	50	89	83	100
BDE-66	33	44	25	70
BDE-77	17	6	0	10
BDE-99	100	100	75	100
BDE-100	67	100	75	100
BDE-85	33	22	17	25
BDE-119	0	0	0	35
BDE-138	33	22	25	5
BDE-153	50	50	75	80
BDE-154	50	67	75	100
BDE-183	67	50	75	40
BDE-196	33	17	50	10
BDE-206	50	39	83	30
BDE-209	100	78	92	95

4.1 Environmental concentrations

4.1.1 Air

The emerging brominated flame retardants and dechlorane plus were frequently found in air which indicates that the atmosphere is an important transport media for these substances. However the air concentrations varied for the different substances and among the different sampling sites.

The review of the environmental concentrations in chapter 2.1 showed that information on air concentrations from previous measurements of the emerging brominated flame retardants is scarce.

Phenolic BFRs

Phenolic BFRs occurred in air both from urban and background sites. 24DBP and 246TBP were most frequently found and the levels varied from <0.8 pg/m^3 to 21 pg/m^3 and <0.3 pg/m^3 to 27 pg/m^3, respectively. The concentrations of the individual substances are given in Table 4.2.

At Råö, both 24DBP and 246TBP occurred in higher levels compared to the PBDEs measured within the Swedish monitoring program for air pollutants (www.ivl.se).

Pentabromophenol was only found in urban air, in one sample from Oslo (Alna 2; 1.5 pg/m^3). Tetrabromobisphenol-A (TBBPA) occurred in two samples from Oslo at concentrations of 50 pg/m^3 and 280 pg/m^3, respectively, while the air concentrations at other sites were below the detection limits. As a comparison, TBBA has previously been detected in air in a Swedish screening study in concentrations up to 30 pg/m^3 (Remberger *et al.* 2002).

No phenolic BFRs were detected in indoor air samples; note that detection limits in indoor air was higher due to lower sample volumes.

Table 4.2 Concentration of phenolic BFRs in air

Site class	Site, site	24DBP pg/m^3	246TBP pg/m^3	PBP pg/m^3	TBBPA pg/m^3
Background	DK Lille Valby	6.0	17	<1	<1
Background	SE Råö, Nov.	21	27	<0.5	<0.5
Background	SE Råö. Jan.	9.7	20	<0.5	<0.5
Urban	NO Oslo, Alna 1	<0.8	<0.3	<1	<1
Urban	NO Oslo, Alna 2	<0.8	0.99	1.5	50
Urban	NO Oslo, Alna 3	5.1	<1	<3	280
Urban	DK H.C.Andersson	3.6	9.3	<0.5	<0.5
Urban	SE Stockholm, Nov.	2.8	4.0	<0.3	<0.3
Urban	SE Stockholm, Jan.	5.6	10	<0.2	<0.2
Urban, indoor	NO Oslo, SFT 1	<60	<20	<100	<100
Urban, indoor	NO Oslo, SFT 2	<60	<20	<100	<100
Urban, indoor	NO Oslo, SFT 3	<60	<20	<100	<100

BFR esters and ethers

Brominated ethers and esters occurred both in background and urban air, which is shown in Figure. 4.1.

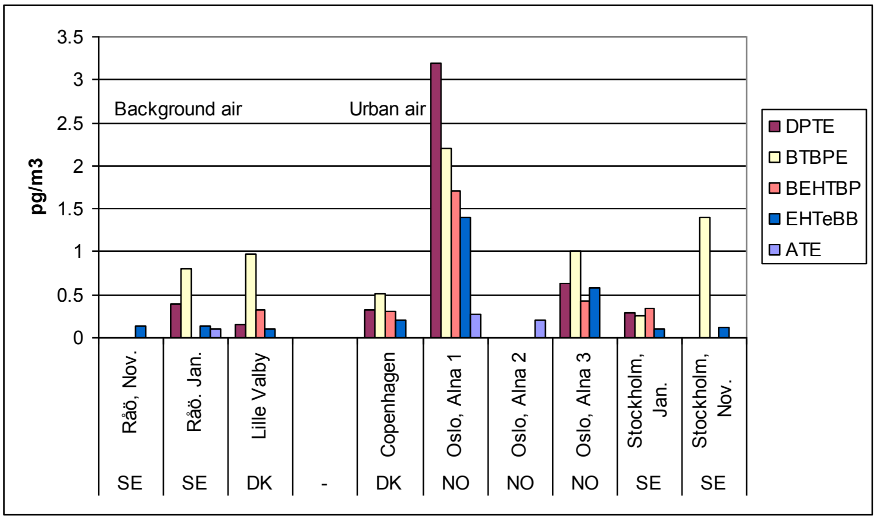


Figure 4.1 The concentrations of detected brominated ethers and esters in background and urban air.

The concentrations of the BFR ethers and esters varied for different substances and sites. The highest concentrations occurred in one of the samples from Oslo which was collected at street level. EHTeBB, and BTBPE were the substances most frequently detected while DPTE was measured in the highest concentration (3.2 pg/m^3). BTBPE has been detected in China in similar concentrations, see Chapter 2.1. At the background stations BFR ethers and esters occurred in similar levels as PBDEs (data from the Swedish monitoring program for air pollutants, www.ivl.se).

The levels of brominated ethers and esters were higher in the indoor air samples compared to outdoor air. In indoor air BTBPE showed the highest concentration, see Figure 4.2.

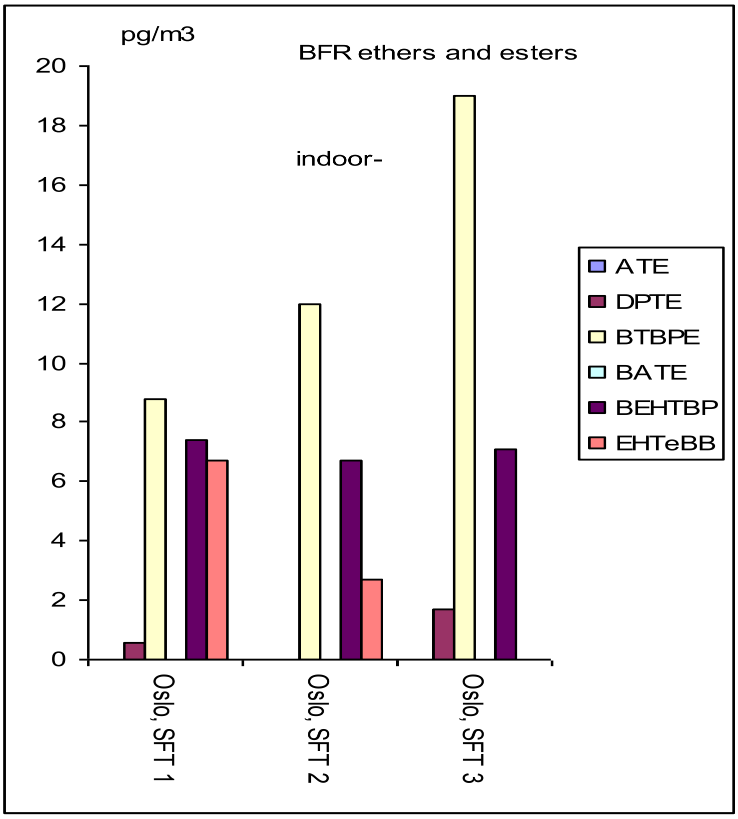


Figure 4.2 The concentrations of detected brominated ethers and esters in indoor air

2, 4, 6 –Tribromanisol (TBA) was found in all analysed samples. However it was only determined in four of the air samples. The highest concentration was found in the sample from Copenhagen, H.C. Andersson Boulevard where 13 pg/ m^3 was found. TBA has previously been found in background air (gas-phase) at Lista (Vetter et al. 2002).

Other brominated flame retardants

All of the substances included in the group “other“ brominated flame retardants occurred in the air samples. However there was a great variation in both concentrations and the relative distribution of the substances among the different sampling sites which is demonstrated in Figure 4.3.

All the BFR compounds shown in Figure 4.3 were detected in the samples from background sites but in lower levels and frequencies compared to the urban areas. The highest concentrations occurred for most of the substances in the indoor air samples. Decabromodiphenylethane (DBDPE) occurred in the highest concentrations. The highest concentrations were measured at street level and in indoor air in Oslo (44 and 56 pg/m^3) during the same sampling period. Hexabromobenzene (HBB) and pentabromotoluene (PBT) were the most frequently detected substances, which occurred in elevated concentration in the indoor air samples. HBB has previously been found in similar air concentrations in a Norwegian screening study (Møskeland, 2010). The concentrations of the 1,2-dibromo-4-(1,2-dibromoethyl)cyclohexane isomers (TBECH) were however higher in urban air compared to indoor air. The concentrations of TBECH in the urban air samples collected in Copenhagen and in one of the Stockholm samples were higher compared to the air concentrations found in Oslo.

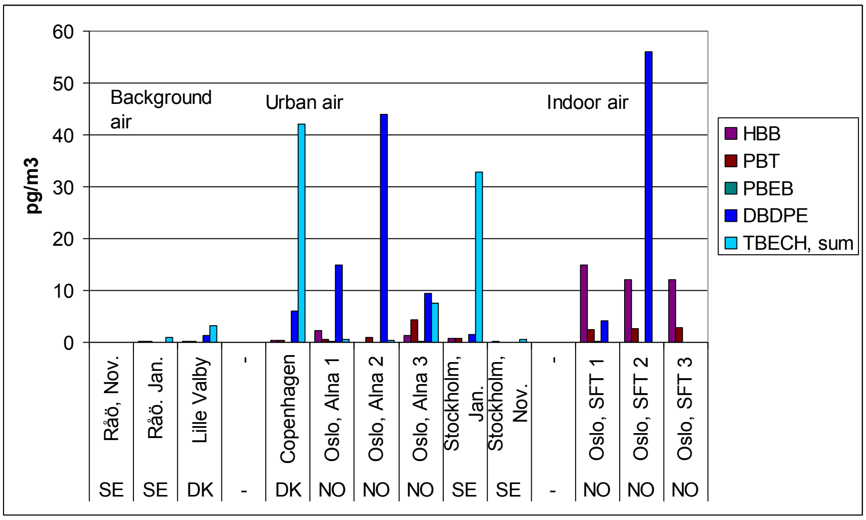


Figure 4.3 The concentrations of "other brominated flame retardants" in air.

Dechlorane plus

DP was found in all outdoor air samples. The concentration was lowest at the background station Råö (0.13–0.58 pg/m3) and in Stockholm (0.11–0.17) pg/m3. In Denmark the concentration at the rural station Lille Valby (9.4 pg/m^3) was higher than in central Copenhagen (2.7 pg/m^3). The concentrations were similar to what was reported from USA (Hoh, 2006) and Sweden (Kaj, 2010). The urban samples from Oslo showed the highest concentrations (27–160 pg/m^3). These values are in the highest range of what was reported from urban areas in USA (Hoh, 2006) (see table in 0.)

The relative abundance of the DP-anti isomer was close to the value for the original product (0.71–0.78%) in the majority of the samples; somewhat lower in one sample each from Oslo, Stockholm and Råö (0.57–0.64%).

4.1.2 Moss

Moss samples from Faroe Islands were collected around two incineration facilities at Torshavn and Leirvik.

Phenolic BFRs were only found in the moss sample from Torshavn where 24DBP and 246TBP occurred in concentrations of 0.53 ng/g d.w. and 0.46 ng/g d.w., respectively. Of the brominated esters and ethers, BTBPE occurred in the moss samples from both sites (0.15 ng/g d.w. and 0.056 ng/g d.w.) while BEHTBP only was found in the sample from Leirvik.

All of the substances included in the group “other” flame retardants were present in the moss samples from both sampling sites. DBDPE occurred in highest concentrations which were at the same level as the concentrations of the reference substances BDE 47 and BDE 99. Dechlorane plus (DP) was present in the moss samples from both sampling sites in concentrations of 0.06 ng/g d.w. and 0.017 ng/g d.w., respectively.

Several of the brominated flame retardants and dechlorane plus which occurred in the air samples were also found in the mosses. Mosses could be an indicator of atmospheric transport of organic compounds *e.g.* the emerging BFRs. In this case the nearby incineration plants’ emission to air is probably an important source of the BFRs in moss. However, as moss samples from background areas were not included in this screening the degree of influence of the point sources is difficult to estimate.

4.1.3 Biota

Phenolic BFRs

246TBP was detected in 91% of the biota samples. 24DBP and PBP were detected in 39% and 17% of the samples respectively (Table 4.1). TBBPA was not detected in any of the biota samples.

The concentrations of the phenolic BFRs in the different biota samples are shown in Figure 4.4.

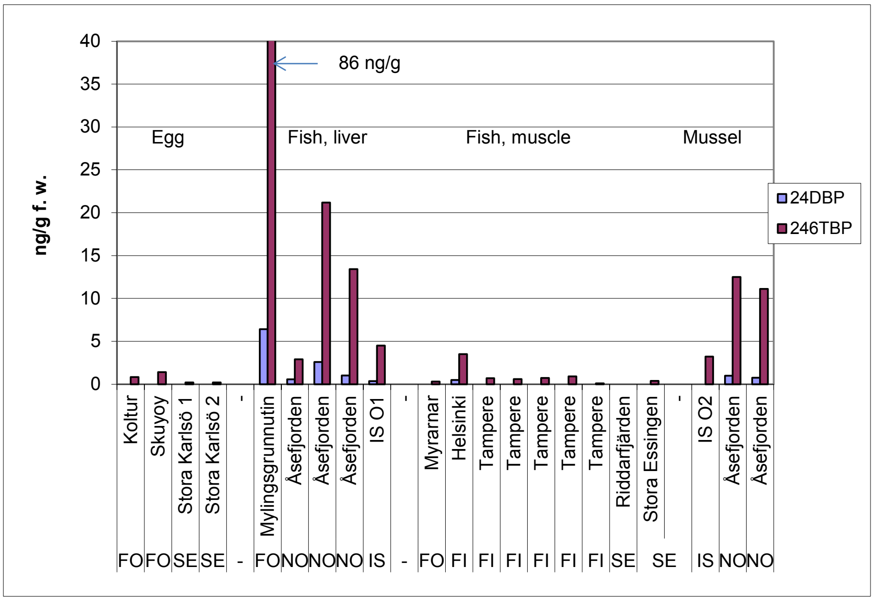


Figure 4.4 Concentrations of brominated phenolic flame retardants in biological samples.

246TBP occurred in the highest concentrations (<0.03–86 ng/g fresh weight, f.w.). The highest concentration was measured in a cod liver sample (Mylingsgrunnurin, Faroe Island). Increased concentrations of 246TBP (11–13 ng/g f.w.) were also found in mussel and cod liver samples from the urban influenced marine water body Åsefjorden (Norway).

The levels found in this investigation are in agreement with previously reported results from a Norwegian screening 2010 (Møskeland, 2010) but higher than was found in arctic fauna (common eider liver 0.1 ng/g f.w., ring seal liver 0.05 ng/g f.w.; Sagerup *et al.* 2010).

24DBP showed similar relative distribution as 246TBP but at a lower levels (<0.03–6.4 ng/g f.w.). The highest concentration was found in a cod liver sample from the Faroe Islands and increased concentrations compared to the other samples were also detected in biota from Åsefjorden (mussel 0.75–0.97 and cod liver 0.55–2.6 ng/g f.w.). Previous measurement data on 24DBP in biota has not been found.

PBP was only detected in egg samples from Stora Karlsö island (Sweden, 0.40–0.43 ng/g f.w.) representing a brackish background environment and from Faroe Islands (0.12–0.18 ng/g f.w.) representing a background marine environment.

More data on "Phenolic BFRs" are summarised in chapter 2.2, (Table 2.2–2.3).

BFR esters and ethers

BTBPE (91%), BEHTBP (70%) and EHTeBB (57%) were frequently detected in the biota samples. 2,4,6-tribromoanisol (TBA) was detected in all biota. The 2,4,6-tribromophenol derivatives ATE, DPTE and BATE had a low detection rate (4–14%).

The highest concentration was recorded for the non flame retardant TBA in a cod liver sample from Faroe Islands (Mylingsgrunnurin, 14 ng/g f.w. Figure 4.5). In fish muscle, egg and mussel samples the concentration range for TBA was 0.01–1.3 ng/g f.w which is comparable with the BDE-99 concentration detected in these samples (0.0087–0.85 ng/g f.w.). TBA is naturally produced in the marine environment but there are other possible sources for this compound (see 2.1.2).

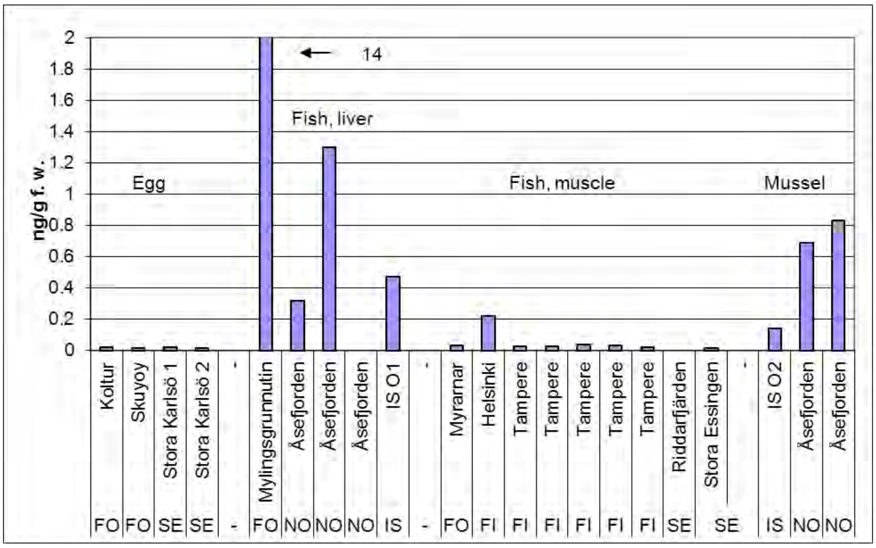


Figure 4.5 Concentration of TBA in biological samples.

The concentrations of BTBPE, BEHTBP and EHTeBB in this investigation were all below 0.5 ng/g f.w which is lower than TBA-concentrations and at the same levels as BDE-100 (0.0087–0.85 ng/g d.w).

BEHTBP was detected in concentrations between 0.002 and 0.46 ng/g f.w. (Figure 4.6). The highest concentration occurred in one of the five fish muscle samples from Tampere, while the other samples contained significantly lower concentrations. The cause to the high value in one of the fish samples is unknown. BEHTBP has frequently been detected in arctic fauna (Sagerup *et al.* 2010). The reported concentration range was 0.56–2.1 ng/g f.w. which is somewhat higher than what was found in this investigation. Gauthier *et al.* (2009) detected BTBPE in Herring Gull egg collected in 2006. The concentration range was <0.06–0.20 ng/g f.w. which agree with the range detected in the present study (Figure 4.6).

