Nordic Council of Ministers

PFASs in the Nordic environment

Screening of Poly- and Perfluoroalkyl Substances (PFASs) and Extractable Organic Fluorine (EOF) in the Nordic Environment

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Anna Kärrman, Thanh Wang and Roland Kallenborn
Co-authors: Anne Marie Langseter, Siri Merete Grønhovd, Erik Magnus Ræder, Jan Ludvig Lyche, Leo Yeung, Fangfang Chen, Ulrika Eriksson, Rudolf Aro and Felicia Fredriksson.

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Nordic Council of Ministers/Publication Unit
Ved Stranden 18
DK-1061 Copenhagen K
Denmark
Phone +45 3396 0200
pub@norden.org

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The Nordic Council of Ministers
Nordens Hus
Ved Stranden 18
DK-1061 Copenhagen K, Denmark
Tel.: +45 3396 0200
www.norden.org

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Preface

Per- and polyfluoroalkyl substances (PFASs) are synthetic chemicals with wide commercial and industrial usage since they have very low surface tension, are resistant to heat and chemical degradation as well as being water and oil repelling. Well known application areas include aqueous film forming foams, textiles and food packaging, but some other application areas have been less investigated such as cosmetics, dental restorative materials and dirt-repellent coating for smartphones.

During the recent decade, an abundance of scientific results have confirmed that some PFASs are persistent, bioaccumulative and toxic to wildlife and humans. An early study published in 2004 and funded by the Nordic Council of Ministers highlighted the widespread presence of a few selected PFASs, including the highly persistent perfluoroalkyl acids (PFAAs), in the Nordic environment. The report was highly valued by the scientific community and regulators and was a key instrument for initiating national monitoring studies in the Nordic countries, as well as contributing to the regulation of perfluorooctane sulfonate (PFOS). Although the application of harmful PFASs such as PFOS and perfluorooctanoic acid (PFOA) have slowly been reduced and replaced in recent years, their substitutes are often other PFASs, usually with shorter chain lengths or containing other functional groups. More than 4 000 highly fluorinated substances are estimated to be in commercial circulation on the global market today.

The rapid advancement of analytical instrumentation and quantification methods has expanded the number of conventional and emerging PFASs for targeted analysis in recent years. However, a comprehensive screening of all potential PFASs in environmental samples still remains a huge challenge. One method to investigate unknown PFASs is to measure the total extractable organic fluorine (EOF) in addition to targeted PFASs in a sample. If the measured amount of target PFASs cannot account for all measured TOF, then there is an indication that not all organofluorine substances are accounted for in the respective sample.

The aim of this new initiative is to monitor an extensive list of conventional and emerging PFASs in a wide variety of environmental matrices from the Nordic countries and compare the results with measured EOF in order to account for any unknown organofluorine compounds.

The results will also contribute to the ongoing regulatory discussions on PFASs as well as initiating new studies on novel and currently unknown PFAS substances.

The study was conducted on behalf of the Nordic Screening group (www.nordicscreening.org) which commissioned and funded the work with financial support graciously provided by the Nordic Council of Ministers Chemicals Group, and the participating agencies and institutes. The Nordic Screening Group members designed the sampling strategy, and performed and /or coordinated the sampling.

Members of the Nordic Screening Group are:

- Denmark: Susanne Boutrup, DCE, Aarhus University
- Faroe Islands: Maria Dam, Environment Agency
- Finland: Jaakko Mannio, Finish Environment Institute SYKE
- Greenland: Morten Birch Larsen, Greenland Institute of Natural Resources
- Iceland: Eiríkur Þórir Baldursson, Environment Agency of Iceland
- Norway: Bård Nordbø and Eivind Farmen, Norwegian Environment Agency
- Sweden: Britta Hedlund, Linda Linderholm and Maria Linderoth, Swedish Environmental Protection Agency.

Summary

This report describes the screening of an extensive list of conventional and emerging per- and polyfluoroalkyl substances (PFASs) in the Nordic environment. PFASs is a large class of substances that have become an environmental problem due to extreme persistence and potential toxic effects in biota and humans. More than 4 000 PFASs are estimated to be in circulation on the global market and the environmental distribution is poorly understood. This screening study covers in total ninety-nine (99) PFASs and analysis of extractable organic fluorine (EOF). The latter can provide the amount, but not identity, of organofluorine in the samples, which in turn can be used to assess the mass balance between known and unknown PFASs. The study was initiated by the Nordic Screening Group and funded by the Nordic Council of Ministers through the Chemicals Group as well as agencies and institutes represented in the Nordic Screening Group.

A total of 102 samples were analyzed in this study, including bird eggs, fish, marine mammals, terrestrial mammals, surface water, WWTP effluents and sludge, and air. Samples were collected by institutes from the participating countries and self-governing areas; Denmark, Faroe Islands, Finland, Greenland, Iceland, Norway, and Sweden. The majority of samples were collected in 2017. PFASs were analyzed using liquid-, supercritical fluid-, and gas chromatography coupled to mass spectrometry. EOF was analyzed using combustion ion chromatography.

The PFAS profile in seabird eggs and marine mammals was dominated by the perfluoroalkyl acids (PFAAs) that are perfluoroalkyl carboxylic acids (PFCAs) and perfluoroalkyl sulfonic acids (PFSAs), and mainly perfluorooctane sulfonic acid (PFOS) and long chain PFCAs (>C8). The range of total PFAS concentrations in egg samples were 627 – 707 ng/g w.w. for Sweden, 44.9 – 99.9 ng/g w.w. for Iceland, and 56.9 – 81.4 ng/g w.w. for Faroe Islands. Among the marine mammals, polar bear liver samples (Ursus maritimus) from Greenland showed the highest sum of PFASs (1426 – 1890 ng/g) as well as highest EOF (1782 – 2056 ng fluoride/g). The total PFASs in other marine mammal samples ranged between 35.1 ng/g in grey seal (Halichoerus grypus) from Denmark to 123 ng/g in harbour porpoise (Phocoena phocoena), also from Denmark.

Reindeer (Rangifer tarandus) and freshwater fish livers from European perch (Perca fluviatilis), brown trout (Salmo trutta) and Arctic char (Salvelinus alpinus) also showed predominating PFCA and PFSA profiles with some minor contribution from PFCA precursor compounds. The total PFAS concentrations in the reindeer samples in descending order were 5.4 ng/g for Greenland, 3.3 ng/g for Sweden, 1.4 ng/g for Finland and 1.1 ng/g for Iceland. The brown bear sample (Ursus arctos) from Finland had a total PFAS concentration of 18.9 ng/g. Marine fish livers from Atlantic pollock (Pollachius pollachius), Greenland cod (Gadus ogac), Atlantic cod (Gadus morhua), European flounder (Platichthys flesus) and Atlantic herring (Clupea harengus), ranged from 10.6 ng/g to 18.2 ng/g. The average of total PFAS concentrations in the freshwater fish samples in

descending order were 154 (74.7 – 302) ng/g for perch from Finland, 112 ng/g for perch from Norway, 35.4 (34.7 – 36.2) ng/g for trout and char from Faroe Islands, 24.5 (19.8 – 29.1) ng/g for perch from Denmark, 5.9 (0.30 – 11.47) ng/g for trout from Iceland, and 5.7 (5.2 – 6.2) ng/g for perch from Sweden.

Sludge samples were dominated by PFCA precursors, on average accounting for 75% of all identified PFASs, and mainly contributed by different isomers of polyfluoroalkyl phosphoric acid diesters (diPAPs). The PFASs in the sludge samples, in descending order, were 142 (136 – 149) ng/g for Denmark, 103 (67.8 – 180) ng/g for Sweden, 100 (74.9 – 126) ng/g for Finland, 75.2 (64.1 – 86.2) ng/g for Norway and 36.8 (34.9 – 38.8) ng/g for Faroe Islands

Effluent samples contained a mix of PFAS classes including PFCAs, PFSAs, ultra-short PFASs (mainly perfluoropropionic acid, PFPrA) and PFCA precursors. The average total PFAS concentrations in the effluent samples were 113.3 ng/L for Sweden, 75.4 ng/L for Greenland, 55.4 ng/L for Iceland, 49.7 ng/L for Finland, 48.2 ng/L for Denmark, 44.0 ng/L for Norway and 34.2 ng/L for Faroe Islands.

The PFASs in surface water mainly ranged between 1 and 10 ng/L, with one exception of 61 ng/L in Helsinki which could indicate strong influence from point source(s). PFCAs dominated the profile with the highest concentration for perfluorohexanoic acid (PFHxA) followed by perfluorobutanoic acid (PFBA).

Air was collected using glass fiber filters (GFF) and PUF/XAD-2/PUF and analyzed for conventional PFASs and a suite of novel PFASs. Conventional PFASs detected in air included PFOA, perfluorobutane sulfonic acid (PFBS), perfluorohexane sulfonic acid (PFHxS), and PFOS. Novel PFAS such as 1,3-Bis(trifluoromethyl)-5-bromo-benzene (BTFBB) was frequently detected although their levels need to be further confirmed.

Another novel PFAS that was detected in this study was perfluoroethylcyclohexane sulfonic acid (PFECHS). PFECHS was detected in fish liver, marine mammal liver, and also in surface water and WWTP effluent.

The target analysis of PFASs could explain between 2% and 102% of the measured EOF. The average explanation degree for detected samples was 8% for surface water, 9% for WWTP sludge, 11% for WWTP effluents, 18% for reindeer, 26% for fresh water fish, 28% for bear, 37% for marine mammals, 42% for marine fish and 68% for bird eggs.

This study demonstrates the need to include more PFAS classes in environmental assessments. Shorter chain PFASs with carbon chain lengths of 2-4 were frequently detected in surface water and WWTP effluent. Although having low bioaccumulation potential, they are likely as persistent as their longer chain homologues, and their long term effects on the environment and humans are unknown. Precursor compounds also contributed to the total PFASs in the present study and were frequently detected in many matrices. It is therefore important to include a comprehensive set of PFAS besides the stable end-products in environmental monitoring and to support regulatory discussions aiming at reducing PFAS exposure sources. The large proportion of unknown extractable organofluorine in most environmental samples in the Nordic environment also calls for further studies. The identity of substances contributing to the measured extractable fluorine in environmental samples also needs to be elucidated to further assess environmental and human health risks.

1. Frame of the study

Environmental screening studies can provide early identification of potential harmful substances. Screening studies are important to identify the need of further environmental monitoring. With a screening approach it is possible to consider environmental issues on an early stage and such studies should be considered as a first step rather than a comprehensive assessment. Results from a screening study can be used to determine the level of details needed of further environmental studies and direct efforts towards potential risks. The outcome of this study will provide recommendations on further monitoring, and hopefully initating processes to reduce or prevent potentially negative environmental impacts on the Nordic environment.