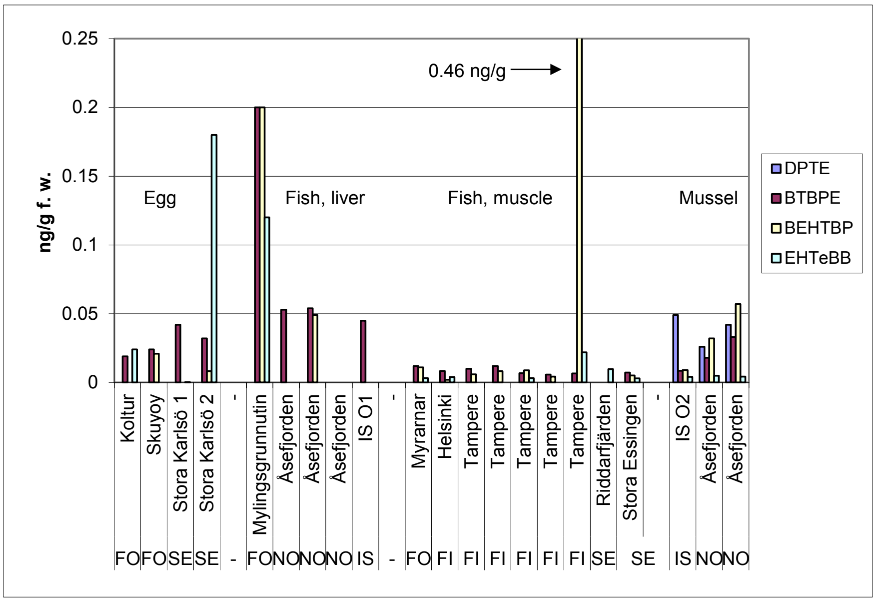


Figure 4.6 Concentrations of some BFR ethers and esters in biological samples.

DTPE was only detected in three samples, fish liver from Island and mussel from Norway, at rather low concentrations (0.026–0.049 ng/g f.w.). DPTE was not detected in arctic biota (Sagerup, 2010) or the Norwegian environment (Møskeland, 2010). ATE was only found in one mussel sample from Åsefjorden, Norway which contained 0.005 ng/g f.w.

More data on "BFR ethers and esters" to compare this reports results are summarised in chapter 2.2, (Table 2.4–2.9).

Other flame retardants

The fully brominated benzene (HBB) and toluene (PBT) were detected in all biota samples. TBECH (81%) and DBDPE (67%) were detected in somewhat lower frequency. PBEB was detected in 43% of the biota samples at low concentrations (0.0001–0.004 ng/g f.w.).

The concentrations of HBB and PBT substances for the different biota samples are shown in Figure 4.7. The concentrations of HBB and PBT were higher in fish liver and guillemot egg compared to fish muscle and mussel tissue.

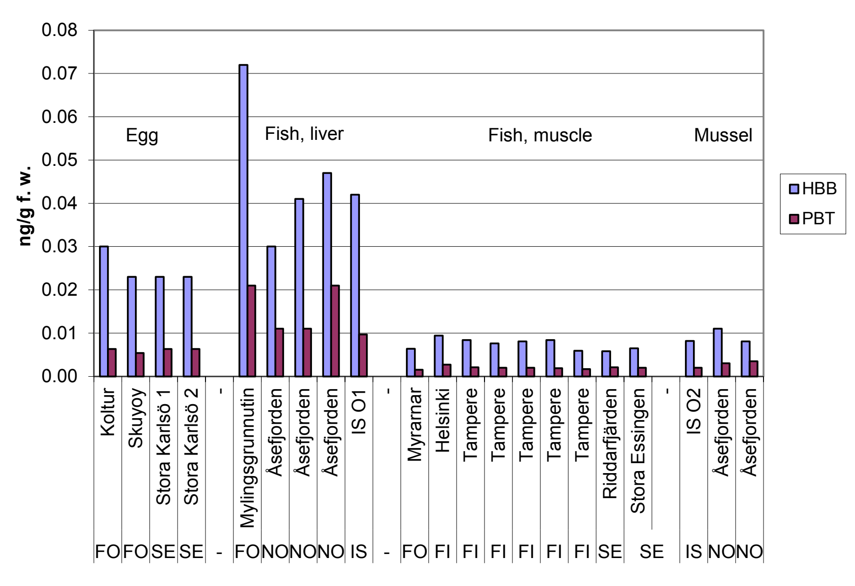


Figure 4.7 Concentrations of HBB and PBT in biological samples.

The concentrations of DBDPE (0.02–0.12 ng/g f.w. Figure 4.8) were in the same range as HBB and PBT. TBECH was detected in low concentrations in lean fish (Finland) and in mussels (Åsefjorden, Norway) (0.001–0.019 ng/g d.w.). In lipid rich samples such as cod liver and egg the concentration was in the range 0.077–1.6 ng/g f.w. (Figure 4.8). As described in Chapter 0 the quantification of γ/δ-TBECH in biological samples is influenced by an interfering compound and the results given here may be slightly overestimated.

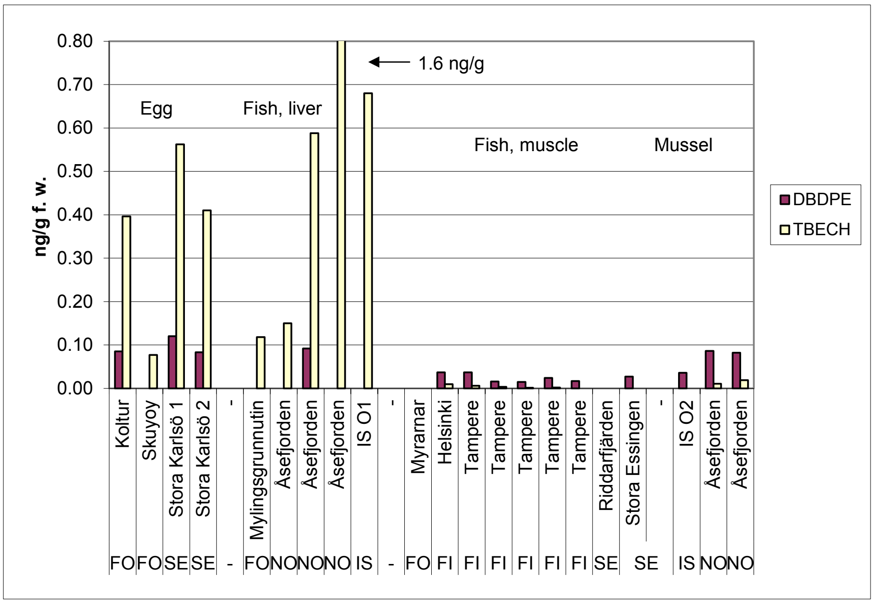


Figure 4.8 Concentrations of DBDPE and sum of α-, β-, γ-TBECH in biological samples.

The highest concentrations of HBB, PBT and DBDPE were found in fish from Mylingsgrunnurin (Faroe Islands) and Åsefjorden (Norway) and in guillemot egg (Sweden and Faroe Islands) (Figure 4.7 and 4.8). Generally, lipid rich samples such as cod liver (Åsefjorden) and Guillemot egg (Sweden and Faroe Islands) contained significantly higher concentration of the investigated flame retardants compared to samples with low lipid content such as fish muscle and mussel (Figure 4.7–4.9). This also holds for the less liphophilic (log K_{ow} 4.13) flame retardant 246TBP (Figure 4.4).

Sagerup *et al.* (2010) did not detect HBB, PBT or PBEB in the Arctic fauna. Furthermore, HBB, PBT, PBEB and DBDPE were not detected in biota collected from the Norwegian marine environment but DBDPE was detected in one sample of arctic guillemot (Møskeland 2010).

Gauthier *et al.* (2009) reported HBB in Herring gull egg (Great Lakes U.S.) in a concentration range of 0.27–0.66 ng/g f.w. which is one magnitude higher than in the present investigation (Figure 4.7).

Dechlorane plus (DP) was detected in 52% (Table 4.1) of the biota samples. The highest concentrations (Figure 4.9) occurred in egg samples from Stora Karlsö (0.079–0.083 ng/g f.w). Mussel and fish liver from Åsefjorden contained somewhat lower concentrations (0.019–0.026 ng/g f.w. and 0.030–0.042 ng/g f.w., respectively). The concentration in cod from a background area at Faroe Islands was below LOQ (<0.003 ng/g f.w.). The concentration of DP in lean fish from Finland was also below LOQ (<0.002 ng/g f.w.) except for one sample (0.007 ng/g f.w.).

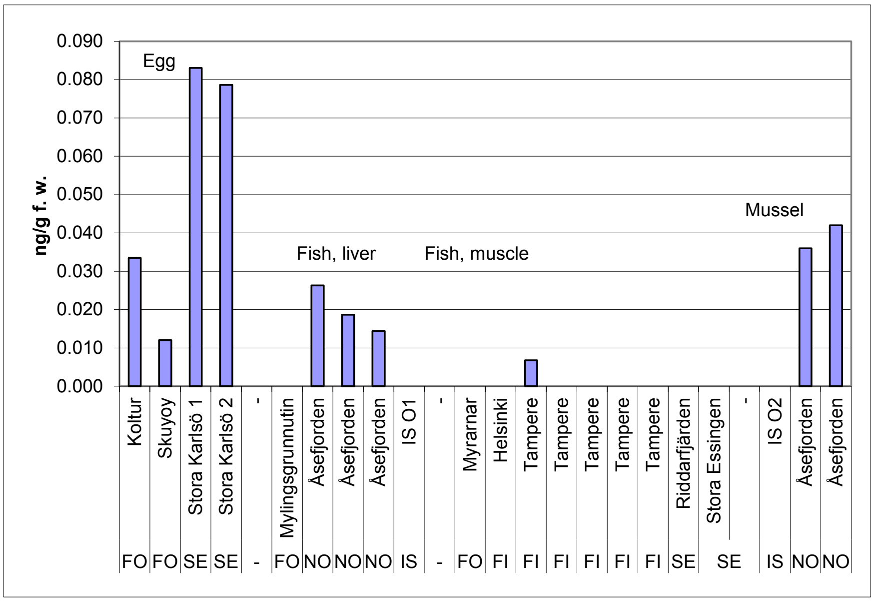


Figure 4.9 Concentrations of the sum of syn- and anti-Dechlorane Plus in biological samples.

The concentrations of DP found in the Nordic biota in this screening were in most cases low compared to data reported in other studies. For example, egg (Herring gull) from the Great Lakes area contained at least 25 times higher concentrations (2–6 ng/g f.w.) compared to Guillemot eggs from Faroe Islands and Stora Karlsö Sweden.

On lipid base, fish from Lake Erie contained 0.14–0.91 ng/g l.w., fish from South Korea, rural sites, 1.4 g/g l.w. and from South Korea, urban sites, 36.1 ± 35.3 ng/g l.w. On lipid base, in the present investigation, cod liver from Norway contained 0.24–0.63 ng/g l.w., fish muscle from Finland 0.01 ng/g l.w. and mussels from Åsefjorden, Norway, contained the highest DP concentrations (1.3–1.7 ng/g l.w.).

More data on “Other FRs” to compare this report results are summarised in chapter 2.2, (Table 2.10–2.15).

4.1.4 Sediments

Phenolic BFRs

24DBP and 246TBP were frequently detected in sediments (Table 4.1). PBP and TBBPA were only detected in some sediment samples from the urban areas Åsefjorden (Norway; PBP) and Torshavn (Faroe Islands; TBBPA) (Figure 4.9; Appendix 2.1).

The concentrations of 246TBP in the marine sediments ranged from 0.21 to 7.8 ng/g d.w. and in brackish sediments (Sweden) from <0.02 to 4.8 ng/g d.w. The highest concentration of 24DBP were also detected in marine sediments (0.096–2.9 ng/g d.w.) compared to brackish (<0.07–0.49 ng/g d.w.).

The sediment from Torshavn contained the highest concentrations of 246TBP (7.8 ng/g d.w.), 24DBP (2.9 ng/g d.w.) and TBBPA (16 ng/g d.w.). The second highest concentration of 24DBP (1.7 ng/g d.w.) and 246TBP (1.1 ng/g d.w.) occurred in the samples from Åsefjorden. The sediment from Åsefjorden also contained PBP in a concentration of 2.0 ng/g d.w. (Figure 4.10).

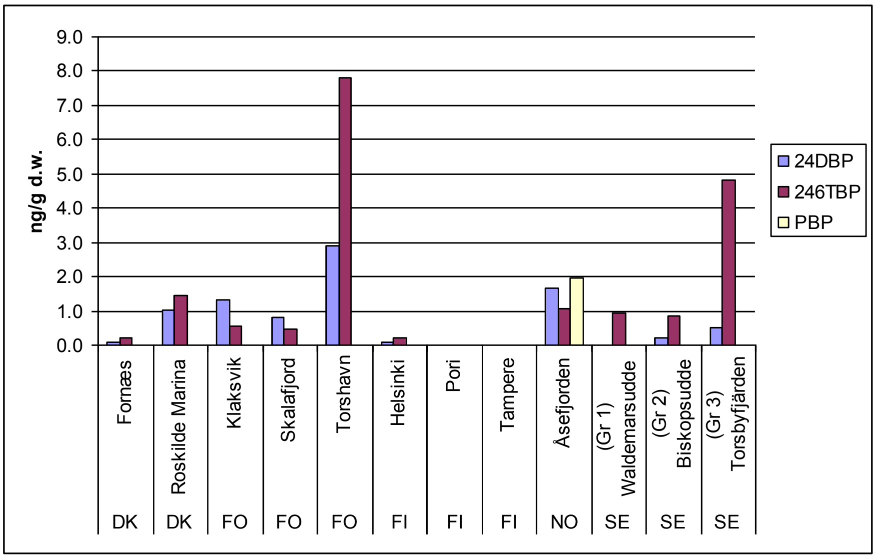


Figure 4.10 Concentrations of phenolic BFRs in sediment samples. GR1-3 is a sampling gradient in Stockholm archipelago.

Increasing concentrations of 24DBP and 246TBP were found in the Swedish sediments which were collected in a gradient out from Stockholm. No obvious explanation can be given to this observation. The sediments were collected from an urban area (archipelago of Stockholm) this means that there may be many anthropogenic sourses for the bromophenols. The contribution of bromophenols from natural sources is largely unknown.

More data on “Phenolic BFRs” to compare this reports result are summarised in chapter 2.2, (Table 2.2–2.3).

BFR esters and ethers

TBA was detected in all analysed sediment samples (matrix interference excluded some samples from the analysis). The concentration range was 0.0009–0.66 ng/g d.w. which is lower than 246TBP concentrations (0.2–7.8 ng/g d.w.) in the same sediments. This indicate that de-*O*-methylation of TBA to the phenol 246TBP may occur in the sediment (Remberger *et al.* 1986) (Figure 4.11).

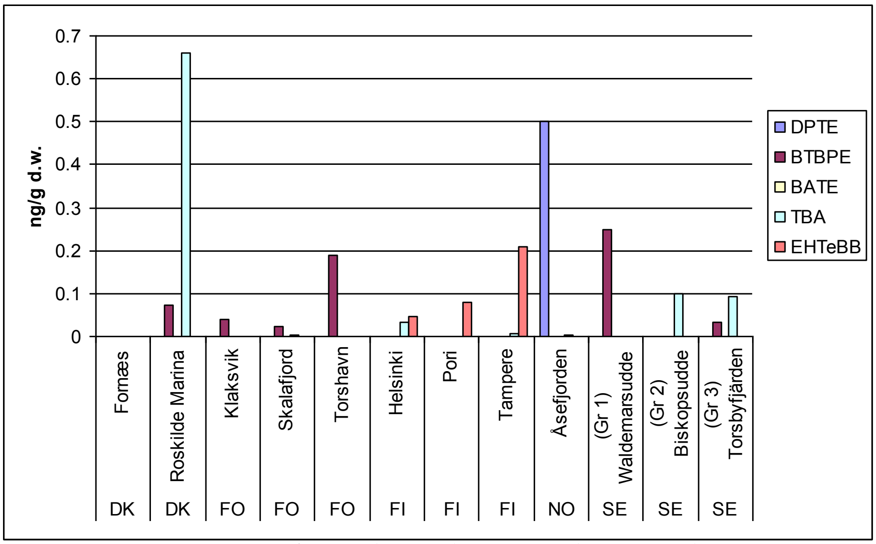


Figure 4.11 Concentrations of BFR ethers and esters in sediment samples.

The detection frequency for the brominated phthalate ester BEHTBP and the brominated benzoate ester EHTeBB was low (3 and 2 out of 12 samples respectively). The concentration range of EHTeBB was 0.046–0.21 ng/g d.w. BEHTBP (not in the figure) was detected at somewhat higher concentrations (0.23–3.3 ng/g d.w). The highest concentration was found in sediment from Waldemarsudde (Stockholm, Sweden) close to WWTP outlet.

ATE (0.092 ng/g d.w; not in the figure) and DPTE (0.5 ng/g d.w.) were only detected in one of the sediments (Åsefjorden, Norway).

BTBPE was detected in 50% of the samples and the concentration range was 0.024–0.25 ng/g d.w. The highest concentration of BTBPE was like BEHTBP found in the sediments from Waldermarsudde (0.25 ng/g d.w.) and Torshavn, Faroe Island (0.19 ng/g d.w.), both influenced by WWTP-effluents. BATE was not detected in any of the sediment samples.

More data on "BFR ethers and esters" to compare this reports results are summarised in chapter 2.2, (Table 2.4–2.9).

Other flame retardants

All the flame retardants in this group were detected with a frequency of 50% or higher. The most frequently detected flame retardants were DP (100%) and PBT (92%) (Tabell 4.1).

The DP-concentrations varied in the range 0.0084 to 3.4 ng/g d.w. with a median concentration of 0.83 ng/g d.w. The median concentration of PBT was lower (0.011 ng/g d.w.) but the sediment from Waldermarsudde contained a higher concentration (2.7 ng/g d.w.). This sediment also contained increased concentrations of DBDPE compared to the median concentration (0.22 ng/g d.w.). The concentration of DBDPE detected in the sediments from Waldermarsudde and Torsbyfjärden were 2.4 and 0.1 ng/g d.w. respectively. Ricklund et al. (2009) also detected DBDPE in sediment from Waldermarsudde and Torsbyfjärden. The concentrations were 8.6–11 ng/g d.w. and 0.18–2.1 ng/g d.w., respectively. Ricklund (2009) suggest the nearby WWTP-effluent as a source for DBDPE.

HBB was detected in 6 out of 12 samples and the highest concentration was again found in sediment from Waldermarsudde (0.19 ng/g d.w.). PBEB was detected in 7 out of 12 sediments but generally at low concentrations (0.0012–0.0075 ng/g d.w) (Figure 4.12).

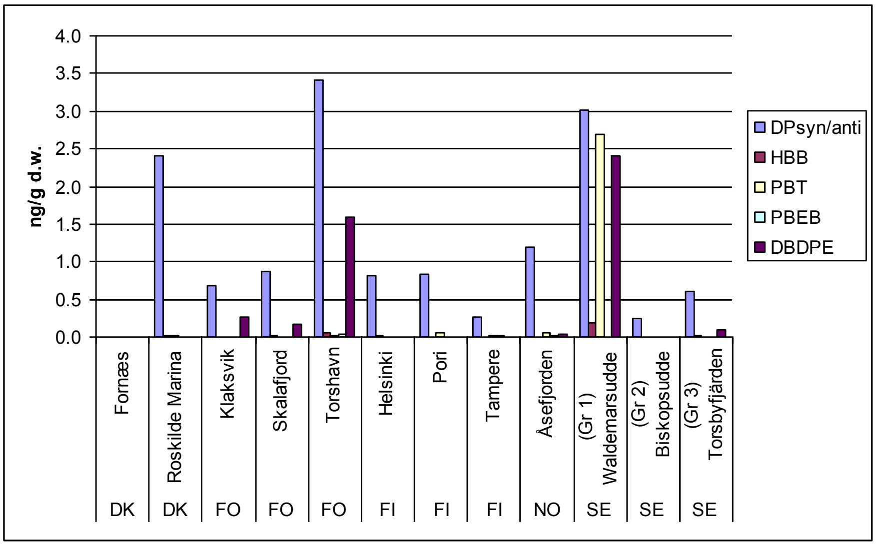


Figure 4.12 Concentrations of "other flame retardants" in sediment samples.

TBECH was detected in 50% of the samples. Low concentrations were detected in most of the samples (0.047–0.88 ng/g d.w.) but the sediments from the urban influenced Åsefjorden contained a high concentration (350 ng/g d.w.).

More data on "Other FRs" to compare this reports results are summarised in chapter 2.2, (Table 2.10–2.15).

4.1.5 Sludge

Phenolic BFRs

The detection frequencies of phenolic BFRs in sludge were low. The most frequently detected bromophenol was 246TBP (23%) followed by PBP (15%), TBBPA (15%) and 24DBP (8%).

The concentrations in sludge were however generally quite high compared to sediment samples from the environment. For example the concentration of 246TBP in sediments was 0.2–7.8 ng/g d.w. and in sludge 5–100 ng/g d.w. The highest value was found in sludge from Henriksdal WWTP (Stockholm).

TBBPA was detected in sludge in samples from Torshavn (Faroe Islands) and Roskilde (Denmark) (11 and 32 ng/g d.w., respectively). PBP was detected in two sludge samples, Roskilde (1.02 ng/g d.w.) and Reykjavik (3.5 ng/g d.w.).

The concentrations of the phenolic BFRs in the two landfill sludge samples, (Sweden) were below LOQ. In sludge from the recycling facilitys Grønmo and Hellik Teigen (Grønmo, Norway) only 246TBP was detected (0.14–0.19 ng/g d.w.).

Storm water sludge was collected in Finland from three stations, Herttoniemi, Hyvinkää and Ämmässuo. The sludge from Herttoniemi contained TBBPA (59 ng/g d.w.) and low concentrations of 246TBP (0.07 ng/g f.w.). The Ämmässuo sample contained all phenolic BFRs analysed except TBBPA. The concentration range was 0.17–0.26 ng/g d.w. Phenolic BFRs were not present in the sample collected from Hyvinkää. More data on "Phenolic BFRs" to compare this reports result with are summarised in chapter 2.2, (Table 2.2–2.3).

BFR esters and ethers

The detection frequency of the 246TBP-derivatives ATE, DPTE and BATE were 31%, or 4 out of 13 samples. DPTE occurred in the highest concentration (120 ng/g d.w.) which was found in a sludge sample from Reykjavik, Iceland. The DPTE concentration was however mostly lower than the concentrations of BDE-209 (62–2000 ng/g d.w.) but higher than BDE-47 (3.5–31 ng/g d.w.).

TBA, BTBPE and BEHTBP were detected in all the included WWTP sludge samples (100% detection frequency) while EHTeBB was present in 77% of the samples. The brominated phthalate ester (BEHTBP) occurred in the highest concentration. The median concentration was 18 ng/g d.w. in sludge from the different countries.

In landfill sludge from Sweden BTBPE (3.4 ng/g d.w.) and BEHTBP (1.1 ng/g d.w.) was detected. Sludge from Alfsnes (Iceland) contained only one substance above LOQ, the tetrabromobenzoat ester EHTeBB (0.74 ng/g d.w.).

The most polluted waste deposit runoff sludge was from Ämmässuo (Finland) (Figure 4.13) and contained BTBPE (3.3 ng/g d.w.), BEHTBP (3.9 ng/g d.w.), EHTeBB (0.76 ng/g d.w.) and TBA (0.014 ng/g d.w., not shown in the figure).

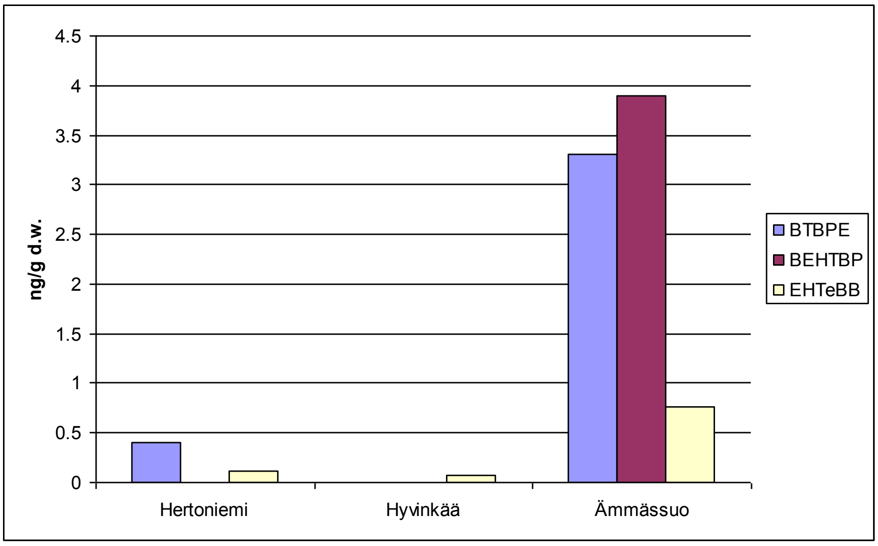


Figure 4.13 Concentrations of the most important BFR esters and ethers in industrial storm water sludge (Herttoniemi) and sludge from waste deposit drainage wells (Hyvinkää and Ämmassuo).

The waste water runoff sludge and storm water sludge from Hyvinkää and Herttoniemi respectively, contained some of the "BFR ethers & esters" in quite low concentrations (Figure 4.13; Appendix 2.2).

More data on "BFR ethers and esters" to compare this reports results are summarised in chapter 2.2, (Table 2.4–2.9).

In the two recycling facilities in Norway were only DPTE (0.14 and 0.19 respectively) and EHTeBB (0.12 and 1.7 ng/g d.w. respectively) detected which is approximatly in the same concentration range as BDE-47(<0.062 and 0.21 respectively) and BDE-209 (0.025 and 0.34 ng/g d.w. respectively).

Other flame retardants

DP, DBDPE, and PBT were detected in all samples. TBECH was detected in 46% of the samples.

The concentration range for DP was 0.81–34 ng/g d.w. The highest concentrations were found in Silkeborg WWTP (34 ng/g d.w.) and a hospital WWTP (32 ng/g d.w.; Torshavn), (Figure 4.14).

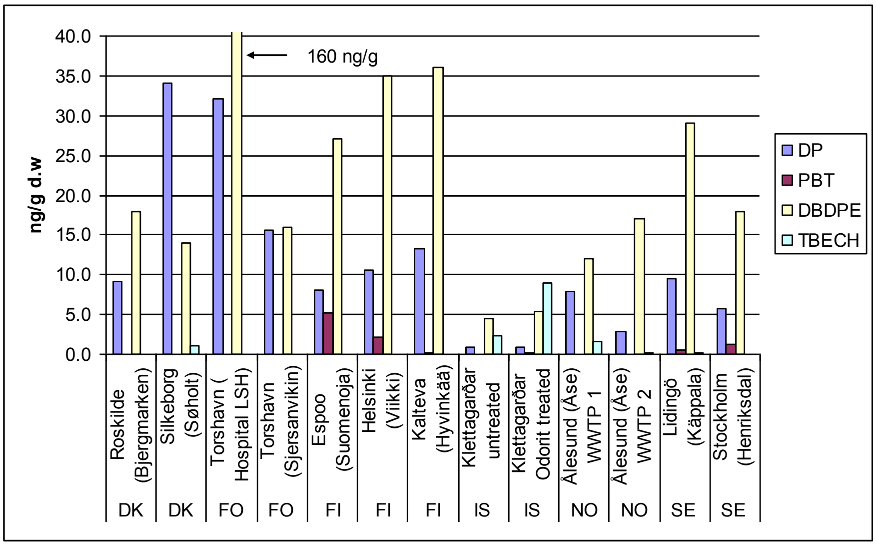


Figure 4.14 Concentrations of the most important flame retardants in sludge samples.

These levels are in the same range as for BDE-47 and BDE-99.

The concentration range for the fully brominated diphenylethane DBDPE was 4.5–160 ng/g d.w. This concentration range is comparable with the reference substances BDE-47 and BDE-209 (Appendix 2.3). The highest concentration was detected in hospital sludge (160 ng/g d.w.; Torshavn Faroe; Islands) and the lowest concentrations in samples from Reykjavik WWTP (4.5–5.4 ng/g d.w.). The concentrations in the Finnish sludge samples were somewhat elevated compared to the other countries (Figure 4.14).

The concentration range for PBT and TBECH was 0.027–5.2 ng/g d.w. and <0.27–9.0 ng/g d.w. respectively. The highest concentrations of PBT were found in sludge from Helsinki and Espoo WWTP and the highest concentration of TBECH in a sample from Reykjavik, Iceland (Figure 4.14).

PBEB and HBB were detected at a frequency of 69% and 31% respectively (Table 4.1) and at lower concentrations than the other flame retardants in this group. The concentration range was <0.022–0.13 ng/g d.w. and <0.18–0.20 ng/g d.w respectively. The highest concentrations were found in sludge collected from Torshavn WWTP, Faroe Islands and Reykjavik, Iceland respectively (Figure 4.15).

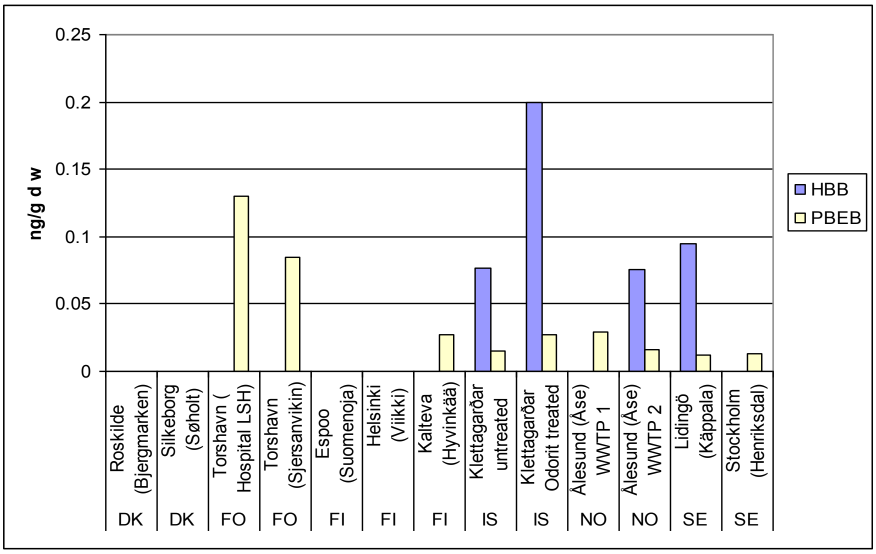


Figure 4.15 Concentrations of the most important flame retardants in sludge samples.

Sludge from the Swedish land fills contained 9.5 and 26 ng/g d.w. of DP, which is in the same concentration range as BDE-47. DP was not detected in landfill sludge from Iceland. In sludge from recycling facilities (Norway), industrial storm water sludge (Herttoniemi, Finland) and sludge from waste deposit drainage wells (Hyvinkää and Ämmassuo, Finland) only low concentrations were detected (<0.02–1.8 ng/g d.w. Figure 4.16).

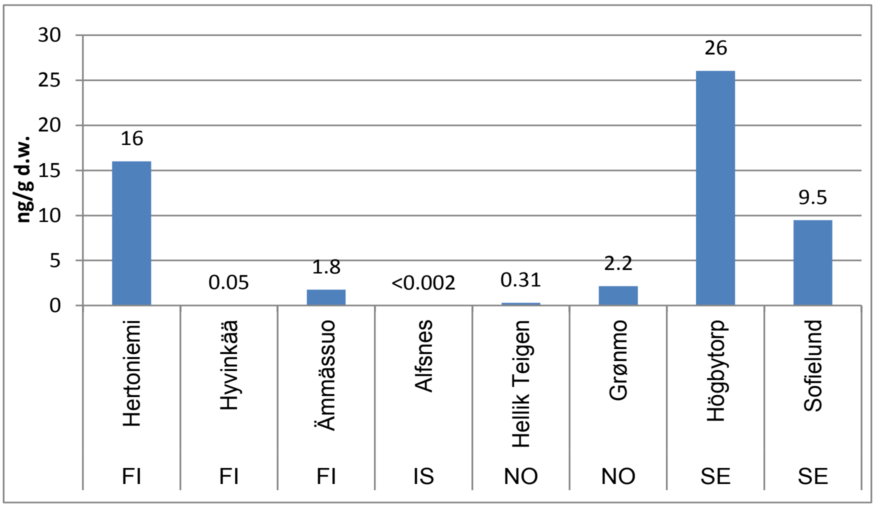


Figure 4.16 Concentration of DP in industrial storm water sludge (Herttoniemi), sludge from waste deposit drainage wells (Hyvinkää, Ämmassuo), landfill sludge (Alfsnes), sludge from recycling facilities (Hellik Teigen and Grønmo) and landfill sludge (Högbytorp and Sofielund, Sweden).

The highest measured concentration of PBEB was in waste deposit runoff sludge collected from Ämmässuo (0.09 ng/g d.w.). DBDPE was detected in storm water sludge from Herttoniemi (0.76 ng/g d.w.). DP was detected in all but one sample (Alfnes; Figure 4.16). HBB was found in all but not the Swedish samples, however, the concentration range (0.015–0.72 ng/g d.w.) was lower compared to DP (Appendix 2.2).

More data on "Other FRs" to compare this report results are summarised in chapter 2.2, (Table 2.10– 2.15).

4.2 Concentration patterns at geographically related sites

Air sampling was only performed occasionally in three of the Nordic countries why a whole picture for the Nordic countries is not possible to obtain. The emerging brominated flame retardants and dechlorane plus occurred in the Nordic atmosphere both in background and urban areas. However, the concentrations and the distribution of the different substances varied among the different sampling sites. Brominated phenols occurred at the Swedish west coast in higher levels compared to the PBDEs while BFR ethers and esters occurred in similar levels as PBDEs (data from the Swedish monitoring program for air pollutants, www.ivl.se).

The emerging brominated flame retardants and dechlorane plus were frequently found in sediments from the Nordic environment. However most of the samples were collected in urban areas with WWTP and close to point sources and other affected areas such as marinas and harbours. Data from background sites are missing. Generally a variation in the detection frequencies and concentrations among the BFRs was found at different sampling sites. The concentration levels in the sediments of the reference substances (PBDEs) varied, *e.g.* for BDE 99 between 0.05 and 6.3 ng/g d.w. which is lower or in the same order of magnitude as the concentration of the BFRs in this study. The highest PBDE concentrations were measured in a sediment sample from Åsefjorden (Norway).

The geographic distribution in the Nordic countries for some of the flame retardants found in sludge and biota are presented below. Substances presented here are bis(2-ethylhexyl)tetrabromophthalate (BEHTBP), decabromodiphenylethan (DBDPE), dechlorane plus (DP) and the reference substance BDE-47. These compounds occurred frequently; they represent the different groups and have somewhat different distribution patterns.

In Figure 4.17 concentrations of the reference substance BDE-47 in biological samples from different locations are presented. The highest concentration occurred in fish liver from Åsefjorden (Norway) which is in agreement with the increased concentrations found in sediments. Lower concentrations were found in Iceland, the Faroe Islands and Finland. The sampling sites in Iceland and the Faroe Islands are considered to be background areas while the samples from Finland were collected in urban areas. The low concentrations in the Finnish samples may be due to that lean fish were analysed. The concentrations of PBDE in guillemot eggs from the Baltic Sea were higher compared to those collected at the Faroe Islands.

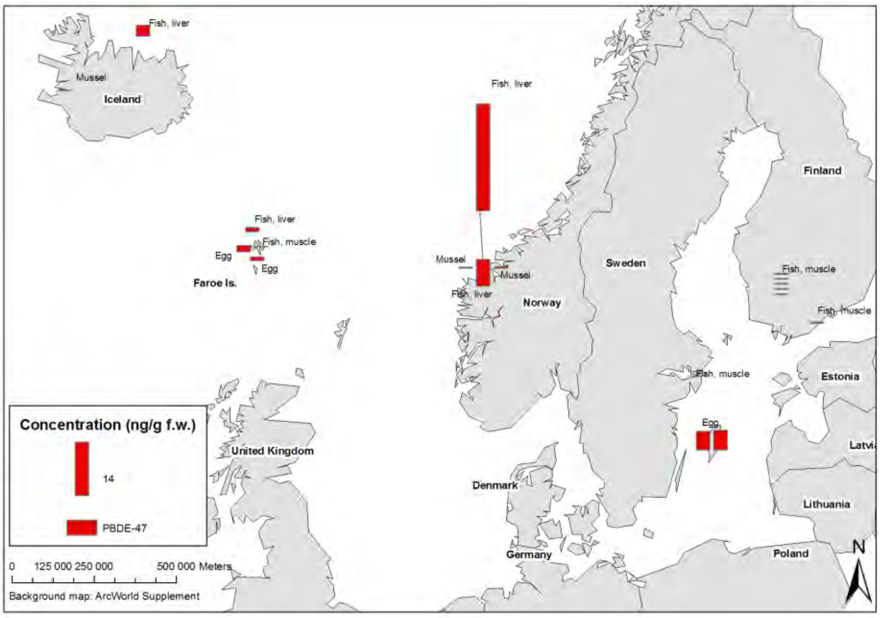


Figure 4.17: Geographical distribution of the concentration of the BDE-47 congener in biological samples (note that the bars are not placed at the precise sampling location).