The result from this screening study will enable comparison between different Nordic locations and also the different PFAS profiles in different matrices from the biotic and abiotic environment. The matrices suggested by the Nordic Screening Group covers a relevant cross-section necessary to assess presence of historical as well as emerging PFASs in the environment. This will be evaluated by comparing the contamination pattern in the selected matrices. The study allows detection of PFASs in fresh and marine water environments as well as remote terrestrial environments supposedly influenced by mainly atmospheric distribution. The sources and hence the PFASs occurrence can differ between these environments and this can then be assessed within this project. Wastewater treatment plants have been found to be an important source of PFASs to the environment. Active air sampling from background and remote areas was selected since it could collect high volumes during a realtively short time frame. The screening study covers both previously studied PFASs, called "conventional" PFASs, and "novel" PFASs for which environmental data mostly is lacking. A total of ninety-nine (99) substances were analyzed, divided into the following categories:

1. Volatile PFASs (vPFASs)
2. Ultra-short chain PFASs
3. Perfluoroalkyl carboxylic acids and sulfonic acids (PFCAs and PFSAs)
4. Precursor PFASs
5. Perfluoroalkyl phosphonic and phosphinic acids (PFPA/PFPiAs)
6. Novel PFASs

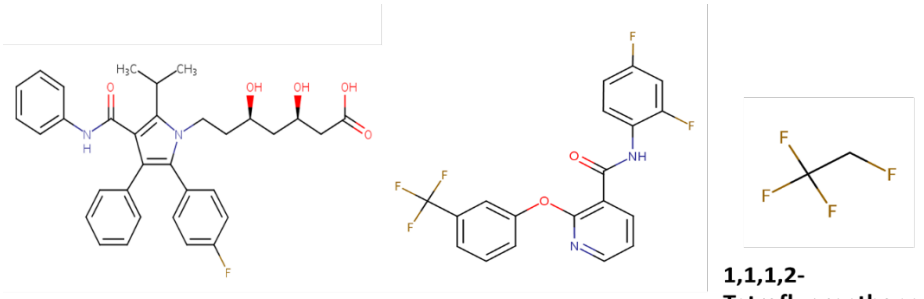
Neutral vPFASs, such as fluorotelomer alcohols (FTOHs) and perfluoroalkane sulfonamides (FASAs), have been found in various indoor and outdoor environments (Winkens *et al.*, 2017, Ahrens *et al.*, 2013). Ultra-short-chain acids including C2 (TFA, PFEtS) and C3 (PFPrA, PFPrSA) acids have been shown to be present as impurities in historical

aqueous film forming foams (AFFFs) (Barzen-Hanson and Field, 2015). Analytical difficulties partly explain why environmental levels of these compounds have not been reported until recently. The novel PFASs includes two replacement products for foremost PFOA; ADONA (3H-perfluoro-3-[(3-methoxy-propoxy)propanoic acid]) and HFPO-DA (hexafluoropropylene oxide dimer acid (GenX)), since they have been detected in waters in Sweden (Örebro and Stockholm), Netherlands, the US, South Korea and China at similar or higher level as PFOA (Pan *et al.*, 2018). Three replacement products for foremost PFOS were included, perfluoroethylcyclohexane sulfonic acid (PFECHS), and 6:2- and 8:2 chlorinated polyfluorinated ether sulfonate. A number of emerging volatile substances listed by the Nordic Screening Group and assessed by the Arctic Monitoring and Assessment Programme (AMAP) as "Chemicals of Emerging Arctic Concern" were also included in the vPFASs group (AMAP, 2017).

2. Background information

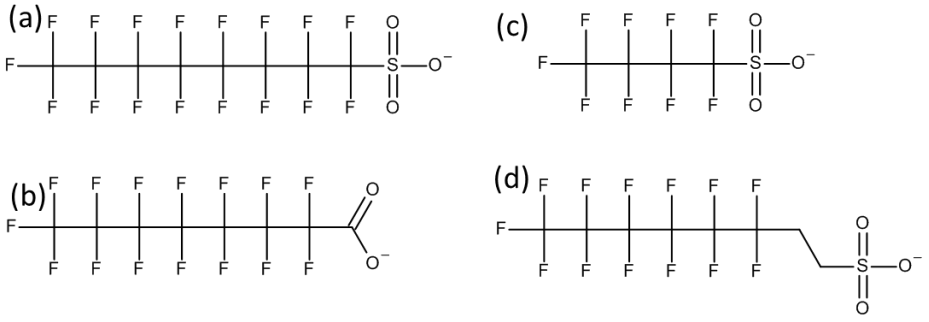
Although fluorine is the most abundant halogen in the Earth's crust, very few biologically produced organofluorine substances have been found in the environment (Key *et al.*, 1997). All of the known biologically produced organofluorine substances contain only one fluorine atom, which is in contrast to most of those that are man-made that often contain multiple fluorine atoms or even fully fluorinated moieties (Key *et al.*, 1997). Only natural processes involving high temperature and pressure, for example volcano eruptions, have been shown to give substances with higher number of fluorine atoms, but these are exclusively small substances. The carbon-fluorine bond is one of the strongest bonds in nature, and organofluorine substances usually display unique properties. The substitution with a fluorine atom or fluorine containing moieties to an organic compound can considerably alter the physical-chemical properties as well as biological activities of a molecule (Wang *et al.*, 2014). Therefore, significant development and large scale production of new organofluorine substances have increased in recent decades due to increasing demand from international markets. For example, hydrofluorocarbons (HFCs) have been used as replacements for chlorofluorocarbons (CFCs) that were banned due to their high global warming potential (Tsai, 2005). Organofluorine substances are currently among the most widely used substances in pharmaceuticals, where about 30% of all newly approved drugs and almost one third of the best-selling pharmaceuticals in the US market contain fluorine (Zhou *et al.*, 2016, O'Hagan, 2010). Another important application area for fluorine containing substances is agrochemicals where more than half of the current-use pesticides contain fluorine (Jeschke, 2017). It should however be noted that most of these organofluorine substances mainly contain a single or few fluorine atoms or having a trifluoromethyl group incorporated into their chemical structure (see Figure 1).

Figure 1: Examples of some manufactured organofluorine substances. Atorvastatin (trade name Lipitor) is commonly used as a lipid-lowering agent. Diflufenican is used as an herbicide. R-134a is a refrigerant



Per-and polyfluoroalkyl substances (PFASs), also referred to as highly fluorinated substances, are by definition chemicals that contain one or more of the perfluoroalkyl moiety, $-C_nF_{2n+1}$ (OECD, 2013, Buck *et al.*, 2011). They have been produced in high volumes since the 1950s and at least 4000 PFASs have been estimated to be in circulation on the global market (Swedish Chemicals Agency, 2015, OECD, 2018). These substances have desirable properties for a variety of commercial applications and products such as high thermal and chemical stability, high surface activity, water and grease repellency. They are also highly effective processing aid agents in industrial processes (Smart, 1994). Some of the broad applications of PFAS include surface treatment (oil-, grease-, and water-resistant coatings on paper and textile products) and performance chemicals (fire-fighting foams, industrial surfactants, acid mist suppression, insecticides, etc.) (USEPA, 2002, Hekster *et al.*, 2003, 3M, 1999). Unfortunately, the above described unique properties of many PFASs may also cause various adverse effects to the environment and different organisms. These include properties such as extreme environmental stability (persistence), potential for bioaccumulation and toxicity (Martin *et al.*, 2003, Lindstrom *et al.*, 2011).

Figure 2: Chemical structures of selected PFASs: a) PFOS, b) PFOA, c) PFBS, d) 6:2-FTSA



Extensive production and usage have led to world-wide environmental contamination of some PFASs, especially the perfluoroalkyl acids (PFAAs) that are very persistent and considered as the end-products from environmental degradation of other so called precursor PFASs. The two groups of PFAAs that are of most concerns are the perfluoroalkyl carboxylic acids (PFCAs) and perfluoroalkyl sulfonic acids (PFSAs), and representative compounds are shown in Figure 2 (a,b,c).

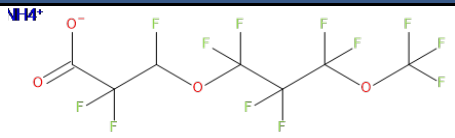
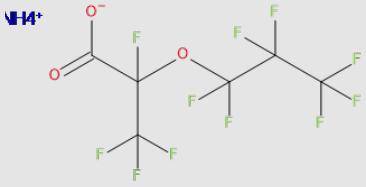
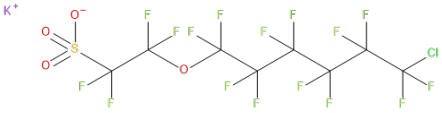
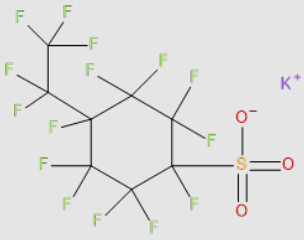
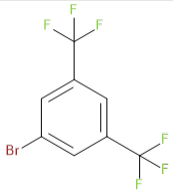
In the early 1970s, Taves and coworkers put forth evidence on the presence of an organofluorine substance in human blood and suspected this to be a synthetic and highly stable compound, most likely perfluorooctanoic acid (PFOA) or a related compound such as perfluorooctane sulfonic acid (PFOS, Figure 2) (Taves, 1968, Taves *et al.*, 1976, Lindstrom *et al.*, 2011, Lau *et al.*, 2004). These two PFAAs have been produced in large quantities since the 1950s but their identification and detection in humans and the environment was hampered by low specificity and sensitivity of chemical analysis methods at that time. It was only until the late 1990s, when significant advances and commercial availability of liquid chromatography coupled with mass spectrometric

(LC-MS) instruments and availability of labelled standards, enabled development of reliable methods for routine compound-specific analysis of PFAAs (Hansen *et al.*, 2001, Moody *et al.*, 2001, Yamashita *et al.*, 2004, Powley *et al.*, 2005, Lindstrom *et al.*, 2011). Subsequently, investigations on environmental and biological samples have revealed the extent of wide spread global contamination of PFAAs. Early studies by Giesy and Kannan (2001) reported the prevalence of PFOS in fish, birds and marine mammals collected from around the world, while Yamashita et al (2005) reported the ubiquitous presence of PFOA in oceanic waters. Further development of gas chromatography coupled with MS (GC-MS) methods have also allowed the detection of volatile PFASs and some of these, so called precursor PFASs, can degrade to PFAAs as end products (Martin *et al.*, 2002). Studies on the environmental occurrence and distribution of PFAAs as well as other PFASs have increased significantly throughout the world during the past decade (Ahrens, 2011, Houde *et al.*, 2011, Lindstrom *et al.*, 2011).

Since the replacement of a hydrogen with a fluorine often result in an increase of the vapor pressure, it is therefore likely that neutral PFASs can be emitted and found in the gas phase in the atmosphere. Many of the known PFAS precursor compounds have been ubiquitously detected in the atmosphere around the world, such as fluorotelomer alcohols (FTOHs), perfluoroalkane sulfonamides (FASAs) and perfluoroalkane sulfonamidoethanols (FASEs) (Barber *et al.*, 2007, Wang *et al.*, 2015, Li *et al.*, 2011, González-Gaya *et al.*, 2014, Rauert *et al.*, 2018b, Wong *et al.*, 2018, Wang *et al.*, 2018). However, compared to the mentioned PFAS precursors, limited information are available about the environmental occurrence and levels of other volatile PFASs with different chemical structures and uses. Such an example is perfluorotributyl amine (PFTBA), which was found in the atmosphere in Toronto, Canada (Hong *et al.*, 2013).

Global environmental contamination and potential toxicity has led to regulation of some PFASs; mainly PFOS, PFOA and long-chain PFCAs. As a consequency there has been major changes in the industry shiftning towards replacement substances such as short chain PFAS, polyfluorinated phosphate esters (PAPs), perfluorinated cycloalkanes, and polyfluorinated ethers. Examples of some of these "novel PFASs" included in the present study are given in Table 1.

Table 1: Information of some included replacement products, called "novel PFAS", in this study

Name	Abbreviations	CAS	Structure
3H-perfluoro-3-[(3-methoxy-propoxy)propa-noic acid]	ADONA	958445-44-8 (ammonium salt)	
Hexafluoropro-pylene oxide dimer acid	HFPO-DA GenX	62037-80-3 (ammonium salt)	
6:2 chlorinated polyfluorinated ether sulfonate	6:2 Cl-PFESA F-53B	73606-19-6 (potassium salt)	
Perfluoro-4-ethylcyclohe-xanesulfonate	PFECHS	335-24-0 (potassium salt)	
1,3-bis-(triflu-oromethyl)-5-bromobenzene	BTFBB	328-70-1	

As the analytical methods becomes more and more refined, it has been clear that a wide range of different PFASs are present in elevated concentrations in the environment (biota and non-biotic matrices). Improvement and lower costs of advanced mass spectrometric (MS) instruments such as quadrupole time-of-flight (qToF) and Orbitrap in combination with ultra-high performance liquid chromatography (UHPLC) allows to apply high accuracy and high resolution chromatography in combination with high resolution MS (HRMS) for the unequivocal determination of PFASs in environmental samples (Wille *et al.*, 2010). These techniques have also been applied for the quantitative identification of novel PFASs (Xiao, 2017, Liu *et al.*, 2015, Yu *et al.*, 2018, Newton *et al.*, 2017, Fakouri Baygi *et al.*, 2016, Strynar *et al.*, 2015, Ruan and Jiang, 2017). However, data analysis and quality control of these advanced screening methods are usually very time consuming and quantification of new compounds might be uncertain if no suitable standards are available.

The large structural diversity of the PFAS group and the introduction of new organofluorine substances that replace already regulated PFASs has led to public concerns about the presence of hitherto unknown PFASs in the environment with potential for uncontrolled exposure to human populations. Due to the large number of commercial PFASs, the identified PFASs might only constitute a small proportion of all PFASs that are present in the environment. In order to address this priority question, different mass balance approaches have been developed to provide information about the extent of unknown PFASs in the environment. One method to account for unknown PFASs involves the addition of a strong oxidizing agent to the sample and then measure the levels of PFAAs before and after the oxidative pretreatment. This total oxidizable precursor (TOP) assay, exploits the fact that PFAAs are very stable and persistent compounds, and the differences in PFAA levels before and after oxidization should be due to degradation of precursor compounds (Houtz and Sedlak, 2012b, Houtz *et al.*, 2013).

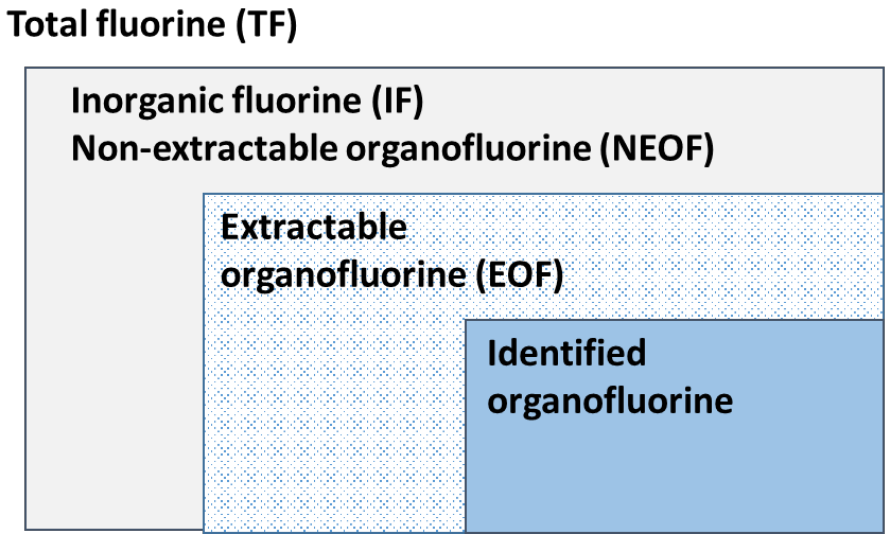
However, other organofluorine compounds not detected through the TOP assay and, thus, not degraded to PFAAs might also be relevant from a environmental and health perspective. Miyake *et al*. (2007a) developed a more comprehensive mass balance method to quantify the sum of total organic fluorine (TOF) in individual samples. This method is based on combustion ion chromatography (CIC), in which an organic extract is combusted and all organofluorine is converted to hydrogen fluoride (HF). The HF is absorbed in milli-Q water and the concentration of fluoride (F^-) ions are subsequently quantified by ion chromatography with electrochemical detection. The same extract can then be analyzed for target PFASs and the quantified PFAS levels can be converted to fluoride equivalents through the following equation:

$$C_F = n_F \times \frac{MW_F}{MW_{PFAS}} \times C_{PFAS}$$

Eq. 1

Where C_F is the corresponding fluoride concentration ($ng \cdot F \cdot mL^{-1}$), n_F is the number of fluorine in the individual target PFAS, MW_F is the molecular weight of fluorine, MW_{PFAS} is the molecular weight of the individual target PFAS and C_{PFAS} is its concentration from targeted analysis, such as LC-MS/MS. The C_F will therefore depend on both the concentration of the individual PFAS as well as its fluorination degree.

Figure 3: Schematic picture showing the total fluorine in a sample and the different steps in the mass balance approach



The total fluorine (TF) in a sample consists of inorganic fluorine (IF) and organic fluorine (OF) (Figure 3). The CIC method can in theory be used directly on a solid or liquid environmental sample but extraction prior to analysis is often needed to reduce interferences and improve detection. The extraction process is also used to remove possible inorganic fluorine since the ion chromatograph cannot separate organic from inorganic fluorine. Depending on the method used, some organofluorine compounds might not be extracted from the sample, i.e. non-extractable organic fluorine (NEOF). Among the remaining extractable organofluorine (EOF) are the PFASs that can be identified using target analysis, but there might also be organofluorine substances that does not originate from any known PFASs. The difference between EOF and quantification of target PFAS is therefore the unidentified proportion of organofluorine substances in the sample (UOF, dotted area in Figure 3). By converting the identified organofluorine into F-concentration, using eq 1, a mass balance between the EOF and identified target PFAS can be calculated, giving the proportion of EOF that is known. This TOF method has been applied for surface water samples (Miyake *et al.*, 2007a), aqueous film forming foams (Weiner *et al.*, 2013), blood matrices (Miyake *et al.*, 2007b, Yeung *et al.*, 2008, Yeung and Mabury, 2016), marine mammal livers (Yeung *et al.*, 2009b) and sewage sludge (Yeung *et al.*, 2017).

3. Samples for PFASs screening in the Nordic environment

3.1 Sample selection

A wide range of sample types were selected by the Nordic Screening Group to be included in the screening study. Liver tissue was selected as the target tissue for all biota except bird eggs. An overview of the samples is given in Table 2. The sample information provided by the participating countries can be found in Appendix 1.

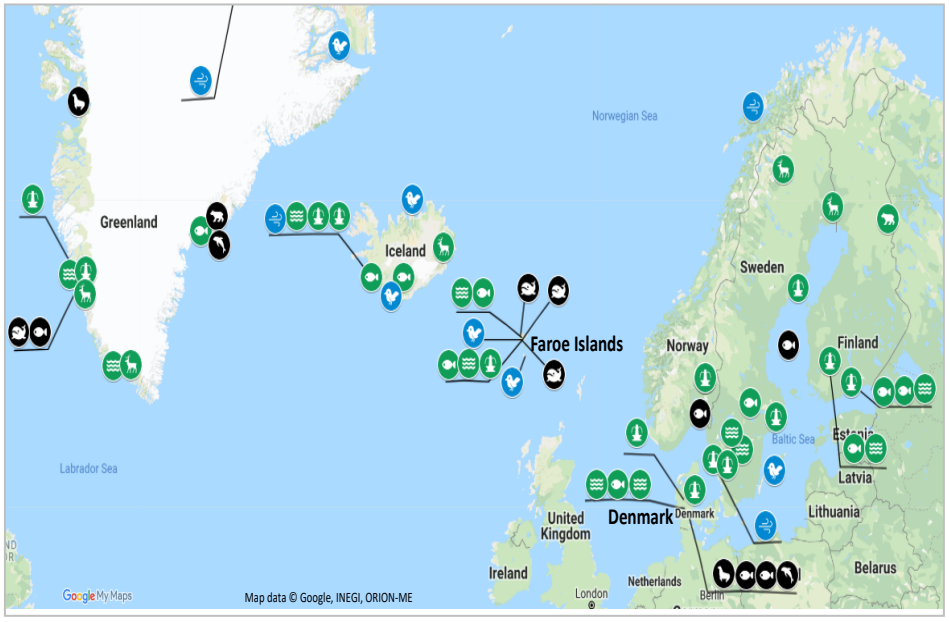
Table 2: Overview of samples included in the screening study. Bold values indicate pooled biota samples.

	Denmark	Faroe Islands	Finland	Greenland	Iceland	Norway	Sweden
Bird eggs (n=11)							
Black guillemot (*Cepphus grylle*)		1		1			
Northern fulmar (*Fulmarus glacialis*)		5					
Common guillemot (*Uria aalge*)					2		2
Marine fish (n=6)							
Atlantic cod (*Gadus morhua*)	1						
European flounder (*Platichthys flesus*)	1						
Greenland cod (*Gadus ogac*)				1			
Atlantic pollock (*Pollachius pollachius*)						1	
Atlantic herring (*Clupea harengus*)							2
Freshwater fish (n=13)							
European perch (*Perca fluviatilis*)	2		3			2	2
Brown trout (*Salmo trutta*)		1			2		
Arctic char (*Salvelinus alpinus*)		1		1			
Marine mammals (n=12)							
Harbour porpoise (*Phocoena phocoena*)	1						
Grey seal (*Halichoerus grypus*)	1						
Pilot whale (*Globicephala melas*)		5					
Humpback whale (*Megaptera novaeangliae*)				1			
Ringed seal (*Pusa hispida*)				1			
White-beaked dolphin (*Lagenorhynchus albirostris*)				1			
Polar bear (*Ursus maritimus*)				2			
Terrestrial mammals (n=9)							
Brown bear (*Ursus arctos*)			1				
Reindeer (*Rangifer tarandus*)			2	2	2		2
Freshwater (n=14)	2	2	2	2	2	2	2
WWTP effluent (n=14)	2	2	2	2	2	2	2
WWTP sludge (n=10)	2	2	2			2	2
Air (n=14)				3	6	3	2

3.2 Sample collection of surface water, effluent, sludge and biota

A comprehensive sampling manual was prepared by Örebro University and Norwegian University of Life Sciences (NMBU) and distributed to the national institutions. The instructions reflected the desired sampling handling procedures for the current screening study considering the quality control requirements expected by the Nordic Screening Group. Specific emphasis was laid upon effective sampling techniques, comprehensive quality control protocols and minimal risk of contamination. Reproducibility, contamination control, and representativness are examples of important factors that were adressed in the instructions (see Appendix 2). The characteristics of the collected samples were however influenced by current conditions during sampling such as availability of samples from different species and number of individuals. A dedicated sampling form was developed intended for following individual samples from collection to quantitative analysis. The complete sampling manual is given in Appendix 2. In addition to the sample characteristics given in Appendix 1, a short description of the samples are given below.

Figure 4: Map of the sampling locations for the different matrices in the Nordic environment (modified from Google maps)



Notes: Green marking refers to freshwater or terrestrial samples, black refers to marine biota and blue marking denotes bird eggs and air. Greenland air samples were collected at Station Nord at the upper most northern region which was not shown (outside the range of map)

3.2.1 Denmark

Effluent water and sludge samples were taken from two wastewater treatment plants (WWTPs). Sludge was taken after digestion at Randers WWTP and at the storage facility in Viborg WWTP. Both plants are equipped for advanced treatment of wastewater

and receive wastewater from municipalities. The Randers WWTP has capacity for 155,900 population equivalent (PE) and the Viborg WWTP has capacity for 80,000 PE. One water samples was collected from the east end of Silkeborg Langsø. Silkeborg Langsø is within the city of Silkeborg and a part of the river Gudenåen. The surface area of Silkeborg Langsø east is 92 ha and has a max depth of about 5 m. Another water sample was taken from Ørn Sø close to the western part of Silkeborg. The surface area of Ørn Sø is 42 ha and the max depth 10.5 m. The sample from Silkeborg Langsø was collected from 0.2 m depth while the sample from Ørnsø was a mixed sample from 0.5 and 2.5 m depth.

Freshwater fish samples were perch collected from Silkeborg Langsø, east and Ørn Sø, the same lakes as the freshwater samples. The marine fish samples of cod and scrub were from Agersø Sund in the Big Belt. The station is considered to be slightly impacted by industry and ship traffic. All fish samples were pooled from approximately ten individual fish.