For BEHTBP in biological samples, Figure 4.18, higher concentrations occurred, like for BDE 47, in the biota samples from Åsefjorden. Increased concentrations occurred also in one fish sample from Finland and in one from Faroe Islands. The Finnish sample is from an urban area while the sample from Faroe Island originates from a background area.

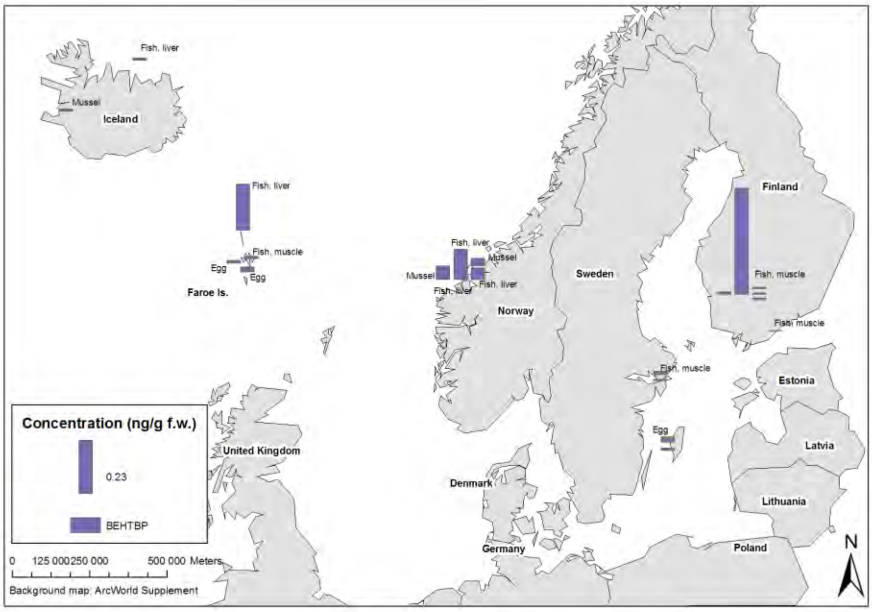


Figure 4.18: Geographical distribution of the concentration of bis (2-ethylhexyl) tetrabromophthalate (BEHTBP) in biological samples (note that the bars are not placed at the precise sampling location).

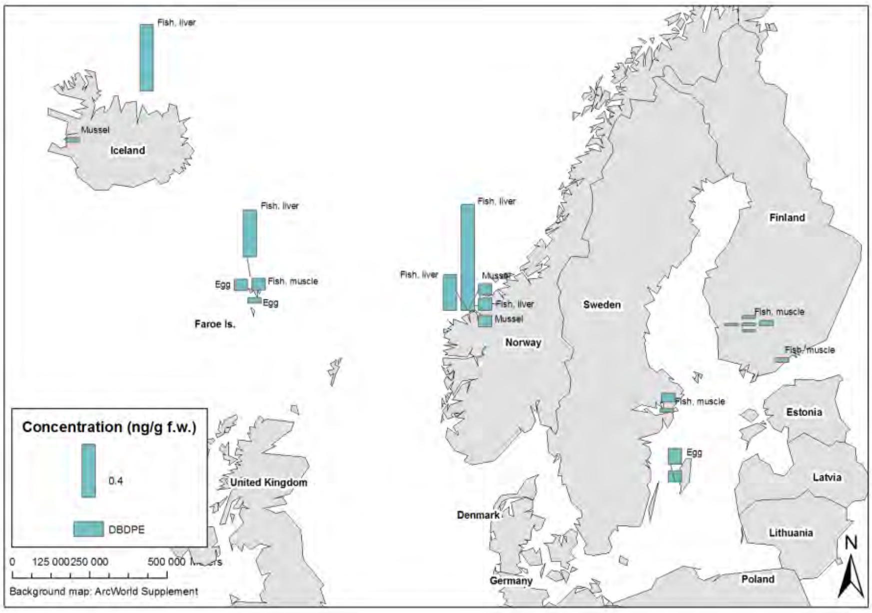


Figure 4.19: Geographical distribution of the concentration of decabromodiphenylethan (DBDPE) in biological samples (note that the bars are not placed at the precise sampling location).

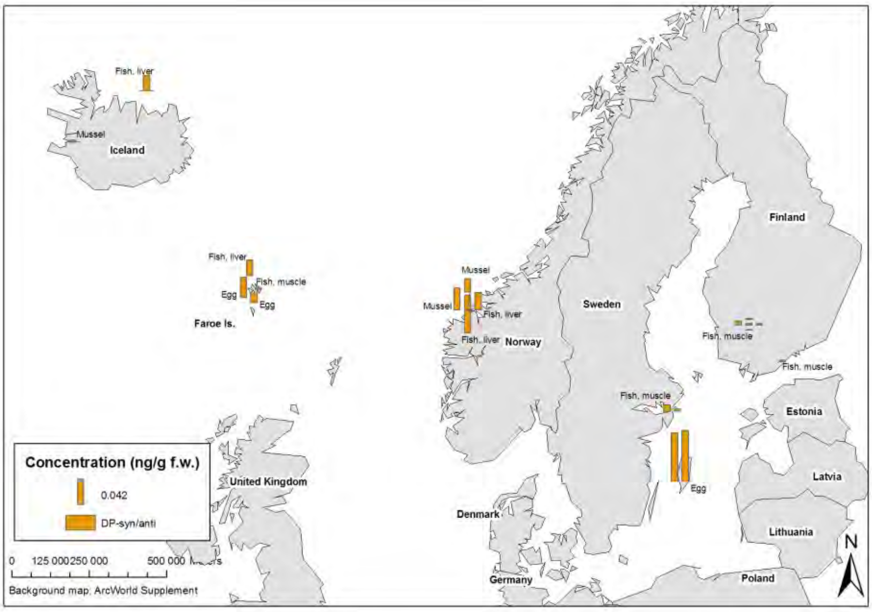


Figure 4.20: Geographical distribution of concentrations of Dechlorane Plus (syn+anti) in biota samples (note that the bars are not placed at the precise sampling location).

In Figure 4.19 the geographical distribution of DBDPE in biological samples is shown. DBDPE and BDE-47 shows a fairly equal occurrence in biological samples which may indicate a common source or use.

The geographical distribution of DP in biological samples is shown in Figure 4.20. No apparent geographical difference in the DP levels was found. Increased concentrations occurred in affected areas in Finland and Norway. As for BDE 47, increased concentrations of DP occurred in the guillemot eggs from the Baltic Sea compared to those from the Faroe Islands. The concentrations in fish muscle (Faroe Islands, Finland) were low or just above LOD (0.002 ng/g f.w.) except in one sample from Finland.

The geographical distribution of BDE-47, BEHTBP, DBDPE and DP in sludge shows a fairly equal occurrence (Figure 4.21). This may indicate a widespread use of these FRs in the Nordic countries. However, there are variations in the distribution among different substances; especially DBDPE deviates in one sample from the Faroe Islands.

In Table 4.3 concentration ranges, as measured in the present study, are presented for the most frequently detected substances and the reference PBDE. Concentrations of the emerging FRs are, with a few exceptions, in the same order of magnitude or lower compared to the sum of BDE congeners BDE-28, -47, -99, -100, -153 and -154 (congeners of PBDE included in WFD).

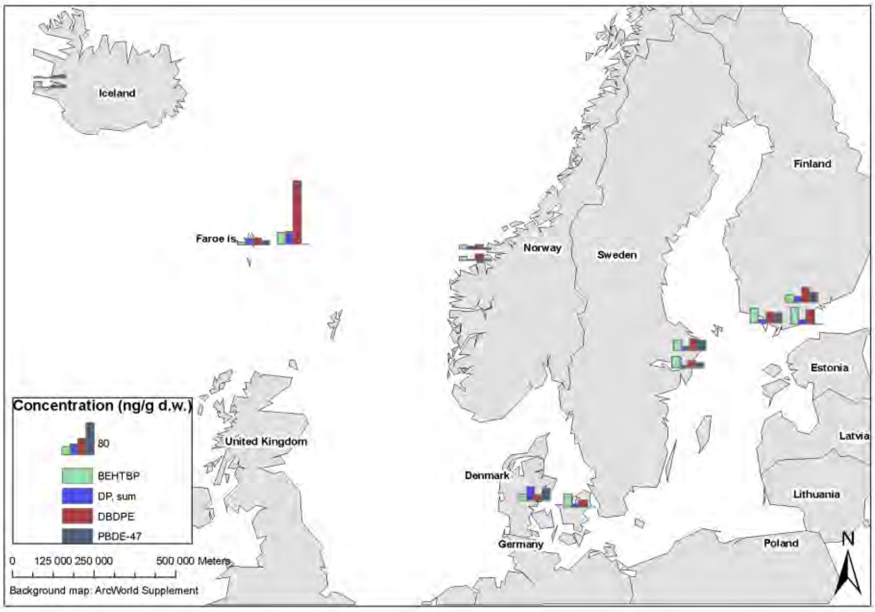


Figure 4.21 Geographical distribution of concentrations of BDE-47, BEHTBP, DBDPE and Dechlorane Plus (syn+anti) in sludge samples (note that the bars are not placed at the precise sampling location).

Table 4.3 Concentration ranges for the substances most frequently detected in biota, sediment and sludge.

Matrix	**Biota (ng/g f.w.)**[a]	**Sediment (ng/g d.w.)**[b]	**Sludge (ng/g d.w.)**[c]
Phenolic BFRs			
24DBP	<0.02–6.4	<0.03–2.9	<0.04–40
246TBP	<0.03–86	<0.03–7.8	<0.01–100
BFR esters & ethers			
BTBPE	<0.0052–0.2	<0.0081–1.7	<0.075–3.9
TBA	0.013–14	0.0009–0.66	0.00034–2
BEHTBP	<0.026–0.46	<0.013–3.3	<0.13–42
EHTeBB	<0.006–0.18	<0.0082–0.21	<0.25–2.6
Other BFRs			
DP syn+anti	0.002–0.083	0.0084–3.4	0.051–34
HBB	0.0058–0.072	<0.022–0.19	<0.14–0.72
PBT	0.0015–0.021	<0.011–2.7	<0.027–5.2
PBEB	<0.00034–0.0044	<0.0098–0.046	<0.00095–0.13
DBDPE	<0.082–0.12	<0.00001–2.4	<2.5–160
TBECH, sum	0.0032–1.6	0.010–350	0.018–9.0
Reference compounds			
pentaBDE[d]	0.062–36	0.096–13	0.18–76

The values are min-max and "<" indicates concentration under the limit of quantification (LOQ), and the lowest LOQ is listed here. For individual compounds in groups concentrations below the LOQ have been set to 0.5×LOQ.

a: Matrices: egg, fish muscle, fish liver and mussel
b: Marine, brackish and freshwater sediments
c: Landfill/waste deposit, WWTP and stormwater
d: Sum of congeners 28, 47, 99, 100, 153 and 154

4.3 Initial ecotoxicological assessment

In the present study an initial ecotoxicological assessment was made for the FRs most frequently detected in sediment and biota (see Table 4.1).

The data on ecotoxicological effects of the emerging BFRs, as well as the chlorinated Dechlorane plus, are scarce. In the Norwegian screening study (Møskeland, 2010) predicted no-effect concentration (PNEC) were thus assigned to these substances by read-across from the BDEs and for TBBPA which have PNEC derived in EU risk assessments and by the Swedish Chemicals Agency, see Table 4.4. The table also includes quality standards for pentaBDE as developed under the Water Framework Directive (WFD) as well as additional ecotoxicological effect concentrations as described by Møskeland (2010), listed in the ECOTOX database or reported in other literature sources. These additional data have not been further validated.

The pentaBDE quality standards for marine waters under the WFD were used for comparison with the measured concentrations, in analogy with the "read-across" method by Møskeland (2010).

A comparison of the sediment concentrations as measured in the present project (Table 4.3) with the pentaBDE quality standard for marine sediment (QSsediment, 310 ng/g d.w., Table 4.4) showed that the measured concentrations were below the QS, with the exception of the concentration of sum TBECH (350 ng/g d.w.) in one sample.

Table 4.4 Ecotoxicological data for the flame retardants most frequently detected in sediment and biota in the present study.

BFR	PNEC$_{water}$ (µg/l)[a]	PNEC$_{sediment}$ (mg/kg d.w.)[a]	Additional ecotoxicological effect concentrations
Phenolic BFRs			
24DBP	-	-	ICG$_{50}$ (*Telrahymena pyriformis*) ciliate, 60 hrs: 9.97 mg/l (Schultz and Riggin, 1985)
246TBP	0.53	1.55	ICG$_{50}$ (*Telrahymena pyriformis*) ciliate, 60 hrs: 2.95 mg/l (Schultz and Riggin, 1985) EC$_{50}$ (*Daphnia magna*), invertebrate, immobility, 48 hrs: 1.31 mg/l (Kopperman *et al.* 1974) NOEC (*Nitocra spinipes*) invertebrate, larvae development, 6 days: 300 µg/l; mortality 6 days: >1000 µg/l; LC$_{50}$ (Nitocra spinipes) invertebrate, 96 hrs: 920 µg/l (Breitholtz *et al.* 2008) NOEC (*Psammechinus miliaris*) invertebrate, inhibition of fertilization, 75 min: 0.1 µM (Schäfer *et al.* 2009) LC$_{50}$ (*Pimephales promelas*) fish, 96 hrs: 6.5–6.8 and 1.1 mg/l (Simonesen et al. 2000); 96 hrs: 6.5–6.8 mg/l; 8 days: 4.5–4.9 mg/l (Phipps *et al.* 1981); 96 hrs: 6.54 mg/l (Geiger *et al.* 1985); 96 hrs: 6.25 mg/l (Broderius *et al.* 1995) LC$_{50}$ fish, 96 hrs 0.24–6.6 mg/l (Fisk *et al*. 2003)
BFR esters & ethers			
BTBPE	0.53	1.55	
TBA	-	-	
BEHTBP	≥ 0.2	≥ 127	
EHTeBB	0.53	1.55	
Other BFRs			
HBB	0.53	1.55	EC$_{50}$ (*Tetrahymena pyriformis*), invertebrate, population growth rate, 24 hrs: 20 mg/l (Yoshioka *et al.* 1985) NOEC (*Nitocra spinipes*) invertebrate, larvae development, 6 days: 33.4 mg/l; mortality 6 days: 33.4 mg/l; LC$_{50}$ (Nitocra spinipes) invertebrate, 96 hrs: >100 mg/l (Breitholtz et al. 2008)
PBT	0.53	1.55	EC$_{50}$ (*Chlorella sp., Skeletonema costatum, Thalassiosira guillardii*) algae, reduced growth, 96 hrs: > 1 mg/l (Walsh *et al.* 1987) LC$_{50}$ fish, 48 hrs: > 5 mg/l (Simonesen et al. 2000)
PBEB	0.53	1.55	EC$_{50}$ (*Chlorella sp., Skeletonema costatum, Thalassiosira guillardii*) algae, reduced growth, 96 hrs: > 0.5 mg/l (Walsh *et al.* 1987)
DBDPE	≥ 0.2	≥ 127	EC$_{50}$ (*Daphnia magna*) invertebrate, 48 hrs: 19 µg/l (Nakari and Huhtala, 2009)
TBECH, sum	-	-	NOEC (*Nitocra spinipes*) invertebrate, larvae development, 6 days: 40 µg/l; mortality 6 days: 360 µg/l; LC$_{50}$ (Nitocra spinipes) invertebrate, 96 hrs: 654 (488–1092) µg/l (Breitholtz et al. 2008)
Reference compounds			
pentaBDE[b]	0.53	1.55	
octaBDE[b]	≥ 0.2	≥ 127	
PBDE (WFD)[c]	AA-EQS (other surface waters): 0.0002 µg/l (The EQS refers to the prevention of secondary poisoning of top predators in the marine environment); QS$_{saltwater}$ (Pelagic community): 0.053 µg/l QS$_{sediment}$ (marine sediment): ≈ 310 µg/kg dry wt TGD standard sediment QS$_{biota}$ (secondary poisoning of predators): 1 mg/kg (tissue of prey, wet wt)		

PNEC values as obtained by read-across from PBDE (Møskeland, 2010), additional ecotoxicological data are Median effective concentration (EC50), Median cell growth inhibition concentration (ICG50) and Median lethal concentration (LC50).

a: PNEC as assigned in Møskeland (2010), valid for freshwater

b: PNEC as derived in the EU risk assessment, see Møskeland (2010), valid for freshwater

c: Water Framework Directive (WFD); EQS is established only for congener numbers 28, 47, 99, 100, 153 and 154 (Directive 2008/105/EC and supportive background documents, CIRCA)

The concentrations measured in biota (Table 4.3) were converted to concentration in water (cbiota/BCF, where the BCF were calculated from logKow (Table 2.1) using the formulas given in the TGD (2003)). The phenolic substances were by this method of approach predicted to have the highest water concentrations (246TBP, max 0.13 µg/l; 24DBP max 0.059 µg/l), which were above the pentaBDE quality standard for marine water (0.053 µg/l, Table 4.4).

As a reference the concentration of pentaBDE in sediment and biota (Table 4.3) was compared with QS for water and sediment (Table 4.4). The sediment QS was not exceeded but the highest re-calculated concentration in water (0.0008 µg/l, BDE congeners 28, 47, 99, 100, 153 and 154) did exceed the EQS.

These comparisons with very few limit values indicate that concentrations of the more water soluble substances may in some cases be in levels that can cause negative effects on the pelagic community. For the sediment compartment the limit value was only exceeded in one sample.

A comparison between the pentaBDE limit values with the additional ecotoxicological data (Table 4.4) does also indicate that the "read-across" limit values may not be protective for some of the substances. This is an indication that substance specific PNEC values need to be developed.

Furthermore, the lipophilic properties of the studied FRs indicate that they may accumulate in living organisms. As several of these FRs have shown toxic properties (see *e.g.* Simonsen et al. 2000; Harju *et al.* 2008) it is thus of relevance to also consider potential negative effects to predators and humans.