The samples of marine mammals were from the Environmental Specimen Bank at Aarhus University. The grey seal was found dead in 2015 on a beach along Flensborg Fjord and close to the city Sønderborg. The harbor porpoise was bycaught in a fishermens net in Åbenrå Fjord in 2017.

3.2.2 Faroe Islands

Seabirds eggs of two species were collected. These consisted of five northern fulmar eggs, sampled in Skúvoy in May 2017, and one pooled sample consisting of five individual black guillemot eggs (weight from 2.4 to 2.5 g) collected in Koltur in June 2016.

For marine mammals, liver samples (n = 5) of juvenile male pilot whales were collected in connection with three occations of traditional whale hunting in June 2017. The average length of the whales was 408 cm (range 385–440 cm).

Two pooled freshwater fish samples were collected. One pooled sample was composed of livers from six males and four females Arctic char. The mean fork length was 23.5 ±1.6 cm, and mean age was 5.2±0.4 years. Also, a pooled liver sample composed from two male and seven female brown trout from Leitisvatn (Sørvágsvatn) in 2017 were colleted. The brown trouts were in average 25.0 ± 1.6 cm in fork length and 175 ± 30 g full weight.

Grab surface water samples were taken from the same lakes as the freshwater fish, using handheld 2 L bottles (as provided by the laboratory), in the Lake á Mýrunum, Vestmanna on September 25th 2017 and on September 24th 2017 in Lake Leitisvatn (Sørvágsvatn), at which time also a field blank was taken.

Sludge were sampled at the Sersjantvíkin WWTP on two occations, with three weeks interval, on the 5th and the 26th September 2017. Effluents were sampled at the make-shift WWTP at the Landssjúkrahúsið (LSH), at 11 am on September 26, 2017 and the same day at 7 pm in the Sersjantvíkin WWTP. The Sersjantvíkin WWTP in Tórshavn receives domestic wastewater from approx. 820 PE and has a sedimentation step. The LSH is the main hospital in the Faroe Islands and has a 700 man-year staff, 120 hospital beds, and performs approximately 663,000 clinical chemical analyses per year, in addition to more than 34,000 x-ray diagnostic analyses. Field blanks were taken as requested by the organizing laboratory.

3.2.3 Finland

All three fish samples from Finland are from perch. These are made up of pooled samples of mixed female and male fish (between 10-13 individuals). All three sampling sites were categorized as freshwater locations although one is from the Helsinki archipelago. This site is influenced by the river Vantaanjoki which was also one of the sites for freshwater samples. The other water sample was collected near Tampere (Pirkkalan Pyhäjärvi). Reindeer samples (n=2) originated from three pooled calv livers and three pooled adult livers in Ylitornio, Western Lapland. The calves were approximately six months old and the adults were all females. The brown bear liver sample (Kuusamo), was a pool from three indivduals, two were males 8–9 years old and 2–3 years old, respectively. There was no information regarding the third individual. The effluent and sludge samples were collected from two large WWTPs; Viikinmäki in Helsinki area and Viinikanlahti, Tampere.

3.2.4 Greenland

There is no wastewater treatment in Greenland, and therefore the two Greenlandic effluent samples were from raw wastewater. One sample (Qernertunnguit) was from a domestic area, while the other sample (Nuukullak) was from an area with both domestic and industrial input.

All cods for the fish sample where caught in Kobbefjord approximately 15 km from Nuuk. The sample was pooled of livers from three females and two males all between 3 and 6 years old. The arctic char sample was pooled from two male fish caught in a lake in Isortoq, South Greenland. Isortoq is a very remote location, where no local sources are expected. The Arctic chars from the lake was also used in the AMAP monitoring programme. One of the freshwater samples was sampled from the same lake in Isortoq, while the other freshwater sample was taken from Badesø – a lake approximately 20 km from Nuuk.

One reindeer sample was a pooled sample of two reindeers also from Isortoq. Their sex was unknown. The other sample was from a large male shot in the inner part of the Amaralik fiord system approximately 85 km east of Nuuk.

The humpback whale sample was pooled from two adult males from the Nuuk area, while the white-beaked dolphin was pooled from six animals from the Tasilaq area in East Greenland. Age and sex was not known, but both adults and calfs as well as male and female animals where present in the sample.

The egg sample from black guillemot was from the Scoresbysund area in East Greenland.

The pooled sample of seal livers was from a stationary stock of ringed seals living in the Ilulissat ice fjord. The sample was pooled from five livers from three males (age 1, 2 and 13 years) and two females (age 0 and 16 years).

The polar bear samples were from a mother and a cub that were shot in self defence in the Tasilaq area in 2014.

3.2.5 Iceland

Fish liver samples from Iceland (n=2) were both pools consisting of 10 individuals each. The brown trout samples was six males and four females of age around 5–7 years (30.6–47 cm, 356–1351 g). The lake is 0.85 km^2 and situated 575 m above sea level and has a maximum depth of 15.5 m (average 6.7 m). Reindeer liver samples (n=2) were collected during a period of six weeks and five individuals were pooled together. Newly laid eggs from common guillmot were pooled resulting in two samples consisting of five eggs each.

Klettagarðar WWTP recieves wastewater from approx. 200,000 PE. Effluent water from Hafnarfjordur and Klettagardar were surface water taken from the outlet of the WWTPs.

3.2.6 Norway

Fish samples were pooled liver from pollack and perch and consisted of 10 indivduals each. The pollack fish were six females and four males; females weighing between 1020 g (46 cm) and 2030 g (57 cm), while males weighed between 1060 g (49 cm) and 1820 g (57 cm).

Sewage sludge and wastewater effluent were collected once in June 2017 and once around September 2017. The surface water samples were taken in Lake Mjøsa, close to the city of Hamar. One sample were taken upstream the discharge point from HIAS WWTP and the other was taken close to the discharge.

3.2.7 Sweden

The biota samples were acquired from the biobank at the Swedish Museum of Natural History. The perch (n=2) and herring (n=2) samples were pools of liver from five individuals each. Both perch samples were predominatly females (nine out of 10 individals) while one herring sample consisted of only males and one of only females. Bird egg samples (n=2) from common guillemot were pools of five individual eggs. Reindeer samples were two pools consisting of five individuals each, and were all females with an age between 3 years and 6+ years. Equal amount of each individal (0.1 g) was taken.

Effluent water and sludge was taken from two WWTPs. The Henriksdal WWTP in Stockholm receives water from the municipality (737,000 people), industries and hospitals. The Gässlösa WWTP in Borås serves 82,000 people and is also connected to textile and chemical industries as well as a hospital. Both WWTPs have mechanical, chemical, biologic, and anaerobic digestion treatment. Sludge samples were collected as composite samples during one day. The residence time of sludge is on average 19 and 25 days in Henriksdal and Gässlösa, respectively. Effluent water was taken as a composite sample collected in seven consecutive days.

Surface water samples were taken in the central part of Lake Vättern, and in Lake Vänern close to the city of Mariestad.

3.3 Sample collection of air samples

All atmospheric samples were sent by the providing national institutions during the period September 2017–March 2018 (sample characteristics – see Appendix 1). In Greenland, the samples were collected at Station Nord at the northern most part (81°35'53.0"N 16°39'35.5"W). The air samples in Iceland was collected at the Norðurhella measuring station owned by the Health Authority of Hafnarfjörður and Kópavogur area. In Norway, the air was collected from the Andøya air station, whereas in Sweden the air samples were collected at Råö station.

As recommended in the sampling manual, for the collection of volatile poly- and perfluoroalkyl substances (vPFASs) a combination of conventional glass fiber filters (GFF) and polyurethane foam (PUF) – XAD-2-PUF sandwich samplers for the gaseous phases should have been used. However, only Norwegian and Greenland samples were collected according to this requirement. At the Swedish and Icelandic stations, the air samples were collected with GFF only. In addition, field blanks were only provided for Norwegian and Iceland atmospheric samples.

4. Analysis and quantification

Biota, surface water and WWTP samples were analyzed at MTM Research Centre, Örebro University. Air samples were analyzed at Norwegian University of Life Sciences, Faculty of Chemistry, Biotechnology and Food Sciences (NMBU-KBM).

To enable EOF analysis, all samples were analyzed in duplicates (except air samples). One replicate was analyzed with addition of labelled internal standard intended for target analysis giving recovery-corrected concentrations (Replicate 1, Figure 5). The second replicate intended for EOF was extracted without labelled standards, since it would interfere with the total fluorine analysis. Target analysis was performed for Replicate 2 as well after splitting the extract into different parts as illustrated in Figure 6. The mass balance calculation, as described in Section 2, was performed using concentrations from Replicate 2 only.

Because the target analytes had very different physicochemical properties, multiple measurements using different instruments and/or conditions were necessary. Tandem mass spectrometry (MS/MS) was used together with two chromatographic system; ultra performance liquid chromatography (UPLC) and ultra performance convergence chromatography (UPC²) (see Section 4.5). An overview of the sample extract handling (except air extracts) is given in Figure 5.

Figure 5: Schematic picture of the sample analysis (except air samples)

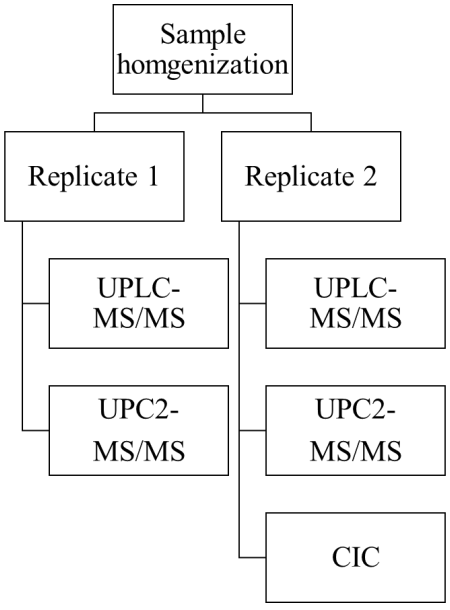
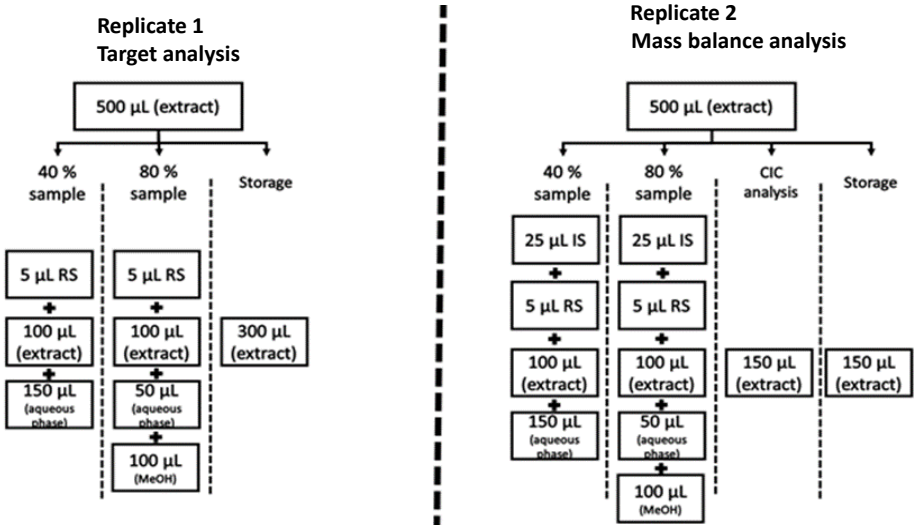


Figure 6: Overview of the sample extract analysis scheme (except air samples). Replicate 1 and 2 were analyzed with two different methanol compositions, 40% and 80%. Replicate 2 was in addition analyzed on CIC for EOF measurement.



4.1 Preparation of sludge samples

Prior to sample extraction, individual sludge sample was well-mixed in a polypropylene (PP) container. An aliquot of the sludge sample was freeze-dried and the water content was noted from the change in mass (see Appendix 7). The freeze-dried samples were homogenized using mortar and pestle. From each homogenized sample, two subsamples (0.25 g) were weighed into 15 mL PP tubes, which were pre-cleaned with methanol (MeOH). The first subsample (denoted as Replicate 1) was spiked with internal standards before extraction and was used for target analysis. The second subsample (Replicate 2) was extracted without spiking any internal standards, which was also analyzed for extractable organofluorine (EOF) by combustion ion chromatography (CIC).

The next step was alkaline digestion, 0.4 mL of NaOH (0.2 M) was added to each subsample, vortexed and allowed to digest for 30 minutes. Then 2 mL of MeOH and 80 µL of HCl (1 M) were added into each subsample, sonicated for 15 minutes and centrifuged for 10 minutes at 8000 g to separate the particulate matter from the liquid phase. The supernatant was transferred to a new PP tube and the extraction was repeated with 2 mL of MeOH. The MeOH extracts were combined and evaporated to 200 µL under a stream of nitrogen (purity grade 5.0).

After alkaline digestion and extraction, the sample extract was subjected to a cleanup step using the ion pair method, as described by (Yeung *et al.*, 2017). In brief, 2 mL of 0.5 M tetrabutyl-ammonium (TBA) solution in water was added to the extract. Then, 5 mL of methyl tert-butyl ether (MTBE) was added to the tube. The mixture was shaken horizontally for 15 minutes at 250 rpm and centrifuged for 10 minutes at 8000 g to separate the organic and aqueous phases. The top layer (MTBE) was transferred to a new PP tube and the extraction was repeated twice with 3 mL of MTBE.

The extracts were combined and evaporated to 200 µL under a gentle stream of nitrogen gas. The residue was reconstituted to 1.0 mL with MeOH and evaporated under a nitrogen flow to 0.5 mL. It was then vortexed, centrifuged and transferred to a LC vial. The PP tube was rinsed with an additional 200 µL of MeOH and it was added to the LC vial, where the combined extract was evaporated down to exactly 500 µL.

The sample extracts were then split for different analyses as shown in Figure 5 and 6. Most of the analytes were quantified in the sample with 40% organic solvent content. The sample with 80% organic solvent content was used for polyfluorinated phosphate ester (PAPs) and ultrashort-chain PFAS analyses.

4.2 Preparation of water and effluent samples

Both surface water and wastewater effluent samples were filtered using GF/F glass microfiber filters (Whatman, 150 mm, 0.7 µm pore size). The filtration unit was rinsed thoroughly with deionized water, MeOH and Milli-Q water before filtration. After filtration, the sample container was rinsed three times with two mL of MeOH. Two subsamples were taken from all filtered samples: Replicate 1 for target analysis and Replicate 2 for EOF analysis. The subsamples (0.25 L or 1 L of effluent or surface water respectively) were weighed into respective containers for subsequent solid phase extraction (SPE). The extraction method, adapted from ISO 25101 (ISO), used weak anion exchange (WAX) cartridges (Waters Oasis, 150 mg, 6 mL, 30 µm). Before extraction, the SPE cartridges were conditioned with 4 mL of 0.1% ammonium hydroxide (NH_4OH) in MeOH, followed by 4 mL of MeOH and 4 mL of Milli-Q water. After conditioning, the sample was loaded onto the cartridge at an approximate rate of 1–2 drops per second. The cartridges were thereafter washed in sequence with 4 mL of Milli-Q water, 4 mL of ammonium acetate buffer (pH=4), followed by 4 mL of 20% MeOH in Milli-Q solution. After that, the cartridges were centrifuged for 2 minutes at 3000 rpm and dried under vacuum for 30 minutes. The analytes were eluted in two fractions and collected separately in 15 mL PP tubes. The first fraction was eluted with 4 mL of MeOH and the second with 4 mL of 0.1% NH_4OH in MeOH. The first fraction contained mainly neutral PFASs; whereas the latter fraction contained principally anionic PFASs. These fractions were evaporated to 500 µL, vortexed and sonicated for 10 minutes before being transferred to LC vials. The PP tubes were rinsed with additional 200 µL of MeOH, after adding the rinse MeOH to the LC vials the combined extracts were evaporated down to exactly 500 µL. The anionic fraction was split as shown by Figure 6 and analysed. The neutral fraction was not analysed in this study.

The filters used to collect particulate matter were cut into small pieces and placed into a 50 mL beaker. A volume of 30 mL of MeOH was added and the beaker was sonicated for 30 minutes and then centrifuged for 5 minutes at 8000 g. The supernatant was thereafter transferred to a 50 mL PP tube. The MeOH extraction was repeated twice with 10 mL of MeOH. The three extracts were combined and evaporated to 500 µL, vortexed and sonicated for 10 minutes before being transferred to LC vial. The tubes were

rinsed with additional 200 µL of MeOH and then added to the LC vial, where the combined extract was evaporated down to exactly 500 µL. These extracts were split as shown in Figure 6 and analyzed for EOF using CIC and PFASs using UPLC-MS-MS.

4.3 Preparation of biota samples

Biota samples were homogenized using an Ultra-Turrax Tube drive homogenizer (IKA, IKA-Werke GmbH & Co. KG, Germany). Two subsamples (0.25 g) were weighed into MeOH rinsed 15 mL PP tubes, and thereafter followed the same steps as for the sludge samples.

The sample extraction was based on ion pairing and followed the same protocol as the second stage in sludge sample extraction (section 4.1). In short, 2 mL of 0.5 M TBA solution in water and 5 mL of MTBE were added to the tube, then shaken, centrifuged and the top layer was transferred to a new PP tube. The extraction was repeated twice with 3 mL of MTBE and the combined extract was evaporated until 200 µL under a stream of nitrogen. The residue was reconstituted to 1.0 mL in MeOH, evaporated under nitrogen flow to 0.5 mL and transferred to an autosampler vial.

The extracts were for different analyses following the same procedure as for sludge samples (Figure 6).

4.4 Preparation of air samples

In agreement with the Nordic Screening Group a method for the quantitative determination of selected volatile perfluoroalkyl substances (vPFASs) was developed at the Norwegian University of Life Sciences, Faculty for Chemistry, Biotechnology and Food Sciences (NMBU-KBM). A trace analytical method was developed and optimized based on a method previously described for conventional PFASs in atmospheric samples (Barber *et al.*, 2007, Jahnke *et al.*, 2007b). The method was further refined to meet the analytical requirements of the list of target vPFAS (Table A2-3). A full description of the method development can be found in Appendix 4.

A complete sampling manual was sent to the participants recommending sampling on glass fiber filters (GFF) for particulate collection and polyurethane-XAD-2 sandwich sampling (PUF/XAD-2/PUF) for gaseous phase collection. For details on sampling and QC, see sampling manual section in Appendix 2. A completed sample form (as presented in the sample manual) was completed by some sampling institution or the analytical laboratory personnel at NMBU/KBM for individual follow up of the samples. After receipt, all samples were registered and stored at -20 °C until extraction and chemical analysis.

4.4.1 Particle phase (GFF filters)

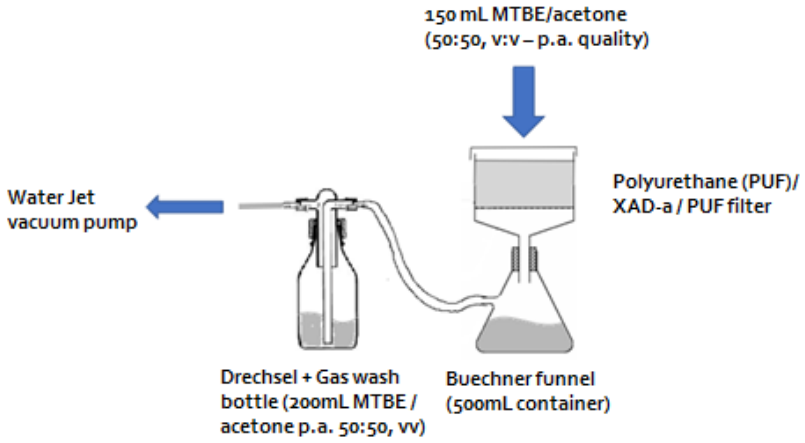
The glass fiber filters (Whatman, ID 110 mm, 50 µm cut-off) were cut into four equal aliquots and transferred into 200 mL pre-cleaned Erlenmeyer glass container. 50 mL of methyl-*tert* butyl ether (MTBE): acetone (p.a. quality, 1:1, v:v) was added. 40 ng of internal standard (stock solution 10 ng/µL) was added prior to extraction. The solution was then extracted for 15 minutes at room temperature in an ultrasonic bath. The extract was transferred into a Tubovap container (200 mL) and the extraction of the GFFs was repeated twice. All extracts were collected and combined in a Tubovap container. After adding 10 mL n-hexane, the extract (3 x 200 mL) was carefully reduced (at 30 °C water bath) on a Turbovap® (Zymark, Biotage, Stockholm, Sweden) with nitrogen (N_2, 6.0 quality AGA gas, Porsgrunn) to a final volume of 1 mL. The resulting solution was transferred into a 1.5 mL GC vial and 80 ng TCN (recovery standard) in 200 µL chloroform ($CHCl_3$) was added before reducing to a final volume of 500 µL under a gentle N_2 flow. The extract was finally transferred to the GC/MS for quantitative analysis.

4.4.2 Gas phase (PUF/XAD-2/PUF)

All gaseous samples (collected on PUF/XAD-2/PUF) were stored at -20 °C prior to extraction. For sample preparation, the PUF/XAD-2/PUF sandwich was carefully thawed and transferred to a large Buechner funnel (Figure 7). A volume of 150 mL MTBE:acetone (p.a. quality, 50:50, v:v) was added to the sample and 40 ng ISTD (stock solution 10 ng/µL) before extraction. The sample solvent mixture was then covered with precleaned aluminium foil or glass cover and allowed to interact for 60 min. Afterwards, the extracting solvent was slowly removed under low vacuum (controlled water jet, 400 atm) and collected in a 200 mL Turbovap® (TV) container. After solvent removal, a new batch of 150 mL MTBE:acetone was added for repeated extraction (after 60 min interaction with the PUF/XAD-2/PUF). 30 min after the solvent mixture was added, the extracting solvent was again removed from the Buechner funnel and collected into the 200 mL TV container. After volume reduction, the two sub-samples were combined. In order to control potential loss of highly volatile PFASs, a gas washing flask (Drechsel flask) was connected between sample collector and water jet. During extraction, the Drechsel flask was filled with 200 mL MTBE-Acetone and ISTD. After extraction the solvent was kept and analysed separately for documenting potential vPFAS losses as an integrated part of the quality control program for the this air monitoring study.

After the extraction, the solvent was combined and reduced carefully to 1 mL (30 °C water bath) on a Turbovap® with nitrogen (N_2, 6.0 quality). This applies also to the Drechsel gas wash flask sample. The extract was finally transferred into a 1.5 mL GC vial and 200 µL n-hexane + RSTD (recovery standard TCN 80 ng out of a 10 ng/µl solution) was added (PUF/GFF & Drechsel). After reduction to a final volume of 500 µL, the samples were injected into the GC/MS for quantitative analysis.

Figure 7: PUF-XAD-2/PUF Extraction set-up for vPFAS analysis



4.5 Quantification of water, sludge, and biota

Chemical analysis of most target analytes was performed using UPLC-ESI-MS/MS (ultra performance liquid chromatography electrospray ionization tandem mass spectrometry) in negative mode. The chromatographic system consisted of a Waters Acquity UPLC with a BEH column (2.1 × 100 mm, 1.7 µm) coupled to a Waters XEVO TQ-S tandem mass spectrometer. The mobile phases were MeOH and 30:70 MeOH:water mixture, both with 2 mmol/L ammonium acetate and 5 mmol/L 1-methylpiperidine as additives. Ultrashort-chain compounds (C_2–C_3) were separated by a supercritical fluid chromatographic system (UPC², Waters) coupled to the Waters XEVO TQ-S MS/MS detector. Quantification of HFPO-DA and ADONA was performed using Waters QPXE MS/MS detector. Selected samples were also analyzed for HFPO-DA and ADONA at Eurofins Food and Feed testing Sweden AB to verify the results.