5. Conclusions

In total 64 samples have been analyzed. The samples included air, different biota, sediment, and sludge. In general, the emerging brominated flame retardants, the chlorinated substance dechlorane plus, and the reference compounds (BDEs) were regularly found in all the sample matrices indicating a widespread distribution in the Nordic environment. However, there are differences among substances and group of substances and indications of geographic differences.

Some FRs were frequently found in air. However, the air concentrations varied for the different substances and among the different sampling sites. No obvious concentration pattern among the different Nordic countries was identified, except for DBDPE which occurred in higher concentrations in Oslo air.

The air concentrations were generally higher in urban areas than in background areas indicating the vicinity to emission sources. Increased concentrations of some BFRs in indoor air indicated that diffuse emission from products may occur. The occurrence of FRs in background air indicates that the atmosphere is an important transport medium and that, as for PBDEs, a long range transport in the atmosphere may take place.

Several of the FRs, which occurred in air, were also found in the moss samples. This indicates that atmospheric deposition is a possible pathway for these contaminants to the terrestrial ecosystem. However, the two samples included in the screening were collected close to possible point sources.

Some of the emerging FRs were like the reference substances (PBDEs) widespread in fish, mussels and guillemot eggs in Nordic region. Hexabromobenzene (HBB), pentabromotoluene (PBT) and decabromodiphenylethane DBDPE as well as 2,4,6-tribromoanisol (TBA) were present in all the 21 biota samples. Generally the highest concentrations were found in lipid rich samples such as fish liver and Guillemot egg.

Several FRs were frequently found in sediments from the Nordic environment. Most of the sediment samples were however collected in urban areas where emissions from WWTPs and other diffuse sources affect the concentrations. Increased concentrations of the FRs were also found in sediments taken in harbours or marinas.

FRs was present in sludge from WWTPs, storm water sludge and sludge from landfills. Some of the substances, BTBPE, TBA, and DP, occurred in all the sludge samples from WWTPs. The frequent occurrence of these substances in the different sludge samples indicates a widespread use of these FRs in the Nordic countries.

In this screening study the concentrations of the selected FRs were determined in a variety of media, collected at different geographical sites in the whole Nordic environment. The samples represents different source characteristics *e.g.* point sources and background. Thus the measurements of the FRs have been carried out in several media at several sites but with only a few samples from each site which gave a “snap shot” of the situation. This screening study does not give a complete overview over the general contamination level in the Nordic countries. Furthermore, the data on exotoxicological effects of these compounds are rather scarce. An intial risk assessement based on “read-across” from pentaBDE cannot exclude negative effects on pelagic community. However, it was not possible to assess the ecotoxicological risk satisfactorily.

The conclusions above are based on relatively few data, however the screening has identified a widespread occurrence of several emerging BFRs in the Nordic environment and follow-up studies for identification of emission sources and important pathways, as well as investigations of the ecotoxicology and human effects is recommended.

6. Acknowledgements

Denmark

Thanks to Rossana Bossi, National Environmental Research Institute, Aarhus University (NERI), Martin Larsen, (NERI), Jakob Nykrog †, Miljøcenter Århus and Stine Kjær Jespersen, Eurofins for assistance during selection of sampling sites providing samples for this project.

Faroe Islands

Samples of marine sediments were taken with assistance from Bjørki Geyti, Gunnvør á Norði at Faroe Marine Research Institute and Steini Andreassen, Magni Auðunsson and Martin Gregersen at pf Bakkafrost. Black guillemot eggs were sampled by Bjørn Patursson and Jóannes Mikkelsen. Arctic char was sampled by Kristian Martin Hansen and Jón í Haraldsstovu. Samples of cod were secured by Petur Steingrund at Faroe Marine Research Institute. Assistance in sampling and sample preparation otherwise was provided by Katrin Hoydal and Eirikur Danielsen.

Finland

Thanks to Kirsti Kalevi, Finnish Environment Institute (SYKE) and Markku Korhonen (SYKE) for assistance during selection of sampling sites and providing samples for this project.

Iceland

Georg B. Fridriksson, Icelandic Museum of Natural History, and Sigurdur B. Finnsson, the Environment Agency of Iceland, are acknowledged for sample collection.

Norway

Thanks to Thomas Møskeland and colleague at Det Norske Veritas (DNV) for sampling and sample preparation.

Sweden

Professor Åke Bergman is gratefully acknowledged for the help with derivatisation of the bromophenols included in this investigation.

The collection of Swedish samples was coordinated by the Swedish Environmental Reserach Institute.

7. References

Allard, A.-S., M. Remberger and A. H. Neilson (1987). “Bacterial O-methylation of halogen-substituted phenols.” *Appl. Environ. Microbiol.* 53: 839–845.

Asplund L., Egebäck A-L., Eriksson U., Haglund M. and Winberg A.: “Screening av Tetrabrombisfenol A”. ITM report, Stockholm University. http://www3.ivl.se/miljo/projekt/dvss/pdf/TBBPA.pdf

Ballschmiter, K. and Zell, M. (1980). Analysis if polychlorianted biphenyls (PCB) by glass capilalry gas chromatography. Composition of technical aroclor- and clophen-PCB mixtures. *Fresenius Z. Anal. Chem.* 302: 20–31.

Betts, K. S., C. M. Cooney, et al. (2006). “A new flame retardant in the air |Environmental Science & Technology 40(4): 1090–1095.

Betts, K. S. (2010) Flame retardants are the suspected source of a new compund in the environment. Environ. Sci. Technol. Vol 44 546–547.

Breitholtz, M., Rattfelt Nyholm, J., Karlsson, J. and Andersson, P.L. (2008) Are individual NOEC levels safe for mixtures? A study on mixture toxicity of brominated flame–retardants in the copepod Nitocra spinipes. Chemosphere 72: 1242–1249

Broderius, S.J., Kahl M.D. and Hoglund, M.D. (1995) Use of Joint Toxic Response to Define the Primary Mode of Toxic Action for Diverse Indus-trial Organic Chemicals. Environ.Toxicol.Chem. 14(9):1591–1605 (Au-thor Communication Used). Cited in the ECOTOX database.

CIRCA priority substances library http://circa.europa.eu/Public/irc/env/wfd/library?l=/framework_directive&vm=detailed&sb=Title 2010.09.30

ECOTOX database, homepage of US EPA (http://cfpub.epa.gov/ecotox/); the data search was made with CAS numbers as listed in Table 1, 2010.09.28

Fielman K.T., Woodin S.A. och Lincoln D.E. (2001) Polychaete indicator species as a source of natural halogenated organic compounds in marine sediments. Environ. Tox. Chem. 20, 738–747.

Fisk, P.R., Girling, A.E. and Wildey, R.J. (2003) Prioritisation on Flame Retardants for Environmental Risk Assessment. Environment Agency of the United Kingdoms.

Gauthier, G., Potter, D., Hebert, C. and Letcher, R. (2009). Temporal trends and spatial distribution of non-polybrominated diphenyl ether flame retardants in the eggs of colonial populations of Great Lakes Herring Gulls. Environ. Sci. Technol. 43: 312–317.

Geiger, D.L., Northcott, C.E., Call, D.J. and Brooke, L.T. (1985) Acute Toxicities of Organic Chemicals to Fathead Minnows (Pimephales pro-melas), Vol. 2. Ctr.for Lake Superior Environ.Stud., Univ.of Wisconsin-Superior, Superior, WI :326 p. Cited in the ECOTOX database.

Gouteux, B., M. Alaee, S. A. Mabury, G. Pacepavicius and D. C. G. Muir (2008). “Polymeric Brominated Flame Retardants: Are They a Relevant Source of Emerging Brominated Aromatic Compounds in the Environment?” *Environmental Science & Technology* 42(24): 9039–9044.

Gribble, G. W. (2000). “The natural production of organobromine compounds.” *Environ. Sci. Pollut. Res.* 7: 37–49.

Harju, M., Heimstad, E., Herzke, D., Sandanger, T., Posenr, S. and Wania, F. Current state of knowledge and monitoring requirements – Emerging “new” brominated flame retardants in flame retarded products and the environment. TA-2462/2008

He, M., Lou, X., Yu, L., Liu, J., Zhang, X., Chen, S., Chen, D. and Mai, B. (2010). Tetrabromobisphenol-A and hecacyclododecane in birds from an e-waste region in south China: influence of diet on diastereoisomer- and enantiomer-specific distribution and trophodynamics. Environ. Sci. Technol. 44: 5748–5754.

Hoh, E., Zhu, L. and Hites, R. (2005). Novel flame retardants, 1,2-Bis(2,4,6-tribromophenoxy)ethane and 2,3,4,5,6-Pentabromo ethylbenzene, in United

States' environmental samples. Environ. Sci. Technol. 39: 2472–2477.

Hovander, L., M. Athanasiadou, et al. (2000). "Extraction and cleanup methods for analysis of phenolic and neutral organohalogens i plasma." J. Anal. Toxicol. Environ. 24: 696–703.

Hovander, L., T. Malmberg, M. Athanasiadou, I. Athanassiadis, S. Rahm, Å. Bergman and E. Klasson Wehler (2002). "Identification of hydroxylated PCB metabolites and other phenolic halogenated pollutants in human blood plasma." *Arch. Environ Contam. Toxicol.* 42(1): 105–117.

Jensen, S., L. Häggberg, H. Jörundsdottir and G. Odham (2003). "A quantitative lipid extraction method for residue analysis of fish involving nonhalogenated solvents." *J. Agric. Food Chem.* 51(19): 5607–5611.

JIG 2007, Joint Industri guide (JIG) Material Composition Declaration for Electronic Products. http://www.ce.org/Standards/JIG-101_Ed_3_0_(2).pdf.

Johnson-Resterpo, B., Adams, D. and kannan, K. (2008). Tetrabromobisphenol A (TBBPA) and hexabromocyclododecanes (HBCD) in tissues of humans, dolphins, and sharks from the United States. Chemosphere, 70: 1935–1944.

Kaj, L Norström,K Egelrud, L Remberger, M Lilja, K Brorström-Lundén, E (2010) Results from the Swedish National Screening Programme 2009: Subreport 2. Dechlorane Plus IVL report in prep.

Kirkegaard, A., Björklund, J. and Fridén, U. (2004). Identification of the flame retardant Decabromodiphenyl ethane in the environment. Environ. Sci. Technol. 38: 3247–3253. Lam, J. C. W., R. K. F.

Kopperman, H.L., Carlson, R.M. and Caple, R. (1974) Aqueous Chlorination and Ozonation Studies. I. Structure-Toxicity Correlations of Phenolic Compounds to Daphnia magna. Chem.Biol.Interact. 9(4):245–251. Cited in the ECOTOX database.

Lau, M. B. Murphy and P. K. S. Lam (2009). "Temporal trends of hexabromocyclododecanes (HBCDs) and polybroninated diphenyl ethers (PBDEs) and detection of two novel flame retardants in marine mammals from Hong Kong, south China." *Environ. Sci. Technol.*

Morris, S., Allchin, C., Zegers, B. Belpaire, C. Leonards, P., van Leeuwen, S. and de Boer, J. (2004). Distribution and fate of HBCD and TBBPA brominated flame retardants in North Sea estuaries and aguatic food webs. Environ. Sci. Technol. 38: 5497–5504.

Møskeland, T. (2010). Environmental screening of selected "new" brominated flame retardants and selected polyfluorinated compounds 2009". Klima- of Forurensnings Direktoratet. TA-2625/2010. Oslo, Norway.

Nakari, T. and Huhtala, S. (2009). In Vivo and In Vitro Toxicity of Decabromodiphenyl Ethane, a Flame Retardant. Environmental Toxicology. DOI 10.1002/tox.20499. Cited in Møskeland (2010).

Neilson, A. H., A.-S. Allard, P.-Å. Hynning and M. Remberger (1988). "Transformations of halogenated aromatic aldehydes by metabolically stable anaerobic enrichment cultures." *Appl. Environ. Microbiol.* 54: 2226–2236.

Neilson, A. H., A.-S. Allard, P.-Å. Hynning and M. Remberger (1991). "Distribution, fate and persistence of organochlorine compounds formed during production of bleached pulp." *Toxicol. Environ. Chem.* 30: 3–41.

Neilson, A. H., A.-S. Allard, C. Lindgren and M. Remberger (1987). "Transformations of chloroguaiacols, chloroveratroles and chlorocatechols by stable consortia of anaerobic bacteria." *Appl. Environ. Microbiol.* 53: 2511–2519.

Neilson, A. H., C. Lindgren, P.-Å. Hynning and M. Remberger (1988). "Methylation of halogenated phenols and thiophenols by cell extracts of gram-positive and gram-negative bacteria." *Appl. Environ. Microbiol.* 54: 524–530.

Nomani A.A., Ajmal M. och Ahmad S. (1996) Gas chromatography – mass spectrometric analysis of four polluted river waters for phenolic and organic compounds. Environ. Monitor. Assess. 40, 1–9.

Phipps, G.L., Holcombe, G.W. and Fiandt, J.T. (1981) Acute Toxicity of Phenol and Substituted Phenols to the Fathead Minnow. Bull.Environ.Contam.Toxicol. 26(5):585–593 (Author Communication Used) (OECDG Data File). Cited in the ECOTOX database.

Remberger, M., A.-S. Allard and A. H. Neilson (1986). "Biotransformations of chloroguaiacols, chlorocatechols, and chloroveratroles in sediments." *Appl. Environ. Microbiol.* 51: 552–558.

Remberger M., Sternbeck J. and Strömberg K., (2002): "Screening av triclosan och vissa bromerade fenoliska ämnen i Sverige". IVL report B1477.

http://www3.ivl.se/miljo/projekt/dvss/pdf/dbdpe_screening.pdf.

Schultz, T.W. and Riggin, G.W. (1985) Predictive Correlations for the Toxicity of Alkyl- and Halogen-Substituted Phenols. Toxicol.Lett. 25:47–54. Cited in the ECOTOX database.

Schäfer, S., Bickmeyer, U. and Koehler, A. (2009) Measuring Ca2+Signalling at Fertilization in the Sea Urchin Psammechinus miliaris: Alterations of this Ca2+Signal by Copper and 2,4,6-Tribromophenol. Comp.Biochem.Physiol.C 150(2):261–269. Cited in the ECOTOX database.

Sim, W.-J., S.-H. lee, I.-S. Lee, S.-D. Choi and J.-E. OH (2009). "Distribution and formation of chlorophenols and Phenolic BFRs in marine and river environment." *Chemosphere* 77: 552–558.

Simonsen, F. A., Stavnsbjerg, M., Moller, L.M. and Madsen, T. (2000) Brominated flame retardants; toxicity and ecotoxicity. København, Miljøstyrelsen (Environmental Project No. 568) URL: http://www2.mst.dk/udgiv/publications/2000/87-7944-288-9/pdf/87-944-289-7.pdf. Cited in Møskeland (2010).

Stapleton, H., Allen, J., Kelly, S., Konstantinov, S., Warkins, D., McClean, M and Webster, T. (2008). Alternate and new brominated flame retardants detected in U.S. hous dust. Environ. Sci. Technol. 42:6910–6916.

Sverko, E; Tomy, G T; Marvin, C H; Zaruk, D; reiner, E; Helm, P A; Hill, B; McCarry, B E (2008) Dechlorane Plus levels in sediment of the lower Great Lakes. Environ. Sci. Technol. 42 (2) 361–366.

Technical Guidance Document on Risk Assessment (TGD) (2003) Part II. European Chemicals Bureau.

Tomy, G., Pleskach, K., Arsenault, G., Potter, D., McCrindle, R., Marvin, C., Sverko, E. and Tittlemier, S. (2008). Identification of the novel cycloaliphtic brominated flame retardant 1,2-dibromo-4/1,2-dibromoethyl)cyclohexane in Canadian Arctic beluga (*Delphinapterus leucas*). Environ. Sci. Technol. 42:543–549.

Venier, M. and Hites, R. (2008). Flame retardants in the atmosphere near the great lakes. Environ. Sci. Technol. 42: 4745–4751.

Vetter, W., Schlabach, M., Kallenborn, R., (2002), Evidence for presens of natural hologenated hydrocarbons in southen Norwegian and polar air., Fresenius Environ. Bull., 11:4, 170–175.

Vetter, W. and D. Janussen (2005). "Halogenated natural products in five species of antarctic sponges: Compounds with POP-like proporties?" *Environ. Sci. Technol.* 39(11): 3889–1418.

von Der Recke, R., and Vetter, W., 2007, Synthesis and characterization of 2,3-dibromopropyl-2,4,6-tribromophenyl ether (DPTE) and strukturall related compounds evidenced in seal blubber and brain. Environ. Sci. Technol., 41, 1590–1595.

Walsh, G.E., Yoder, M.J., McLaughlin, L.L. and Lores, E.M. (1987) Responses of Marine Unicellular Algae to Brominated Organic Com-pounds in Six Growth Media. Ecotoxicol.Environ.Saf. 14:215–222. Cited in the ECOTOX database.

Yoshioka, Y., Ose, Y. and Sato, T. (1985) Testing for the Toxicity of Chemicals with Tetrahymena pyriformis. Sci.Total Environ. 43(1/2):149–157. Cited in the ECOTOX database.

Sammanfattning

Det övergripande syftet med föreliggande screening var att undersöka förekomsten av främst nya bromerade flamskyddsmedel i de nordiska länderna. Med nya flamskyddsmedel menas här flamskyddsmedel som nyligen har introducerats och vars användning och förekomst i miljön förväntas öka (på engelska används termen " emerging brominated flame retardants").

På grund av utfasningen av polybromerade difenyl etrar (PBDE)som flamskyddsämnen har ett stort och ökande antal alternativa flamskyddsmedel introducerats på marknaden för att fylla kraven på brandsäkerhet i olika konsumentprodukter. För många av dessa nya ämnen finns det bara sporadiska, och i en del fall inga mätningar alls, rapporterade för de nordiska länderna.

Utöver de nya bromerade flamskyddsmedlen inkluderades också Decloran Plus^{TP} (DP), ett klorerat flamskyddsmedel, i denna undersökning. Några utvalda PBDE-kongener bestämdes också för att underlätta utvärderingen av resultaten. Totalt ingick 16 olika flamskyddsmedel i screeningen.

Vissa flamskyddsmedel uppmättes frekvent i utomhusluft (*e.g.* EHTeBB, DP, HBB och PBT) och förhöjda halter påvisades också för en del föreningar i inomhusluft. Några av de undersökta föreningarna förekom på samma sätt som PBDE allmänt i biologiskt material som fisk, musslor och sillgrissleägg. De högsta halterna uppmättes i leverprover från torsk fångade i förorenade/påverkade miljöer.