Quantification of analytes was done using native and isotope labelled internal standards purchased from Wellington Laboratories (Guelph, Canada), except for 10:2 monoPAP and 10:2 diPAP, which were purchased from Chiron (Trondheim, Norway), and HFPO-DA (GenX), which was purchased from Apollo Scientific (Bredbury, UK). Structural isomers of diPAPs for which no commercial standards were available were semiquantified using the diPAP homologues closest in retention time. Branched isomers of PFOS were calculated against a certified reference PFOS isomer standard from Wellington, and reported as the sum of the isomer groups of 1*m*-PFOS, 6/2*m*-PFOS, 3/4/5*m*-PFOS, 4.4/4.5/5.5-m_2-PFOS. Branched isomers of PFHxS and PFOA were semi-quantified against their respective linear isomer, assuming same response for the linear and the branched isomers.

Concentrations of all analytes were recovery-corrected using labelled internal standards. For those homologues of PFCAs, PFSAs, PAPs, FTSAs, FTCA/FTUCAs, and FOSAAs where no isotope labelled standard were available, the internal standard closest in retention time within the same compound class was used for quantification. For Cl-PFESAs, PFECHS, PFECAs, PFPA/PFPiAs, and ADONA, the internal standard closest in retention time of the compound classes PFCAs and PFSAs was used for quantification. Multiple reaction monitoring (MRM) was used and at least two transitions were monitored for all analytes, except for TFA, PFPrA, PFBA, PFPeA, PFEtS, and PFPrS, where one transition was monitored. Detailed information on the mass spectrometric analysis can be found in Appendix 6.

4.6 Quantification of EOF

Extractable organofluorine (EOF) content was analyzed using combustion ion chromatography (CIC). The CIC system consists of a combustion module (Analytik Jena, Germany), a 920 Absorber Bodule and a 930 Compact IC Flex ion chromatograph (Metrohm, Switzerland). Separation of anions was performed on an ion exchange column (Metrosep A Supp5 – 150/4) using carbonate buffer (64 mmol/L sodium carbonate and 20 mmol/L sodium bicarbonate) as eluent in isocratic elution. In brief, the sample extract (0.1 mL) was set on a quartz boat and placed into the furnace at 1000–1050 °C for combustion, during which, all organofluorine was converted into hydrogen fluoride (HF); the HF was then absorbed into Milli-Q water. The concentration of F^- ions in the solution was measured using ion chromatography.

Fluoride signal was observed in combustion blank even when no sample was analyzed. Prior to sample analysis, multiple combustion blanks were performed until stable fluoride signals were reached; the combustion blank was found to be 15±2.8 ng F. Certified multielement ion chromatography anion standard solution was used as standard solution (Sigma-Aldrich). Anion standard solution of different concentrations was injected onto CIC. The peak area of the standard solution was first subtracted with the peak area of a previous combustion blank before plotted against concentration for the external calibration curve. A six-point calibration curve at 20, 50, 100, 200, 500 and 1000 µg/L standards was constructed, and exhibited good linearity with R^2>0.9999. Quantification of samples was based on an external calibration curve after the peak area of the sample had been subtracted from the previous combustion blank.

4.7 Quantification of air samples

4.7.1 Quantification of volatile PFASs

A new and optimized method was developed for the here conducted atmospheric screening. A list of 21 target substances (Appendix 2) was selected based on the recommendations of the Nordic Screening Group and outlined in the tender documentation. In addition, two isotope labeled internal standards and target contaminant quantification and one recovery standard (tetrachloronaphthalene = TCN) were selected and validated (Appendix 2). The principle method validation was performed according to internationally accepted QC strategies (Asmund and Cleemann, 2000, Asmund *et al.*, 2004, Mitchum and Donnelly, 1991).

Quantitative determination is based on internal standard (ISTD) quantification and sample specific recovery determination.

4.7.2 Quantification of conventional PFASs

A list of 15 target conventional PFASs were quantified in the atmospheric samples using validated and established LC/MS methods (Skaar *et al.*, 2018, Rauert *et al.*, 2018a, Daly *et al.*, 2018, Brusseau, 2018). All samples were prepared according to the method described in Section 4.4. After vPFAS analysis, the solvent was slowly changed to 500 µL methanol (p.a.) under gentle nitrogen stream (6.0 quality) and quantified as earlier described (Skaar *et al.*, 2018).

4.8 Quality assurance and control for water, sludge and biota

4.8.1 Target analysis

Limit of detection

The limit of detection (LOD) was determined as mean concentrations of the signal in procedural blanks with addition of three times the standard deviation for surface water and effluent samples. For biota and sludge samples, the LOD was determined as three times the blank concentration. If an analyte was not present in the blanks, the lowest point of the calibration curve was used.

Recoveries, precision and accuracy

Recoveries of internal standards for different matrices are presented in Table 3. Samples with recoveries between 20 and 150% were considered as acceptable as mass labelled internal standards were used for quantification. Samples with recoveries below 20% or great than 150% were not reported and were denoted as not quantified (n.q) in the results.

Additional recovery tests were performed for the novel PFASs included in this study (Table 4), since authentic labelled standards were missing for some of them. The results show that surrogate internal standards can be used for high qualitative analysis for PFECHS and ADONA. Further, participation in interlaboratory study for validation of ISO 21675 in 2018 showed similar values for ADONA and HFPO-DA as the assigned value in the ILS report (z-score <1), and further assures the quality control/quality assurance of analytical determinations of novel PFASs (Taniyasu, 2018). For fish and marine mammals the performance was somewhat poor in regards to 6:2 Cl-PFESA in this study, and unacceptable for 8:2 Cl-PFESA. Performance was also weaker for ADONA and HFPO-DA in sludge and bird egg. Although ADONA showed signal enhancement, it could not be detected in any of the samples (Section 5).

Quality control (QC) samples were included in each batch to assess the reproducibility and accuracy of the method. For sludge analysis, the NIST 2781 from the National Institute of Standards and Technology (NIST) at the US Department of Commerce (Washington, USA) was used as QC sample. For fish, bird egg, reindeer, marine mammal analysis, interlaboratory study samples were used as QC samples. The observed relative standard deviations (RSD) of L-PFOS and L-PFOA concentrations in QC samples were below 30%.

Table 3: Results of mean internal standard recovery (%) in surface water, wastewater effluent, sludge and biota. Relative standard deviation (RSD) is presented in the parentheses

Mean Recovery (%) (RSD)							
Analyte	**Surface water**	**Wasterwater Effluent**	**Sludge**	**Reindeer**	**Fish**	**Bird egg**	**Marine mammal**
	n=14	**n=12**	**n=12**	**n=6**	**n=16**	**n=10**	**n=7**
13C-PFBA	39 (46)	53 (37)	107 (16)	73 (10)	62 (23)	98 (5)	46 (15)
13C-PFPeA	85 (27)	72 (23)	98 (22)	76 (10)	71 (18)	96 (5)	44 (18)
13C-PFHxA	103 (12)	74 (18)	106 (12)	76 (8)	70 (20)	99 (5)	40 (21)
13C-PFHpA	100 (8)	79 (20)	122 (16)	75 (8)	66 (27)	109 (7)	36 (22)
13C-PFOA	103 (7)	86 (17)	108 (13)	80 (7)	73 (19)	96 (6)	36 (19)
13C-PFNA	103 (7)	80 (15)	107 (14)	80 (9)	67 (19)	97 (7)	35 (24)
13C-PFDA	96 (8)	69 (17)	112 (16)	81 (9)	74 (18)	98 (5)	34 (26)
13C-PFUnDA	79 (15)	66 (18)	106 (12)	80 (9)	72 (20)	98 (3)	36 (23)
13C-PFDoDA	60 (30)	54 (23)	12 (73)	57 (10)	33 (29)	47 (9)	34 (24)
13C-PFTDA	64 (61)	17 (36)	29 (150)	22 (47)	34 (43)	45 (40)	69 (47)
18O-PFHxS	109 (8)	88 (15)	109 (14)	81 (8)	75 (18)	97 (6)	40 (24)
13C-PFOS	97 (6)	72 (15)	108 (15)	83 (7)	75 (18)	99 (6)	38 (24)
13C-6:2 FTSA	124 (15)	85 (24)	307 (40)	65 (22)	73 (31)	22 (10)	70 (58)
13C-8:2 FTSA	138 (20)	89 (23)	157 (55)	82 (13)	90 (30)	105 (32)	64 (58)
13C-6:2 FTUCA	96 (9)	73 (21)	115 (27)	70 (13)	23 (119)	74 (31)	29 (63)
13C-8:2 FTUCA	98 (8)	76 (20)	44 (46)	87 (39)	64 (32)	35 (88)	39 (38)
13C-10:2 FTUCA	88 (14)	65 (29)	49 (63)	68 (11)	22 (114)	42 (86)	32 (41)
13C-6:2 diPAP	38 (101)	13 (94)	368 (42)	25 (14)	64 (60)	297 (18)	110 (29)
13C-8:2 diPAP	53 (77)	4 (69)	104 (44)	16 (18)	72 (61)	147 (18)	61 (33)
2H -Et-FOSAA	86 (14)	64 (19)	207 (24)	22 (10)	80 (49)	94 (15)	39 (22)
13C-HFPO-DA	73 (17)	100 (18)	6 (36)	6 (70)	23 (32)	118 (12)	49 (13)

Table 4: Results of spike-recovery experiments (%) for individual PFASs (1 ng) in fish liver, marine mammal liver, WWTP effluent, sludge, and bird egg. Relative standard deviation (RSD) is presented in the parentheses

Mean Recovery (%) (RSD)					
Analyte	**Fish (n=3)**	**Marine mammal (n=3)**	**Wasterwater Effluent (n=3)**	**Sludge (n=1)**	**Bird egg (n=1)**
8:2 Cl-PFESA	n.r.	n.r.	62 (52)	100	122
6:2 Cl-PFESA	23 (24)	33 (57)	88 (17)	102	105
PFECHS	83 (7)	74 (25)	94 (5)	117	94
ADONA	63 (26)	66 (28)	87 (5)	17	21
HFPO-DA	112 (14)	80 (24)	81 (2)	17	22

Note: n.r. = not recovered.

4.8.2 EOF analysis

Limit of detection

The limit of detection (LOD) was determined as mean concentrations of the signal in procedural blanks with addition of three times the standard deviation. In case the fluoride signal of the procedural blank was found to be lower or similar to that of the combustion blank, the lowest point of the calibration curve was used.

Detectable organofluorine was found in extraction blank; levels of organofluorine in extraction blank ranged from <30–34 ng F/L for surface water samples, and 57–126 ng F/L for effluent samples, <20–60 ng F/g for biota samples and 475 ng F/g for sludge samples, <30–34 ng F/L for surface water samples, and 57–126 ng F/L for effluent samples. Sample concentrations were reported when their levels were at least twice that of the corresponding extraction blank in the batch with the exception of sludge samples where sample conentrations might not necessarily reach this requirement of at least twice of those in the extraction blanks; the EOF reported for sludge should be considered as semiquantitative. The reported values were not corrected for extraction blanks.

Precision and accuracy

Combustion blanks were conducted between sample injections to evaluate the presence of carryover between samples. Combustion of 100 ng (*n=3*) and 500 (*n=3*) ng of SRM 2143 – p-fluorobenzoic (NIST) resulted in recoveries of between 90–98%. Combustion of 500 ng of PFOS (*n=3*) resulted in recoveries ranging from 89 to 92% and combustion 500 ng of PFOA (*n=3*) resulted in 85 to 90% recoveries. In order to evaluate the precision of CIC during sample analysis, a 100 ng F/mL of PFOS standard was injected for every 10 samples; the measured values of 96.3 (RSD 14.4) ng F/mL were observed.