Flamskyddsmedlen förekom frekvent i de insamlade sedimentproverna. De flesta proverna kom från urbana områden med emissioner från avloppsreningsverk och andra diffusa källor. Förhöjda halter påvisades också i sediment insamlade från hamnanläggningar och småbåtshamnar.

Även i slam från kommunala reningsverk och avfallsdeponier påvisades de studerade ämnena.

Generellt visade denna screening att bromerade flamskyddsmedel och DP frekvent förekom i alla provtyper vilket indikerar en omfattande användning och spridning av dessa ämnen i den nordiska miljön. Det fanns emellertid geografiska skillnader, bland annat var halterna vanligen högre i urbana miljöer jämfört med bakgrundsområden.

Summerat, denna screening studie har påvisat en utbredd förekomst av några nya bromerade flamskyddsmedel och DP i de nordiska ländernas miljö. Mätningarna har utförts i många olika medier (provtyper) och på många geografiska platser i Norden. Antalet prover har dock varit begränsat vilket innebär att mätningarna bara kan ge en ögonblicksbild av situationen. Det är därför viktigt att följa upp undersökningen med att identifiera emissionskällor och hur föreningarna sprids och transporteras i miljön. Viktigt är också att undersöka föreningarnas ekotoxicitet och effekt på människan.

Appendices

Sample list

Sample ID	**Country**	**Site**	**Site class**	**Matrix**	**Species**	**Matrix information**	**Sampling date**	**N/S coord. WGS 84**	**E/W coord. WGS 84**
10/484	Denmark	Lille Valby	Rural	Air		510.5 m3		55 41 40,00 N	12 07 07,00 E
10/485	Denmark	Copenhagen	Urban	Air		438.5m3		55 40 30,00 N	12 34 20,00 E
09/3415	Denmark	Fornæs	Urban	Sediment		82% d.w.; 1.5% LOI	2009.05.14	56 26 17,28 N	10 57 42,72 E
09/3414	Denmark	Roskilde Marina	Urban	Sediment		31% d.w.; 23% LOI	2009.11.03	55 39 26,22 N	12 04 30,23 E
09/3413	Denmark	Roskilde (Bjergmarken) WWTP	WWTP	Sludge		63% d.w.; 61% LOI		55 39 10,88 N	12 03 34,48 E
09/3412	Denmark	Silkeborg (Søholt) WWTP	WWTP	Sludge		21% d.w.; 66% LOI	2009.09.16	55 51 24,49 N	09 51 32,91 E
09/3307	Faroe Islands	Koltur	Background	Egg	*Cepphus grylle* (Black guillemot)	9.3% l.w.	2008.06.10	62 00 00,00 N	07 00 00,00 W
09/3317	Faroe Islands	Mylingsgrunnurin	Background	Fish, liver	*Gadus morhua* (Cod)	64% l.w.	2009 Sept	62 30 00,00 N	07 30 00,00 W
09/3315	Faroe Islands	Myrarnar	Background	Fish, muscle	*Salvelinus alpinus* (Artic Char) muscle	2.4% l.w.	2009 July	62 09 49,56 N	06 45 29,10 W
09/3308	Faroe Islands	Skuvoy	Background	Egg	*Cepphus grylle* (Black guillemot)	7.5% l.w.	2008.06.16	61 46 06,00 N	06 48 06,00 W
09/3305	Faroe Islands	Leirvik, incineration plant	Point source	Moss	*Hylocomium splendens*	20% d.w.	2009.11.19	62 00 30,24 N	06 45 42,90 W
								62 12 48,60 N	06 38 59,16 W
09/3306	Faroe Islands	Torshavn, incineration plant	Point source	Moss	*Hylocomium splendens*	18% d.w.	2009.11–10	62 02 46,80 N	06 47 15,24 W
09/3312	Faroe Islands	Klaksvik	Urban	Sediment		50% d.w.; 7.7% LOI	2008.09.09	62 13 49,50 N	06 35 26,88 W
09/3311	Faroe Islands	Skalafjord	Urban	Sediment		35% d.w.; 14% l.i	2009.08.25	62 09 32,40 N	06 46 00,90 W
09/3314	Faroe Islands	Torshavn	Urban	Sediment		40% d.w.; 15% LOI	2007 January	62 00 25,80 N	06 46 26,04 W
09/3313	Faroe Islands	Torshavn (Hospital LSH) WWTP	WWTP	Sludge		14% d.w.; 71% LOI	2009.11.11	62 00 05,88 N	06 46 32,28 W
09/3316	Faroe Islands	Torshavn (Sjersanvikin) WWTP	WWTP	Sludge		19% d.w.; 69% LOI.	2009.11.11	62 00 29,40 N	06 45 43,02 W
09/3298	Finland	Helsinki	Urban	Fish, muscle	*Perca fluviatilis* (Perch) (7 fish)	1.4% l.w.	2009.11.(10–20)	60 12 08,00 N	25 00 15,00 E
09/3299	Finland	Tampere	Urban	Fish, muscle	*Perca fluviatilis* (Perch) (10 fish)	1.4% l.w.	2009.09.21	61 26 37,00 N	23 31 40,00 E
09/3300	Finland	Tampere	Urban	Fish, muscle	*Perca fluviatilis* (Perch) (6 fish)	0.67% l.w.	2009.09.22	61 26 37,00 N	23 31 40,00 E
09/3301	Finland	Tampere	Urban	Fish, muscle	*Perca fluviatilis* (Perch) (10 fish)	1.0% l.w.	2009.09.22	61 26 37,00 N	23 31 40,00 E
09/3302	Finland	Tampere	Urban	Fish, muscle	*Perca fluviatilis* (Perch) (8 fish)	1.2% l.w.	2009.09.29	61 26 37,00 N	23 31 40,00 E
09/3303	Finland	Tampere	Urban	Fish, muscle	*Perca fluviatilis* (Perch) (6 fish)	0.97% l.w.	2009.10.04	61 26 37,00 N	23 31 40,00 E
10/381	Finland	Helsinki	Urban	Sediment		37% d.w; 8.8% LOI	2009.11.17	60 10 16,05 N	24 59 29,25 E
10/380	Finland	Pori	Urban	Sediment		37% d.w.; 6.9% LOI	2009.10.29	61 36 14,87 N	21 32 22,24 E
10/382	Finland	Tampere	Urban	Sediment		43% d.w.; 11% LOI	2009.11.13	61 29 23,66 N	23 45 48,22 E
10/379	Finland	Herttoniemi, ind. area	Urban	Sludge storm water		60% d.w.; 4.3% LOI	2009.11.02	60 11 48,39 N	25 02 50,38 E
10/378	Finland	Hyvinkää, waste deposit	Urban	Sludge		76% d.w.; 2.4% LOI	2009.11.09	60 40 01,02 N	24 48 04,97 E
10/377	Finland	Ämmässuo, waste deposit	Urban	Sludge		31% d.w.; 30% LOI	2009.11.05	60 13 55,14 N	24 32 16,33 E
10/374	Finland	Espoo (Suomenoja) WWTP	WWTP	Sludge		29% d.w.; 59% LOI	2009.11.03	60 09 01,27 N	24 42 38,53 E
10/375	Finland	Helsinki (Viikki) WWTP	WWTP	Sludge		29% d.w.; 58% LOI	2009.11.13	60 13 30,34 N	24 59 32,25 E
10/376	Finland	Kalteva (Hyvinkää) WWTP	WWTP	Sludge		14% d.w.; 64% LOI	2009.11.09	60 35 07,24 N	24 53 02,88 E
10/445	Iceland	Alfsnes, landfill	Urban	Sludge, landfill		-		64 11 11,70 N	21 45 16,00 W
10/446	Iceland	Reykjavik (Klettagarðar) WWTP	WWTP	Sludge		12% d.w.; 92% LOI, non-processed, non-dehydrated sludge		64 09 19,90 N	21 52 24,40 W

Sample ID	Country	Site	Site class	Matrix	Species	Matrix information	Sampling date	N/S coord. WGS 84	E/W coord. WGS 84
10/447	Iceland	Reykjavik (Klettagarðar) WWTP	WWTP	Sludge		16% d.w.; 92% LOI, Odorite treated sludge		64 09 19,90 N	21 52 24,40 W
09/3309	Iceland	IS O1		Fish, liver	*Gadus morhua* (Cod)	59% l.w.	2005	66 35 24,00 N	18 24 26,00 W
09/3310	Iceland	IS O2		Mussel	*Mytilus edulis* (Blue mussel)	0,7% l.w.	2009.11.30	64 21 13,20 N	21 27 12,88 W
10/100	Norway	Oslo, Alna 1	Urban	Air		756 m^3	2009.07.(20–27)	59 55 39,84 N	10 50 47,58 E
10/104	Norway	Oslo, Alna 2	Urban	Air		745.88 m3	2009.09.(07–14)	59 55 39,84 N	10 50 47,58 E
10/106	Norway	Oslo, Alna 3	Urban	Air		321.75 m3	2009.10.(05–08)	59 55 39,84 N	10 50 47,58 E
10/102	Norway	Oslo, SFT 1	Urban	Air, indoor		10.07 m3	2009.07.(21–28)	59 54 47,16 N	10 47 56,27 E
10/105	Norway	Oslo, SFT 2	Urban	Air, indoor		9.81 m3	2009.09.(07–14)	59 54 47,16 N	10 47 56,27 E
10/107	Norway	Oslo, SFT 3	Urban	Air, indoor		10.10 m3	2009.10.(02–09)	59 54 47,16 N	10 47 56,27 E
10/111	Norway	Åse	Urban	Mussel	*Mytilus edulis* (Blue mussel)	1.7% l.w.	2009.03.30	62 27 40,61 N	06 18 29,16 E
10/112	Norway	Åse	Urban	Mussel	*Mytilus edulis* (Blue mussel)	2.2% l.w.	2009.03.30	62 27 39,49 N	06 19 27,59 E
10/108	Norway	Åsefjorden	Urban	Fish, liver	*Gadus morhua* (Cod)	11% l.w.	2009.03.30	62 27 31,50 N	06 19 18,19 E
10/109	Norway	Åsefjorden	Urban	Fish, liver	*Gadus morhua* (Cod)	30% l.w.	2009.03.30	62 27 31,50 N	06 19 18,19 E
10/110	Norway	Åsefjorden	Urban	Fish, liver	*Gadus morhua* (Cod)	42% l.w.	2009.03.30	62 27 31,50 N	06 19 18,19 E
10/099	Norway	Åsefjorden	Urban	Sediment		67% d.w.; 3.3% LOI	2009.09.30	62 27 35,10 N	06 19 5,70 E
10/093	Norway	Ålesund (Åse) WWTP 1	WWTP	Sludge		44% d.w.; 49% LOI	2009.09.30	62 27 43,20 N	06 18 58,86 E
10/094	Norway	Ålesund (Åse) WWTP 2	WWTP	Sludge		23% d.w.; 49% LOI	2009.10.06	62 27 43,20 N	06 18 58,86 E
10/096	Norway	Hellik Teigen; Brakerøya, recycling facility	Point source	Sludge		81% d.w.; 0.77% LOI	2009.10.01	59 45 34,51 N	09 56 34,46 E
10/095	Norway	Grønmo, recycling facility	Point source	Sludge		21% d.w.; 20% LOI	2009.09.28	59 50 14,75 N	10 51 38,34 E
10/586	Sweden	Råö, Nov.	Background	Air		1000 m^3	Nov. 2009	57 23 37,20 N	11 54 51,00 E
10/587	Sweden	Råö. Jan.	Background	Air		1000 m^3	Jan. 2010	57 23 37,20 N	11 54 51,00 E
10/479	Sweden	Stora Karlsö 1	Background	Egg	*Uria aalge* (Guillemot), egg	12% l.w.	2009.05.10	57 17 02,60 N	17 57 24,20 E
10/480	Sweden	Stora Karlsö 2	Background	Egg	*Uria aalge* (Guillemot), egg	12% l.w.	2009.05.10	57 17 02,60 N	17 57 24,20 E
10/585	Sweden	Stockholm, Jan.	Urban	Air		2512 m^3	2010.01.19–02.16	59 20 45,68 N	18 04 23,91 E
10/584	Sweden	Stockholm, Nov.	Urban	Air		1920 m^3	2009.11.05–12.07	59 20 45,68 N	18 04 23,91 E
10/217	Sweden	Riddarfjärden	Urban	Fish, muscle	*Perca fluviatilis* (Perch)	0.40% l.w.	2009.09.16	59 19 25,65 N	18 02 32,82 E
10/221	Sweden	Stora Essingen	Urban	Fish, muscle	*Perca fluviatilis* (Perch)	0.59% l.w.	2009.09.16	59 19 05,78 N	17 58 33,47 E
10/218	Sweden	(Gr 1) Waldemarsudde	Urban	Sediment		16% d.w.; 17% LOI	2009.09.16	59 19 04,83 N	18 06 59,85 E
10/220	Sweden	(Gr 2) Biskopsudde	Urban	Sediment		33% d.w.; 8.5% LOI	2009.09.16	59 19 13,01 N	18 08 06,88 E
10/216	Sweden	(Gr 3) Torsbyfjärden	Urban	Sediment		14% d.w.; 14% LOI	2009.09.17	59 21 21,66 N	18 26 37,44 E
10/219	Sweden	Högbytorp	Urban	Sludge, landfill		15% d.w.; 25% LOI	2009.11.25	59 32 42,98 N	17 36 50,20 E
10/222	Sweden	Sofielund	Urban	Sludge, landfill		9% d.w.; 38% LOI	2010.01.25	59 10 51,63 N	17 58 02,12 E
10/215	Sweden	Lidingö (Käppala) WWTP	WWTP	Sludge		38% d.w.; 67% LOI	2009.11.19	59 21 19,87 N	18 13 41,02 E
10/223	Sweden	Stockholm (Henriksdal) WWTP	WWTP	Sludge		1.9% d.w.; 54% LOI	2009.01–21	59 18 03,07 N	18 06 26,76 E

d.w. = dry weight; l.w. = lipid weight; LOI = loss of ignition (550°C).

Individual results

Sample ID	Country code	Site	Matrix	Unit	24DBP	246TBP	PBP	TBBPA	ATE	DPTE	BTBPE	BATE	TBA	BEHTBP	EHTeBB
10/484	DK	Lille Valby	Air	pg/m3	6.0	17	<1	<1	<0.018	0.16	0.97	0.051	n.d	0.32	0.1
10/485	DK	Copenhagen	Air	pg/m3	7.2	19	<1	<1	<0.016	0.33	0.51	0.049	13	0.31	0.21
09/3415	DK	Fornæs	Sediment	ng/g d.w.	0.096	0.21	<0.06	<0.1	<0.072	<0.048	<0.062	<0.028	0.0014	<0.19	<0.028
09/3414	DK	Roskilde Marina	Sediment	ng/g d.w.	1.02	1.5	<0.2	<0.2	<0.039	<0.12	0.072	<0.017	0.66	<0.27	<0.18
09/3413	DK	Roskilde (Bjergmarken) WWTP	Sludge	ng/g d.w.	<0.5	<0.2	1.02	32	<0.11	<0.42	2.1	<0.057	n.d	33	0.97
09/3412	DK	Silkeborg (Søholt) WWTP	Sludge	ng/g d.w.	<2	7.9	<3	<3	<0.14	<0.53	2	<0.055	0.01	17	0.98
09/3307	FO	Koltur	Egg	ng/g f.w.	<0.07	0.82	0.18	<0.1	<0.0064	<0.009	0.019	<0.0025	0.019	<0.026	0.024
09/3317	FO	Mylingsgrunnurin	Fish, liver	ng/g f.w.	6.4	86	<0.2	<0.2	<0.024	<0.13	0.2	<0.0091	14	0.2	0.12
09/3315	FO	Myrarnar	Fish, muscle	ng/g d.w.	<0.04	0.29	<0.03	<0.03	<0.0037	<0.0042	0.012	<0.0013	0.031	0.011	0.0031
09/3308	FO	Skuvoy	Egg	ng/g f.w.	<0.07	1.4	0.12	<0.1	<0.0077	<0.016	0.024	<0.0036	0.018	0.021	<0.016
09/3305	FO	Leirvik, incineration plant	Moss	ng/g d.w.	<0.3	<0.1	<0.5	<0.5	<0.0011	0.0039	0.15	<0.00054	0.0086	0.039	<0.003
09/3306	FO	Torshavn, incineration plant	Moss	ng/g d.w.	0.53	0.46	<0.4	<0.4	<0.002	<0.0047	0.056	<0.0012	0.0074	<0.021	<0.002
09/3312	FO	Klaksvik	Sediment	ng/g d.w.	1.3	0.54	<0.06	<0.1	<0.0098	<0.39	0.04	<0.0028	n.d	<0.03	<0.14
09/3311	FO	Skalafjord	Sediment	ng/g d.w.	0.79	0.47	<0.1	<01	<0.0028	<0.012	0.024	<0.0012	0.0027	<0.013	<0.0082
09/3314	FO	Torshavn	Sediment	ng/g d.w.	2.9	7.8	<0.1	16	<0.075	<0.18	0.19	<0.03	n.d	0.23	<0.21
09/3313	FO	Torshavn (Hospital LSH) WWTP	Sludge	ng/g d.w.	<2	<0.9	<4	<4	<0.16	<0.39	3.8	<0.041	n.d	29	<0.54
09/3316	FO	Torshavn (Sjersanvikin) WWTP	Sludge	ng/g d.w.	<1	5.5	<2	11	<0.099	<0.32	0.79	<0.047	2	6.3	<0.25
09/3298	FI	Helsinki	Fish, muscle	ng/g f.w.	0.48	3.5	<0.02	<0.02	<0.0025	<0.0028	0.0084	<0.001	0.22	0.002	0.004
09/3299	FI	Tampere	Fish, muscle	ng/g f.w.	<0.02	0.69	<0.02	<0.02	<0.00096	<0.0044	0.01	<0.00051	0.028	0.006	<0.016
09/3300	FI	Tampere	Fish, muscle	ng/g f.w.	<0.02	0.58	<0.02	<0.02	<0.0018	<0.0055	0.012	<0.00076	0.026	0.0082	<0.006
09/3301	FI	Tampere	Fish, muscle	ng/g f.w.	<0.02	0.73	<0.02	<0.02	<0.0024	<0.0049	0.0067	<0.001	0.036	0.0089	0.0032
09/3302	FI	Tampere	Fish, muscle	ng/g f.w.	<0.02	0.89	<0.02	<0.02	<0.0022	<0.0059	0.0057	<0.00088	0.03	0.0043	<0.008
09/3303	FI	Tampere	Fish, muscle	ng/g f.w.	<0.02	0.083	<0.03	<0.03	<0.0017	<0.0026	0.0065	<0.00071	0.02	0.46	0.022
10/381	FI	Helsinki	Sediment	ng/g d.w.	0.10	0.20	<0.1	<0.1	<0.034	<0.061	<0.043	<0.017	0.032	<0.2	0.046
10/380	FI	Pori	Sediment	ng/g d.w.	<0.08	<0.03	<0.1	<0.1	<0.1	<0.14	<0.17	<0.046	0.0009	<0.62	0.081
10/382	FI	Tampere	Sediment	ng/g d.w.	<0.07	<0.02	<0.1	<0.1	<0.072	<0.12	<0.11	<0.021	0.0063	<0.91	0.21
10/379	FI	Herttoniemi, ind. area	Sludge storm water	ng/g d.w.	<0.05	0.07	<0.08	59	<0.004	<0.035	0.4	<0.0017	0.0035	<0.13	0.11
10/378	FI	Hyvinkää	Sludge storm water	ng/g d.w.	<0.04	<0.01	<0.06	<0.1	<0.11	<0.1	<0.075	<0.044	0.00034	<0.38	0.072
10/377	FI	Ämmässuo	Sludge storm water	ng/g d.w.	0.22	0.26	0.17	<0.2	<0.26	<0.9	3.3	<0.15	0.014	3.9	0.76
10/374	FI	Espoo (Suomenoja) WWTP	Sludge	ng/g d.w.	<0.8	<0.3	<1	<1	<0.092	<1.3	2	<0.045	n.d	37	1.7
10/375	FI	Helsinki (Viikki) WWTP	Sludge	ng/g d.w.	<1	<0.3	<2	<2	<0.14	<0.69	3.9	<0.033	n.d	42	1.9
10/376	FI	Kalteva (Hyvinkää) WWTP	Sludge	ng/g d.w.	<2	<0.7	<3	<3	<0.11	<0.34	2.3	<0.036	0.83	18	2.6
10/445	IS	Alfsnes, landfill	Sludge, landfill	ng/g d.w.	n.d.	n.d.	n.d.	n.d.	<0.86	<0.94	<0.98	<0.37	n.d	<3.2	0.74
10/446	IS	Reykjavik (Klettagarðar) WWTP	Sludge	ng/g d.w.	<2	<0.7	3.5	<4	11	120	0.44	2.2	0.091	3.8	0.54
10/447	IS	Reykjavik (Klettagarðar) WWTP	Sludge	ng/g d.w.	<2	<0.8	<4	<4	27	110	0.42	4.1	1.2	15	0.25
09/3309	IS	IS O1	Fish, liver	ng/g f.w.	0.34	4.5	<0.3	<0.3	<0.035	<0.027	0.045	<0.014	0.47	<0.18	<0.022
09/3310	IS	IS O2	Mussel	ng/g f.w.	<0.03	3.2	<0.03	<0.03	<0.0019	0.049	0.0085	0.00072	0.14	0.009	0.0041