4.9 Quality assurance and control for air samples

For the here performed method validation, key components such as linear response range for quantitative determination (relative response factor ±10%) and overall and sample specific recovery range (minimum: 40%) were determined. In addition, method precision and overall uncertainty was estimated based on repeated quantification of samples and standards. The quality control protocol was performed according to standard procedures comprehensively described in the literature (Xu *et al.*, 2013, Liu *et al.*, 2017, Dinglasan-Panlilio and Mabury, 2006, Bartolome *et al.*, 2016, Lankova *et al.*, 2015, Vestergren *et al.*, 2012).

For all atmospheric samples, glass fiber filters (GFF, particulate phase) and PUF-XAD-2/PUF sandwich filters (gaseous phase) were quantified separately. For PUF-XAD-2/PUF sandwich filters (gaseous phase) extraction, the solvent in the Drechsel gas washing flask was qualitatively analysed and reported as + or - for identifying possible breakthrough of analytes (QC). All quantifications were performed in duplicates and average concentrations were reported. Deviations of >50% between the two values were not accepted and the concentration values were discarded.

Limit of detection (LOD) defines the minimum level of the compound which can be reliably detected. Thus, the limit of quantification (LOQ) is the minimum level of which a compound can be quantified. LOD is based on a minimum signal (S) in relation to baseline noise (N) of the chromatogram and as S/N ratio to be minimum 3:1 in the lowest quantifiable standard solution. The LOQ is determined as S/N= 10:1 in case no blank contamination (field blank, lab-blank, solvent blank) was detected. In case a blank contamination was detected, the LOQ was determined as blank value + 10 * standard deviation (SD). For more information please refer to (Klang and Williams, 2016, Rustichelli *et al.*, 2013, 1998).

Table 5: Limit of detection (LOD) and limit of quantification (LOQ) for the final list of target PFASs in air. Their CAS numbers and additional information can be found in the appendix Table A2-3

Compound	Abbreviation	LOD [pg/m³]	LOQ (pg/m³] PUF	LOQ [pg/m³] GFF	Comment
4:2 Fluorotelomer alcohol	*FTET*	1	8/ 65 (PUF Nor)	6	Field blank
Bromopentafluorobenzene	*BPFB*	0.5	5	12	
1,3-Bis(trifluoromethyl)-5-bromo-benzene	*BTFBB*	0.1	3/ 600 (PUF Nor)	900 (PUF Nor)	Field blank
6:2 Fluorotelomer alcohol	*FHET*	0.2	16	5	
8:2 Fluorotelomer alcohol	*FOET*	0.1	18	15	Field blank
N-methyl perfluorooctane sulfonamidoethanol	*EtFOSA*	0.2	11	7	
1,3,7-tetrakis(3,3,3-trifluoropropy)1,3,5,7-tetramethylcyclosiloxane	*TTFMCS*	1	3	6	
N-ethyl, 1,1,2,2,3,3,4,4,5,5,6,6,6-tridecafluoro-N-(2-hydroxyethyl) hexane-1-sulfonamide	*ETDHSA*	0.1	4	4	
N-(Methyl)nonafluorobutanesulfonamide	*MeFBSA*	0.1	1	1	
1,1,2,2,3,3,4,4,5,5,6,6,6-tridecafluoro-N-methylhexane-1-sulfonamide	*TDFMSA*	0.1	1	1	
Perfluoroocante sulfonamide	*FOSA*	0.1	1	1	
N-methyl perfluorooctane sulfonamidoethanol	*EtFOSE*	0.1	1	2	
Linear perfluorobutane sulfonate	*LPFBS*	0.1	1	1	

5. Results

5.1 Levels and distribution

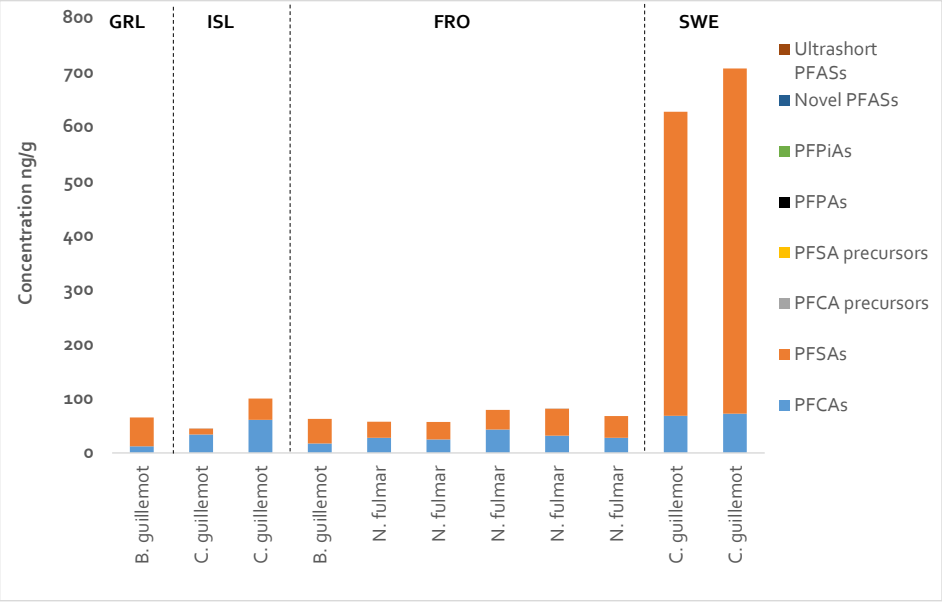
5.1.1 Biota

Bird eggs, marine mammals, terrestrial mammals and fish were analyzed for EOF and a suite of 78 PFASs of different classes, which included persistent PFCAs, PFSAs, and PFCA precursors (FTSAs, FTCAs, FTUCAs, diPAPs, monoPAPs), PFSA precursors (FOSAAs, diSAmPAP, SAmPAP), PFPA and PFPiAs. Concentrations of individual compounds in the samples are provided in Appendix 5.

Bird egg

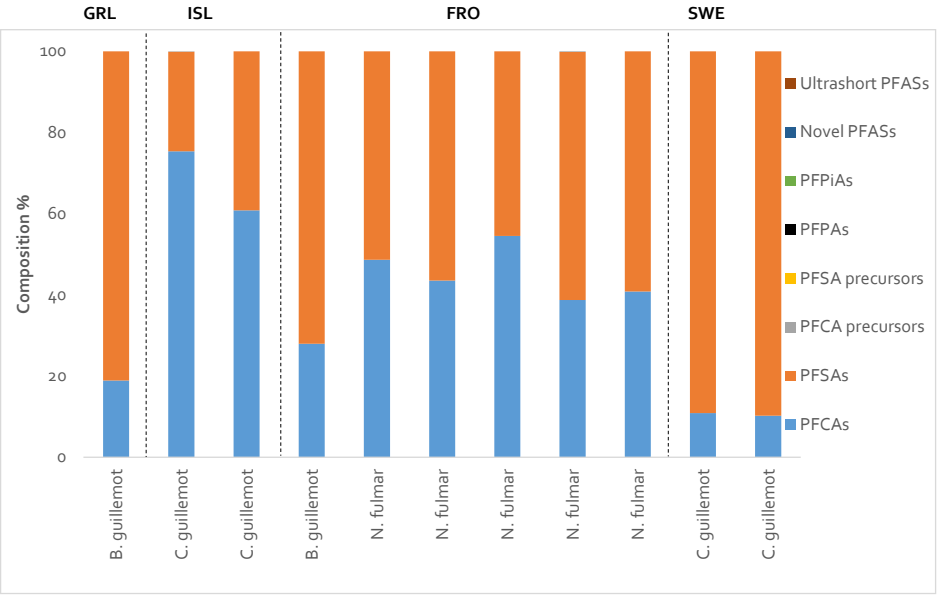
A total of 11 bird egg samples from Greenland (n =1), Iceland (*n*=2), Faroe Islands (*n*=6), and Sweden (*n*=2) were analyzed. The average total PFAS concentrations in descending order were 667 ng/g (627–707 ng/g) for Sweden, 72.4 ng/g (44.9–99.9) for Iceland, 65.1 ng/g for Greenland and 60.1 (56.9–81.4) ng/g for Faroe Islands (Figure 8). PFCAs and PFSAs contributed together over 99.8% of the total PFASs in all egg samples. Detectable PFCA precursors were only found in one sample from Iceland (6:2 diPAP 0.05 ng/g) and one sample from Faroe Islands (6:2 FTSA 0.15 ng/g). All other PFAS classes were below their respective detection limits. Egg samples from different bird species in Iceland and Faroe Islands showed similar concentrations of PFASs while the Swedish samples have considerably higher levels, of primarily PFOS.

Figure 8: Average concentration (ng/g w.w.) of different PFAS classes in bird eggs from the Nordic countries



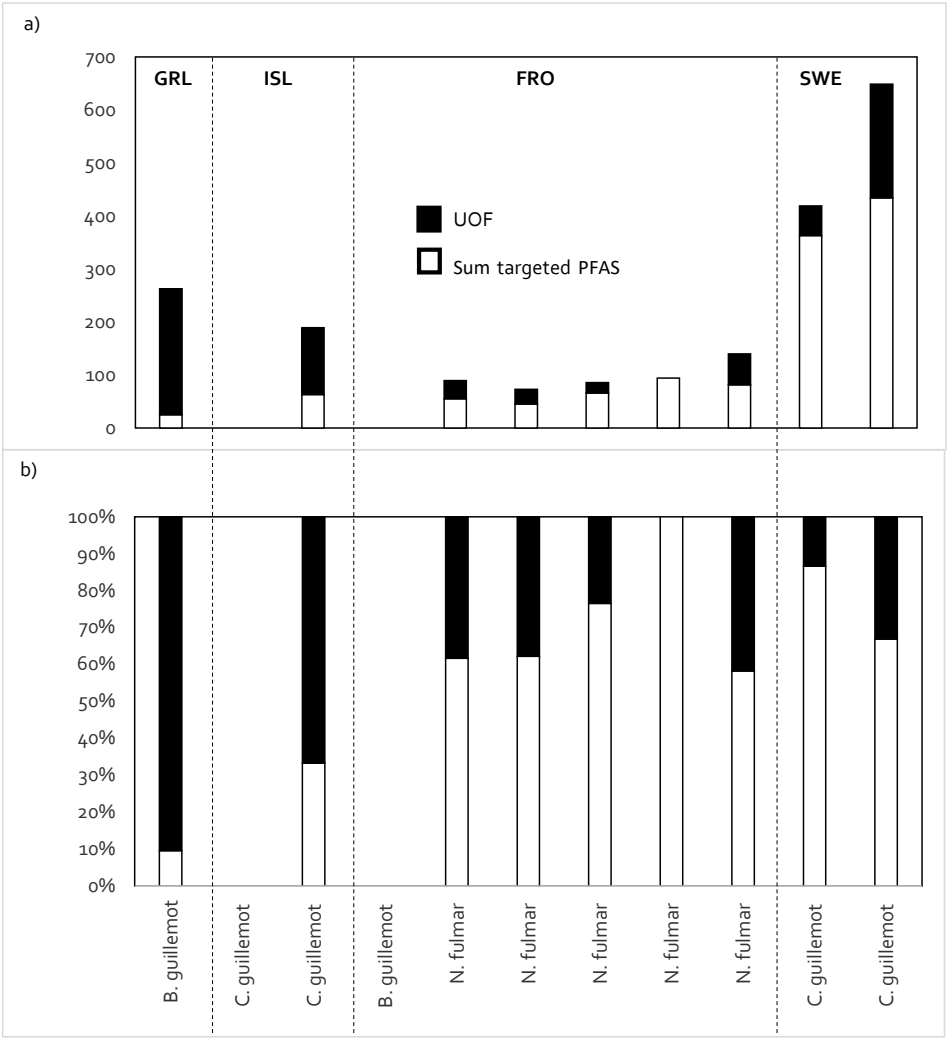
All egg samples showed contamination of PFOS and long chain PFCAs but differences in the homologue concentrations between countries were observed. The PFCA pattern was similar between countries, with increasing concentrations with increasing chain length up to C11 (PFUnDA) which is likely a result of increasing bioaccumulation potential. Concentrations were thereafter higher for odd number chain lengths of PFCA (PFUnDA, PFTrDA) compared to even number PFCA (PFDoDA, PFTDA). PFUnDA and PFTrDA made up on average 39% (31–56%) and 26% (17–33%), respectively. Samples from Iceland showed a higher average contribution of PFCAs (mean 68%) compared to Faroe Islands and Sweden (Figure 9). Within the PFSA class, PFOS contributed with over 99% of the total concentrations. PFHpS and PFHxS were quantified in the samples from Sweden but constituted only around 1% of the PFSA concentration.