Sample ID	Country code	Site	Matrix	Unit	24DBP	246TBP	PBP	TBBPA	ATE	DPTE	BTBPE	BATE	TBA	BEHTBP	EHTeBB
10/096	NO	Hellik Teigen; Brakerøya, recycling facility	Sludge	ng/g d.w.	<0.03	0.14	<0.06	<0.1	<0.054	<0.039	0.12	<0.023	0.0023	<0.48	<0.045
10/095	NO	Grønmo, recycling facility	Sludge	ng/g d.w.	<0.1	0.19	<0.2	<0.2	<0.03	0.013	1.7	<0.019	0.017	0.31	<0.045
10/100	NO	Oslo, Alna 1	Air	pg/m3	<0.8	<0.3	<1	<1	0.27	3.2	2.2	<0.017	0.22	1.7	1.4
10/104	NO	Oslo, Alna 2	Air	pg/m3	<0.8	0.99	1.5	50	0.21	<2.4	n.d	<0.088	n.d	n.d	n.d
10/106	NO	Oslo, Alna 3	Air	pg/m3	5.1	<1	<3	284	<0.1	0.64	1	<0.035	0.97	0.42	0.58
10/102	NO	Oslo, SFT 1	Air, indoor	pg/m3	<60	<20	<100	<100	<1.3	0.59	8.8	<0.5	0.89	7.4	6.7
10/105	NO	Oslo, SFT 2	Air, indoor	pg/m3	<60	<20	<100	<100	<1.7	<1.6	12	<0.49	n.d	6.7	2.7
10/107	NO	Oslo, SFT 3	Air, indoor	pg/m3	<60	<20	<100	<100	<1.6	1.7	19	<0.52	0.73	7.1	<1.2
10/111	NO	Åse	Mussel	ng/g f.w.	0.97	13	<0.03	<0.03	<0.0022	0.026	0.018	<0.00069	0.69	0.032	0.0049
10/112	NO	Åse	Mussel	ng/g f.w.	0.75	11	<0.03	<0.03	0.0045	0.042	0.033	<0.00062	0.83	0.057	0.0043
10/108	NO	Åsefjorden	Fish, liver	ng/g f.w.	0.55	2.9	<0.4	<0.4	<0.023	<0.027	0.053	<0.0073	0.32	<0.083	<0.015
10/109	NO	Åsefjorden	Fish, liver	ng/g f.w.	2.6	21	<0.1	<0.1	<0.0091	<0.019	0.054	<0.0041	1.3	0.049	<0.011
10/110	NO	Åsefjorden	Fish, liver	ng/g f.w.	1.01	13	<0.1	<0.1	<0.044	<0.049	<0.049	<0.014	n.d	<0.26	<0.06
10/099	NO	Åsefjorden	Sediment	ng/g d.w.	1.7	1.1	2.0	<0.1	0.092	0.5	<0.0081	<0.017	0.0023	<0.037	<0.032
10/093	NO	Ålesund WWTP 1	Sludge	ng/g d.w.	<0.7	<0.2	<1	<1	1.2	4.3	0.7	1.6	0.32	11	1.2
10/094	NO	Ålesund WWTP 2	Sludge	ng/g d.w.	<1	<0.4	<2	<2	2.6	10	0.44	1.1	0.25	11	1.1
10/586	SE	Råö, Nov.	Air	pg/m3	21	27	<0.5	<0.5	<0.12	<0.11	<0.16	<0.04	n.d	<0.78	0.14
10/587	SE	Råö. Jan.	Air	pg/m3	9.7	20	<0.5	<0.5	0.11	0.4	0.81	0.051	n.d	<0.74	0.14
10/479	SE	Stora Karlsö 1	Egg	ng/g f.w.	<0.2	0.21	0.40	<0.3	<0.01	<0.018	0.042	<0.0033	0.019	<0.047	0.00001
10/480	SE	Stora Karlsö 2	Egg	ng/g f.w.	<0.2	0.20	0.43	<0.3	<0.0044	<0.019	0.032	<0.0013	0.013	0.0082	0.18
10/585	SE	Stockholm, Jan.	Air	pg/m3	5.6	10	<0.2	<0.2	<0.037	0.29	0.25	<0.012	n.d	0.34	0.099
10/584	SE	Stockholm, Nov.	Air	pg/m3	2.8	4.0	<0.3	<0.3	<0.082	<0.098	1.4	<0.039	n.d	<0.44	0.12
10/217	SE	Riddarfjärden	Fish, muscle	ng/g f.w.	<0.03	<0.03	<0.03	<0.03	<0.0046	<0.0058	<0.0052	<0.0014	n.d	<0.026	0.0096
10/221	SE	Stora Essingen	Fish, muscle	ng/g f.w.	<0.02	0.4	<0.02	<0.02	<0.0018	<0.0032	0.0073	<0.00054	0.017	0.0051	0.0029
10/218	SE	(Gr 1) Waldemarsudde	Sediment	ng/g d.w.	<0.2	0.92	<0.3	<0.3	<0.092	<0.31	0.25	<0.028	n.d	3.3	<0.28
10/220	SE	(Gr 2) Biskopsudde	Sediment	ng/g d.w.	0.20	0.84	<0.2	<0.2	<0.079	<0.19	<0.17	<0.022	0.099	<1.2	<0.2
10/216	SE	(Gr 3) Torsbyfjärden	Sediment	ng/g d.w.	0.49	4.8	<0.4	<0.4	<0.019	<0.029	0.032	<0.0069	0.092	<0.014	<0.037
10/219	SE	Högbytorp	Sludge, landfill	ng/g d.w.	<0.4	<0.1	<0.6	<0.6	<0.13	<0.32	3.4	<0.045	n.d	1.1	<0.48
10/222	SE	Sofielund	Sludge, landfill	ng/g d.w.	<0.7	<0.2	1.9	<1	n.d	n.d	n.d	n.d	n.d	n.d	n.d
10/215	SE	Lidingö (Käppala) WWTP	Sludge	ng/g d.w.	<0.8	<0.3	<1	<1	<0.16	<0.56	1.9	<0.045	n.d	26	1.5
10/223	SE	Stockholm (Henriksdal) WWTP	Sludge	ng/g d.w.	40	101	<20	<20	<0.12	<0.62	1.2	<0.033	0.039	27	<0.63

d.w. = dry weight; f.w. = fresh weight. n.d. = not determined.

Individual results

Sample ID	Country code	Site	Matrix	Unit	DP syn	DP anti	HBB	PBT	PBEB	DBDPE	α-TBECH	β-TBECH	γ/δ-TBECH
10/484	DK	Lille Valby	Air	pg/m3	2.0	7.4	0.27	0.16	0.039	1.3	1.2	0.78	1.2
10/485	DK	Copenhagen	Air	pg/m3	0.68	2.0	0.44	0.37	0.076	6.1	13	11	18
09/3415	DK	Fornæs	Sediment	ng/g d.w.	0.0035	0.0049	<0.034	<0.011	<0.014	<1.9	<0.064	<0.057	<0.19
09/3414	DK	Roskilde Marina	Sediment	ng/g d.w.	0.82	1.6	0.018	0.011	<0.0098	<6.7	0.17	<0.08	<0.25
09/3413	DK	Roskilde (Bjergmarken) WWTP	Sludge	ng/g d.w.	3.5	5.7	<0.24	0.027	<0.024	18	<0.25	<0.23	<0.69
09/3412	DK	Silkeborg (Søholt) WWTP	Sludge	ng/g d.w.	14	20	<0.18	0.036	<0.027	14	0.72	0.43	<0.78
09/3307	FO	Koltur	Egg	ng/g f.w.	0.0093	0.024	0.03	0.0063	<0.0016	0.085	0.02	0.066	0.31[i]
09/3317	FO	Mylingsgrunnurin	Fish, liver	ng/g f.w.	<0.03	<0.02	0.072	0.021	<0.0042	<0.7	<0.042	0.037	0.081[i]
09/3315	FO	Myrarnar	Fish, muscle	ng/g d.w.	<0.004	<0.003	0.0064	0.0015	<0.00063	<0.16	<0.0039	<0.0036	<0.012
09/3308	FO	Skuvoy	Egg	ng/g f.w.	<0.008	0.012	0.023	0.0054	0.00072	<0.082	0.018	0.059	<0.035
09/3305	FO	Leirvik, incineration plant	Moss	ng/g d.w.	0.02	0.04	0.011	0.0032	0.0059	0.14	0.0029	0.0024	<0.0046
09/3306	FO	Torshavn, incineration plant	Moss	ng/g d.w.	0.05	0.12	0.0076	0.0031	0.0038	0.34	0.0046	0.0054	<0.0094
09/3312	FO	Klaksvik	Sediment	ng/g d.w.	0.25	0.44	<0.038	0.0056	0.0075	0.26	<0.019	<0.017	<0.054
09/3311	FO	Skalafjord	Sediment	ng/g d.w.	0.16	0.70	0.011	0.0044	0.0053	0.18	<0.0044	<0.004	<0.012
09/3314	FO	Torshavn	Sediment	ng/g d.w.	0.93	2.5	0.048	0.025	0.046	1.6	<0.13	<0.12	<0.37
09/3313	FO	Torshavn (Hospital LSH) WWTP	Sludge	ng/g d.w.	7.1	25	<0.96	0.069	0.13	160	<0.13	<0.11	<0.37
09/3316	FO	Torshavn (Sjersanvikin) WWTP	Sludge	ng/g d.w.	3.4	12	<0.2	0.039	0.085	16	<0.12	<0.11	<0.35
09/3298	FI	Helsinki	Fish, muscle	ng/g f.w.	<0.003	<0.002	0.0094	0.0027	0.00032	0.037	0.0053	0.0042	<0.02
09/3299	FI	Tampere	Fish, muscle	ng/g f.w.	0.0038	0.0030	0.0084	0.0021	0.00012	0.037	0.0034	0.0027	<0.0054
09/3300	FI	Tampere	Fish, muscle	ng/g f.w.	<0.003	<0.002	0.0076	0.002	<0.00042	0.016	0.0022	0.0013	<0.011
09/3301	FI	Tampere	Fish, muscle	ng/g f.w.	<0.002	0.0011	0.0081	0.002	<0.00067	0.015	<0.0026	0.0014	<0.014
09/3302	FI	Tampere	Fish, muscle	ng/g f.w.	<0.002	<0.002	0.0084	0.0019	<0.00034	0.024	0.0013	0.00073	<0.012
09/3303	FI	Tampere	Fish, muscle	ng/g f.w.	<0.002	<0.002	0.0059	0.0017	0.00028	0.017	<0.0013	<0.0012	<0.0039
10/381	FI	Helsinki	Sediment	ng/g d.w.	0.16	0.66	0.015	0.0076	0.0072	<0.87	<0.061	<0.055	<0.18
10/380	FI	Pori	Sediment	ng/g d.w.	0.22	0.62	<0.044	0.053	<0.025	<0.00001	<0.21	<0.19	<0.64
10/382	FI	Tampere	Sediment	ng/g d.w.	0.06	0.21	<0.17	0.014	0.011	<2.2	0.3	<0.065	<0.22
10/379	FI	Herttoniemi, ind. area	Sludge storm water	ng/g d.w.	5.1	11	0.034	0.011	<0.00095	0.76	<0.0072	<0.0066	<0.022
10/378	FI	Hyvinkää	Sludge storm water	ng/g d.w.	<0.01	0.05	0.015	<0.027	<0.022	<2.5	<0.17	<0.15	<0.5
10/377	FI	Ämmässuo	Sludge storm water	ng/g d.w.	0.58	1.2	0.4	0.4	0.09	90	<0.47	<0.43	<1.4
10/374	FI	Espoo (Suomenoja) WWTP	Sludge	ng/g d.w.	3.1	5.0	<0.14	5.2	<0.022	27	<0.12	<0.11	<0.37
10/375	FI	Helsinki (Viikki) WWTP	Sludge	ng/g d.w.	3.5	7.1	<0.42	2.2	<0.024	35	<0.12	<0.11	<0.36
10/376	FI	Kalteva (Hyvinkää) WWTP	Sludge	ng/g d.w.	5.8	7.4	<0.36	0.25	0.027	36	<0.099	<0.086	<0.29
10/445	IS	Alfsnes, landfill	Sludge, landfill	ng/g d.w.			0.72	0.16	0.11	<16	<0.82	<0.75	<2.5
10/446	IS	Reykjavik (Klettagarðar) WWTP	Sludge	ng/g d.w.	0.24	0.73	0.077	0.069	0.015	4.5	1.3	0.75	0.21
10/447	IS	Reykjavik (Klettagarðar) WWTP	Sludge	ng/g d.w.	0.25	0.56	0.2	0.14	0.027	5.4	4.7	2.6	1.7
09/3309	IS	IS O1	Fish, liver	ng/g f.w.	<0.03	<0.02	0.042	0.0097	<0.0086	<1	0.14	0.22	0.32[i]

Sample ID	Country code	Site	Matrix	Unit	DP syn	DP anti	HBB	PBT	PBEB	DBDPE	α-TBECH	β-TBECH	γ/δ-TBECH
09/3310	IS	IS O2	Mussel	ng/g f.w.	<0.004	<0.003	0.0082	0.002	<0.00049	0.036	<0.0021	<0.0019	<0.0065
10/096	NO	Hellik Teigen; Brakerøya, recycling facility	sludge	ng/g d.w.	0.10	0.21	0.019	0.072	0.006	<5.8	<0.062	<0.056	<0.19
10/095	NO	Grønmo, recycling facility	sludge	ng/g d.w.	0.76	1.4	0.06	0.014	0.0055	1.5	0.21	0.13	<0.1
10/100	NO	Oslo, Alna 1	Air	pg/m3	12	16	2.3	0.61	0.11	15	0.19	0.17	0.19
10/104	NO	Oslo, Alna 2	Air	pg/m3	39	94	<0.93	0.91	<0.062	44	0.25	0.17	<1.4
10/106	NO	Oslo, Alna 3	Air	pg/m3	42	120	1.3	4.4	0.25	9.4	2.6	2.2	2.7
10/102	NO	Oslo, SFT 1	Air, indoor	pg/m3	<16	<16	15	2.5	0.21	4.1	0.77	0.79	<3.9
10/105	NO	Oslo, SFT 2	Air, indoor	pg/m3	<16	<16	12	2.6	<0.4	56	<1.6	<1.4	<4.8
10/107	NO	Oslo, SFT 3	Air, indoor	pg/m3	<16	<16	12	2.8	<0.37	<31	2.3	0.55	<3.2
10/111	NO	Åse	Mussel	ng/g f.w.	0.017	0.018	0.011	0.003	0.00052	0.086	0.0065	0.0044	<0.0072
10/112	NO	Åse	Mussel	ng/g f.w.	0.023	0.019	0.0081	0.0035	<0.0004	0.082	0.0075	0.0046	0.0067 ^{i}
10/108	NO	Åsefjorden	Fish, liver	ng/g f.w.	<0.02	0.026	0.03	0.011	<0.0043	<0.54	<0.023	<0.021	0.15 ^{i}
10/109	NO	Åsefjorden	Fish, liver	ng/g f.w.	<0.02	0.019	0.041	0.011	0.0044	0.092	0.067	0.091	0.43 ^{i}
10/110	NO	Åsefjorden	Fish, liver	ng/g f.w.	<0.02	0.014	0.047	0.021	<0.011	<1.6	0.26	0.25	1.1
10/099	NO	Åsefjorden	Sediment	ng/g d.w.	0.28	0.92	<0.022	0.048	0.014	0.042	120	110	120
10/093	NO	Ålesund (Åse) WWTP 1	Sludge	ng/g d.w.	0.85	7.1	<0.21	0.034	0.029	12	0.72	0.49	0.35
10/094	NO	Ålesund (Åse) WWTP 2	Sludge	ng/g d.w.	1.3	1.5	0.076	0.073	0.016	17	<0.086	0.097	<0.25
10/586	SE	Råö, Nov.	Air	pg/m3	0.15	0.43	0.057	<0.01	<0.025	<4	0.039	<0.083	<0.29
10/587	SE	Råö. Jan.	Air	pg/m3	0.047	0.082	0.12	0.13	0.076	<3.6	0.5	0.43	<0.6
10/479	SE	Stora Karlsö 1	Egg	ng/g f.w.	0.026	0.057	0.023	0.0063	<0.002	0.12	0.022	0.33	0.21 ^{i}
10/480	SE	Stora Karlsö 2	Egg	ng/g f.w.	0.023	0.055	0.023	0.0063	0.0014	0.083	<0.0056	0.25	0.16 ^{i}
10/585	SE	Stockholm, Jan.	Air	pg/m3	0.044	0.065	0.69	0.73	0.084	1.6	11	9.9	12
10/584	SE	Stockholm, Nov.	Air	pg/m3	0.039	0.13	0.095	0.066	0.022	<2.4	0.32	0.18	<0.24
10/217	SE	Riddarfjärden	Fish, muscle	ng/g f.w.	<0.004	<0.003	0.0058	0.0021	<0.0011	<0.13	<0.0047	<0.0042	<0.015
10/221	SE	Stora Essingen	Fish, muscle	ng/g f.w.	<0.002	<0.002	0.0065	0.002	0.00033	0.027	<0.0013	<0.0012	<0.0039
10/218	SE	(Gr 1) Waldemarsudde	Sediment	ng/g d.w.	0.99	2.0	0.19	2.7	<0.011	2.4	0.09	0.15	<0.34
10/220	SE	(Gr 2) Biskopsudde	Sediment	ng/g d.w.	0.08	0.16	<0.15	0.0069	<0.012	<3.1	0.25	<0.08	0.63
10/216	SE	(Gr 3) Torsbyfjärden	Sediment	ng/g d.w.	0.15	0.45	0.02	0.0061	0.0012	0.1	<0.017	<0.014	0.047
10/219	SE	Högbytorp	Sludge, landfill	ng/g d.w.	4.6	5.1	<0.27	0.012	0.029	<8.3	<0.18	<0.16	<0.54
10/222	SE	Sofielund	Sludge, landfill	ng/g d.w.	5.5	21	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
10/215	SE	Lidingö (Käppala) WWTP	Sludge	ng/g d.w.	3.8	5.6	0.095	0.51	0.012	29	0.11	<0.11	<0.36
10/223	SE	Stockholm (Henriksdal) WWTP	Sludge	ng/g d.w.	2.2	3.5	<0.4	1.3	0.013	18	<0.1	<0.085	<0.27

d.w. = dry weight; f.w. = fresh weight. n.d. = not determined.

i: As described in Chapter 3.3.4 the quantification of γ/δ-TBECH in biological samples is influenced by an interfering compound and the results given here may be slightly overestimated. These results are marked with i.

Individual results, reference compounds

Sample ID	Country code	Site	Matrix	Unit	BDE -28	BDE -47	BDE -71/49	BDE -66	BDE -77	BDE -99	BDE -100	BDE -85	BDE -119	BDE -138	BDE -153	BDE -154	BDE -183	BDE -196	BDE -206	BDE -209
10/484	DK	Lille Valby	Air	pg/m3	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
10/485	DK	Copenhagen	Air	pg/m3	0.093	1.3	0.13	0.072	0.029	1.4	0.22	0.1	<0.014	0.066	0.38	0.26	0.37	0.41	0.51	13
09/3415	DK	Fornæs	Sediment	ng/g d.w.	0.0029	0.071	0.003	<0.0018	<0.0011	0.012	0.004	<0.0019	<0.0013	<0.01	<0.008	<0.0049	<0.0051	<0.018	<0.022	0.11
09/3414	DK	Roskilde Marina	Sediment	ng/g d.w.	0.0043	0.11	0.02	<0.0067	<0.0043	0.14	0.017	<0.014	<0.0094	<0.04	<0.03	0.022	0.02	<0.00001	<0.00001	<0.00001
09/3413	DK	Roskilde (Bjergmarken) WWTP	Sludge	ng/g d.w.	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	2.9	4.4	100
09/3412	DK	Silkeborg (Søholt) WWTP	Sludge	ng/g d.w.	0.36	31	3.6	0.43	<0.056	34	5.8	<0.22	<0.12	0.2	3	1.9	0.78	<0.62	4.6	130
09/3307	FO	Koltur	Egg	ng/g f.w.	0.019	1.5	0.02	<0.0066	<0.0044	0.25	0.27	<0.01	0.041	<0.013	0.33	0.16	0.013	<0.027	<0.023	0.21
09/3317	FO	Mylingsgrunnurin	Fish, liver	ng/g f.w.	0.06	1.1	0.29	<0.014	<0.0089	0.049	0.17	<0.019	<0.015	<0.08	<0.063	0.11	<0.053	<0.13	<0.35	0.58
09/3315	FO	Myrarnar	Fish, muscle	ng/g d.w.	0.0027	0.044	0.0071	0.0045	0.0024	0.069	0.024	<0.0029	0.01	<0.008	0.036	0.069	0.015	<0.014	<0.026	0.03
09/3308	FO	Skuvoy	Egg	ng/g f.w.	0.015	0.92	0.035	<0.011	<0.0072	0.2	0.2	<0.013	0.018	<0.02	0.23	0.16	0.012	<0.044	<0.039	0.48
09/3305	FO	Leirvik, incineration plant	Moss	ng/g d.w.	0.00092	0.019	0.0022	0.00053	<0.00042	0.027	0.0043	<0.0016	<0.0012	<0.003	0.0096	0.0074	0.024	0.032	0.067	0.7
09/3306	FO	Torshavn, incineration plant	Moss	ng/g d.w.	0.0031	0.32	0.0064	0.0039	<0.00065	0.39	0.069	0.018	<0.0017	0.0079	0.052	0.036	0.057	0.02	0.067	1.6
09/3312	FO	Klaksvik	Sediment	ng/g d.w.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
09/3311	FO	Skalafjord	Sediment	ng/g d.w.	0.0023	0.062	0.009	0.0029	<0.0018	0.033	0.011	<0.004	<0.003	<0.012	<0.0087	0.008	<0.008	<0.1	<0.12	0.82
09/3314	FO	Torshavn	Sediment	ng/g d.w.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
09/3313	FO	Torshavn (Hospital LSH) WWTP	Sludge	ng/g d.w.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
09/3316	FO	Torshavn (Sjersanvikin) WWTP	Sludge	ng/g d.w.	0.092	10	0.46	<0.036	<0.023	13	2.3	<0.083	<0.062	<0.091	1.4	0.94	0.26	<2.8	5.1	79
09/3298	FI	Helsinki	Fish, muscle	ng/g f.w.	0.0053	0.26	0.057	0.0088	<0.0012	0.058	0.051	<0.0019	<0.0014	<0.0057	0.016	0.027	<0.0035	<0.018	<0.014	0.056
09/3299	FI	Tampere	Fish, muscle	ng/g f.w.	0.005	0.18	0.038	0.0034	<0.00061	0.084	0.047	<0.0027	<0.0021	<0.0021	0.019	0.019	<0.0017	<0.0058	<0.0036	0.031
09/3300	FI	Tampere	Fish, muscle	ng/g f.w.	0.0037	0.13	0.023	<0.0014	<0.0009	0.057	0.029	<0.0018	<0.0014	<0.0023	0.011	0.013	<0.0022	<0.013	<0.0072	0.03
09/3301	FI	Tampere	Fish, muscle	ng/g f.w.	0.0037	0.18	0.029	0.0035	<0.0012	0.068	0.05	<0.0027	<0.002	<0.0025	0.015	0.022	<0.0021	<0.011	<0.0089	0.036
09/3302	FI	Tampere	Fish, muscle	ng/g f.w.	0.0067	0.22	0.044	0.0061	<0.0017	0.11	0.053	<0.003	<0.0023	<0.0046	0.016	0.023	<0.0045	<0.015	0.038	0.26
09/3303	FI	Tampere	Fish, muscle	ng/g f.w.	0.0054	0.24	0.04	0.0062	<0.00094	0.14	0.059	<0.0031	<0.0023	<0.0044	0.02	0.019	<0.0032	<0.0058	<0.0064	0.016

Sample ID	Country code	Site	Matrix	Unit	BDE -28	BDE -47	BDE -71/49	BDE -66	BDE -77	BDE -99	BDE -100	BDE -85	BDE -119	BDE -138	BDE -153	BDE -154	BDE -183	BDE -196	BDE -206	BDE -209
10/381	FI	Helsinki	Sediment	ng/g d.w.	0.0019	0.03	0.0059	<0.0027	<0.0019	0.053	0.0063	<0.0079	<0.0037	<0.041	<0.027	<0.015	<0.023	<0.17	<0.31	2.2
10/380	FI	Pori	Sediment	ng/g d.w.	0.0069	0.12	0.017	<0.0035	<0.0024	0.074	0.012	<0.0063	<0.003	<0.018	0.012	0.013	0.021	<0.089	0.097	2
10/382	FI	Tampere	Sediment	ng/g d.w.	0.0052	0.089	<0.0069	<0.0093	<0.0061	0.077	0.011	<0.018	<0.012	<0.052	<0.043	<0.027	<0.029	<0.58	<0.49	1
10/379	FI	Herttoniemi, ind. area	Sludge storm water	ng/g d.w.	0.009	0.71	0.057	0.021	<0.0027	1.2	0.23	0.051	<0.0084	0.032	0.46	0.15	1.3	3.4	1	11
10/378	FI	Hyvinkää	Sludge storm water	ng/g d.w.	0.0027	0.074	0.0059	<0.0014	<0.0009	0.073	0.011	0.0049	<0.0019	<0.015	0.01	0.007	<0.012	<0.033	<0.041	0.47
10/377	FI	Ämmässuo	Sludge storm water	ng/g d.w.	0.19	6.6	1.6	0.32	<0.0071	18	2.9	<0.14	<0.065	0.12	2.2	1.2	1.1	1.2	1.8	48
10/374	FI	Espoo (Suomenoja) WWTP	Sludge	ng/g d.w.	0.49	25	2.6	<0.3	<0.22	22	2.9	<0.62	<0.4	0.33	2.8	0.98	0.86	1.1	8.6	420
10/375	FI	Helsinki (Viikki) WWTP	Sludge	ng/g d.w.	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	1.6	24	500
10/376	FI	Kalteva (Hyvinkää) WWTP	Sludge	ng/g d.w.	<0.095	24	1.1	160	<1.4	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
10/445	IS	Alfsnes, landfill	Sludge, landfill	ng/g d.w.	<0.43	6.9	<0.77	<1.1	<0.77	3.5	1.1	<3	<1.6	<7.1	<5	<2.5	<6.5	<41	<31	<34
10/446	IS	Reykjavik (Kletta-garðar) WWTP	Sludge	ng/g d.w.	0.093	6.9	0.14	<0.13	<0.093	7.6	0.86	0.49	<0.16	<0.33	0.62	0.28	0.22	<1	<0.9	62
10/447	IS	Reykjavik (Kletta-garðar) WWTP	Sludge	ng/g d.w.	0.11	6.7	0.15	<0.11	<0.079	7.2	1.6	<0.61	<0.34	<0.46	0.78	0.51	0.4	<0.51	2.3	120
09/3309	IS	IS O1	Fish, liver	ng/g f.w.	0.19	2.8	0.5	0.058	<0.013	0.16	0.34	<0.034	<0.025	<0.09	<0.069	0.22	0.028	<0.14	<0.11	<0.19
09/3310	IS	IS O2	Fish, muscle	ng/g f.w.	0.0017	0.04	0.007	<0.00087	<0.00054	0.0087	0.0096	<0.0014	<0.0012	<0.0037	<0.003	<0.002	<0.0028	<0.0068	<0.0071	0.037
10/096	NO	Hellik Teigen; Brakerøya, recycling facility	sludge	ng/g d.w.	0.0034	0.1	0.0098	0.0051	<0.0013	0.23	0.035	0.012	<0.0023	<0.011	0.071	0.025	0.27	<0.056	0.14	4.1
10/100	NO	Oslo, Alna 1	Air	pg/m3	0.12	7	0.32	0.28	<0.029	8.7	1.8	0.27	<0.063	0.09	0.92	0.62	1.7	0.84	2.8	68
10/104	NO	Oslo, Alna 2	Air	pg/m3	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
10/106	NO	Oslo, Alna 3	Air	pg/m3	0.22	5.3	0.21	<0.081	<0.051	3.6	0.69	<0.1	<0.076	<0.22	0.44	0.28	0.6	<0.58	2.7	38
10/102	NO	Oslo, SFT 1	Air, indoor	pg/m3	0.61	5.1	<0.66	<0.76	<0.48	2.6	<0.6	<1.2	<0.91	<3	<2.4	<1.6	<2.7	<10	<8.5	18
10/105	NO	Oslo, SFT 2	Air, indoor	pg/m3	0.69	4.8	<0.76	<0.87	<0.55	2.5	<0.56	<1.1	<0.85	<3.1	<2.5	<1.7	<2.5	<6.3	<5	21
10/107	NO	Oslo, SFT 3	Air, indoor	pg/m3	0.75	4.9	<0.48	<0.59	<0.36	2.7	0.61	<1.1	<0.87	<2.3	<1.9	<1.3	1.3	<7.2	<5.9	34
10/111	NO	Åse	Mussel	ng/g f.w.	0.0067	0.35	0.034	0.014	<0.00088	0.29	0.093	0.0081	<0.0022	<0.0067	0.024	0.027	0.0083	<0.016	0.098	2.4
10/112	NO	Åse	Mussel	ng/g f.w.	0.0094	0.47	0.043	0.016	<0.00099	0.36	0.12	0.011	0.0044	<0.012	0.032	0.026	0.014	<0.015	0.11	3

Sample ID	Country code	Site	Matrix	Unit	BDE -28	BDE -47	BDE -71/49	BDE -66	BDE -77	BDE -99	BDE -100	BDE -85	BDE -119	BDE -138	BDE -153	BDE -154	BDE -183	BDE -196	BDE -206	BDE -209
10/108	NO	Åsefjorden	Fish, liver	ng/g f.w.	0.28	7	0.54	<0.013	<0.0077	0.12	1.6	0.14	<0.014	<0.041	<0.034	1.6	<0.032	<0.13	<0.12	0.2
10/109	NO	Åsefjorden	Fish, liver	ng/g f.w.	1.7	28	4.9	0.32	0.021	0.18	4.7	0.15	0.27	<0.035	<0.029	1.5	<0.02	<0.074	<0.063	0.26
10/110	NO	Åsefjorden	Fish, liver	ng/g f.w.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
10/099	NO	Åsefjorden	Sediment	ng/g d.w.	0.023	4.6	0.022	0.016	<0.0042	6.3	1.1	0.27	<0.0061	0.061	0.53	0.34	0.024	<0.097	2.6	73
10/093	NO	Ålesund (Åse) WWTP 1	Sludge	ng/g d.w.	0.073	4.1	0.15	1.5	<0.022	3.9	0.39	<0.053	<0.037	<0.058	0.49	0.2	0.35	0.65	19	2000
10/094	NO	Ålesund (Åse) WWTP 2	Sludge	ng/g d.w.	0.076	3.5	0.14	<0.023	<0.016	3.4	0.5	0.16	<0.019	<0.075	0.35	0.22	0.27	0.53	9.8	1200
10/586	SE	Råö, Nov.	Air	pg/m3	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
10/587	SE	Råö. Jan.	Air	pg/m3	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
10/479	SE	Stora Karlsö 1	Egg	ng/g f.w.	0.096	5.1	0.75	0.1	<0.0085	0.85	0.3	<0.027	0.1	<0.032	0.25	0.14	<0.025	<0.12	<0.11	0.28
10/480	SE	Stora Karlsö 2	Egg	ng/g f.w.	0.079	4.8	0.72	0.097	<0.0049	0.79	0.26	<0.024	0.12	<0.011	0.23	0.1	<0.0085	<0.03	0.019	0.21
10/585	SE	Stockholm, Jan.	Air	pg/m3	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
10/584	SE	Stockholm, Nov.	Air	pg/m3	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
10/217	SE	Riddarfjärden	Fish, muscle	ng/g f.w.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
10/221	SE	Stora Essingen	Fish, muscle	ng/g f.w.	0.001	0.027	0.0043	<0.0012	<0.00076	0.021	0.007	<0.0053	<0.0044	<0.0039	0.0024	0.0032	<0.0043	<0.015	<0.013	0.016
10/218	SE	(Gr 1) Waldemarsudde	Sediment	ng/g d.w.	0.055	1.2	0.74	<0.19	<0.13	1.8	0.35	<0.42	<0.25	<1.1	<0.88	<0.51	n.d	n.d	n.d	n.d
10/220	SE	(Gr 2) Biskopsudde	Sediment	ng/g d.w.	0.05	0.1	0.022	<0.011	<0.0073	0.078	0.014	<0.016	<0.011	<0.081	<0.062	<0.038	<0.032	<0.36	<0.64	0.89
10/216	SE	(Gr 3) Torsbyfjärden	Sediment	ng/g d.w.	0.0056	0.12	0.015	0.0027	<0.0023	0.048	0.014	<0.0064	<0.0044	<0.018	<0.015	0.0072	<0.011	<0.38	<0.37	1.3
10/219	SE	Högbytorp	Sludge, landfill	ng/g d.w.	0.098	3.1	3.2	<0.11	<0.067	3.2	1.1	<0.14	<0.12	<0.089	1.6	0.76	1.8	<0.00001	<0.00001	<0.00001
10/222	SE	Sofielund	Sludge, landfill	ng/g d.w.	0.27	8.1	2.8	0.18	<0.031	11	2.1	<0.15	<0.11	<0.29	2	1.1	2.3	<3.5	5.7	92
10/215	SE	Lidingö (Käppala) WWTP	Sludge	ng/g d.w.	0.33	26	1.8	<0.1	<0.066	29	4.3	<0.42	<0.28	0.45	2.8	1.3	0.84	3.3	8.8	400
10/223	SE	Stockholm (Henriksdal) WWTP	Sludge	ng/g d.w.	0.19	12	1.5	<0.097	<0.063	17	2.8	<0.24	<0.17	<0.1	1.5	0.71	0.71	<0.43	3.4	260

d.w. = dry weight; f.w. = fresh weight. n.d. = not determined.