Figure 9: Composition (%) of different PFAS classes in bird egg. B. guillemot: Black guillemot, N. fulmar: Northern fulmar, C. guillemot: Common guillemot



Nine out of the eleven egg samples showed measurable extractable organofluorine (EOF), which ranged <40–649 ng F/g for all samples as illustrated in Figure 10(a). Bird egg samples from Sweden (419–649 ng F/g) showed relatively higher EOF levels than those from Greenland (287 ng F/g) of Faroe Islands (<40–140 ng F/g) and Iceland (<40–190 ng F/g). A mass balance between EOF and target PFASs, as described in Section 2, was performed on the eight bird egg samples with EOF above the detection limit. The mass balanace shown in Figure 10 reveals the fraction of EOF that can be explained by target analysis and the remaining unidentified organofluorine (UOF). Results showed that the target analysis could explain 67–87% of EOF for Swedish egg, 58–102% for Faraoe Islands, 33% for Iceland and 9% for Greenland.

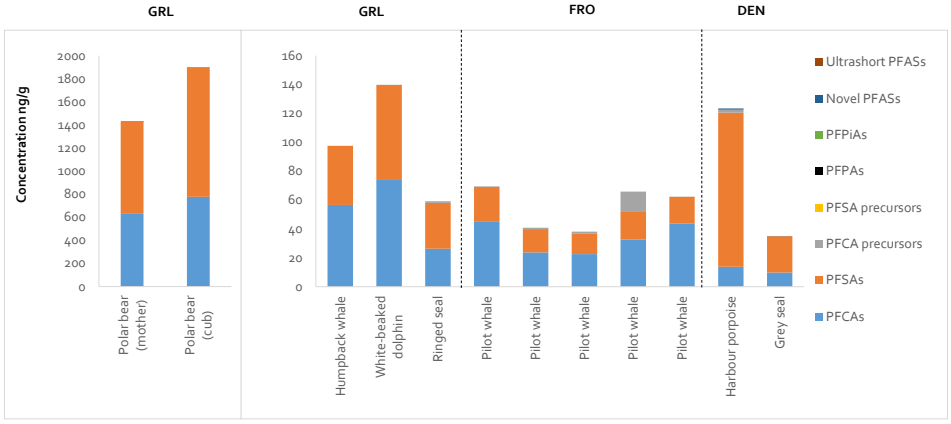
Figure 10: Total concentration of EOF (ng F/g) in bird egg divided into sum of targeted PFASs (white bars) and unidentified organofluorine (UOF, black bars). Empty column indicates sample concentration below limits of detection (<40 ng F/g). b) Composition of sum targeted PFASs and unidentified EOF in percentage of total EOF. B. guillemot: Black guillemot, N. fulmar: Northern fulmar, C. guillemot: Common guillemot



Marine mammals

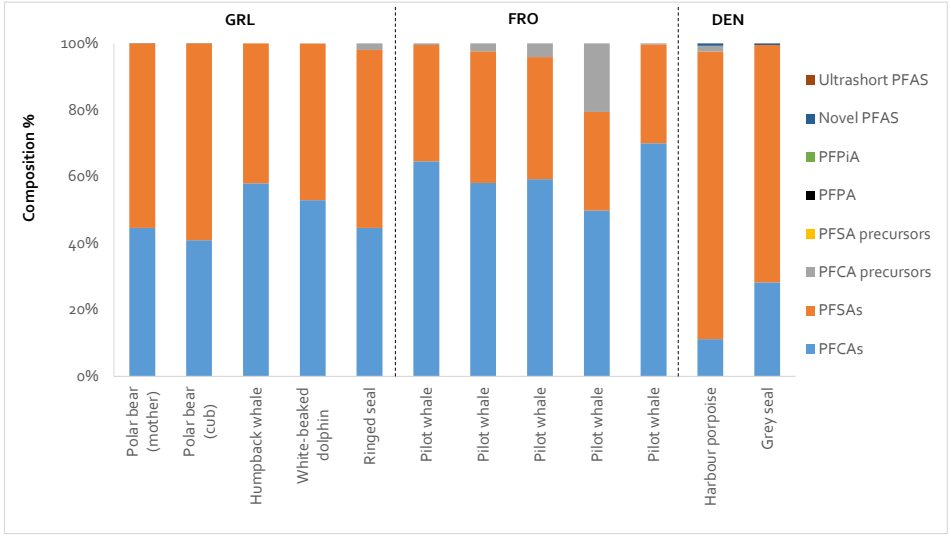
Liver samples from marine mammals from Greenland (n=5), Faroe Islands (n=5), and Denmark (n=2) were analyzed for targeted PFASs and EOF. Polar bear samples demonstrated the highest concentration of total PFASs (up to 1900 ng/g). For the other samples the PFAS levels ranged between 35.1 ng/g in grey seal from Denmark to 140 ng/g in white-beaked dolphin from Greenland (Figure 11).

Figur 11: Concentrations of PFAS classes in marine mammals from Greenland, Faroe Islands, and Denmark (ng/g ww). Note the different concentration scales for the polar bears compared to the other marine mammals



Several PFAS classes were detected in marine mammals, including PFSAs, PFCAs, FTSAs, FTCAs, diPAPs, and PFECAs. The PFAS profile was clearly dominated by the persistent PFAAs and the mean contribution from PFCAs was 46% and for PFSAs 51% (Figure 12).

Figure 12: Distribution of PFAS classes in marine mammals from Greenland, Faroe Islands, and Denmark (in percentage of total PFASs, %)



The PFCA profile was generally predominated by PFUnDA (mean 38%), followed by PFNA (mean 28%), PFDA (mean 23%), PFTrDA (mean 13%), PFDoDA (mean 5%), PFOA (mean 4%), and PFTDA (mean 3%). An exception was the polar bears from Greenland, where PFNA predominated (mean 67%) followed by PFDA (mean 25%).

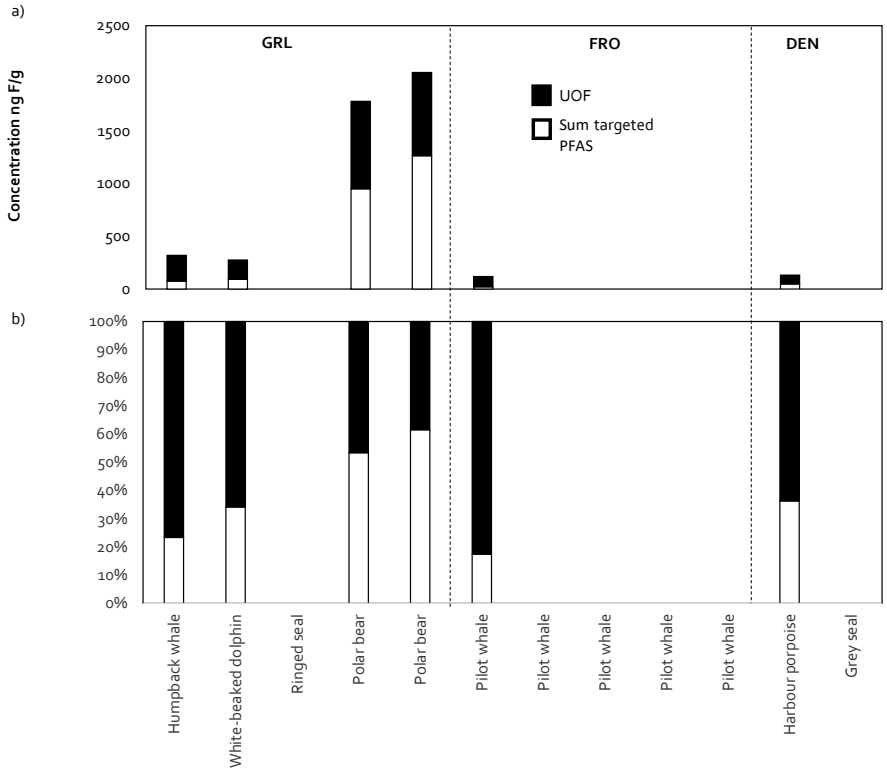
Linear PFOS (L-PFOS) clearly dominated the PFSA profile (mean 90%) and was the highest single homologue contributor to the PFAS profiles. Highest L-PFOS levels were found in polar bear liver from Greenland, with 819 ng/g in cub and 567 ng/g in mother. The contribution of branched isomers to the total amount of PFOS was evaluated and found to range between 3% and 17%. Both polar bears had the highest contribution of br-PFOS (17%) while all five pilot whales had the lowest ratio of br-PFOS (3–4%).

One novel PFAS compound, PFECHS, was detected in marine mammal samples at low ppb levels. PFECHS was quantified in polar bear samples from Greenland (0.10–0.22 ng/g w.w.) and grey seal (0.18 ng/g w.w.) and harbour porpoise (0.87 ng/g w.w) from Denmark.

Precursor compounds of PFCAs were detected in the majority of marine mammal samples and made a significant contribution to the overall PFAS profile in one of the pilot whale samples, as can be seen in Figure 12. The group that was most frequently detected from the precursor classes was FTCA/FTUCAs, which was found in 54% of the samples. Homologues detected were 7:3 FTCA and 6:2 FTUCA in 38% and 14% of samples samples respectively. Other precursor compounds detected were FTSAs and diPAPs. The FTSAs were detected in two samples from Greenland and one sample frome Faroe Islands, ringed seal from Greenland contained 6:2 FTSA (1.02 ng/g) and 8:2 FTSA (0.05 ng/g), and polar bear (Greenland) contained 8:2 FTSA (0.12 ng/g), long-finned pilot whale from Faroe Islands contained 8:2 FTSA (0.12 ng/g). The diPAPs were only quantified in the Faroe Islands samples, with 6:2 diPAP being the most frequently detected (n=3, 0.21–0.74 ng/g). Other diPAPs detected were the longer chain homologues of 6:2/8:2 diPAP, 6:2/10:2 diPAP, 6:2/12:2 diPAP, 6:2/14:2 diPAP, 8:2 diPAP, 8:2/10:2 diPAP, and 8:2/12:2 diPAP. In total, the PFCA precursors only had a minor contribution (mean 2.5%) to the total amount of PFASs.

The concentrations and compositions of EOF (unidentified organofluorine + identified target PFASs) in marine mammals are shown in Figure 13.

Figure 13: Total concentration of EOF (ng F/g) in marine mammals divided into sum of targeted PFASs and unidentified organofluorine (UOF). b) composition of sum targeted PFASs and unidentified EOF in percentage of total EOF. Empty column indicates sample concentration below the batchwise limits of detection (<40 ng F/g for the pilot whales and <132 ng F/g for the other marine mammal samples)



The amount of EOF was above LOD in seven of thirteen samples, ranging from 118 ng/g to 2056 ng/g. Highest levels of EOF were found in polar bear from Greenland (1782–2056 ng/g). Lowest levels of EOF were found in pilot whales from Faroe Islands (<40–118 ng/g). Mass balance between identified and unidentified EOF showed that the proportion of unidentified EOF ranged between 10–62% (average 37%). Highest proportions of identified PFASs were found in polar bears from Greenland (53–62%), which were mainly attributed to PFSAs (29–35% of total EOF), and PFCAs (25–26% of total EOF).

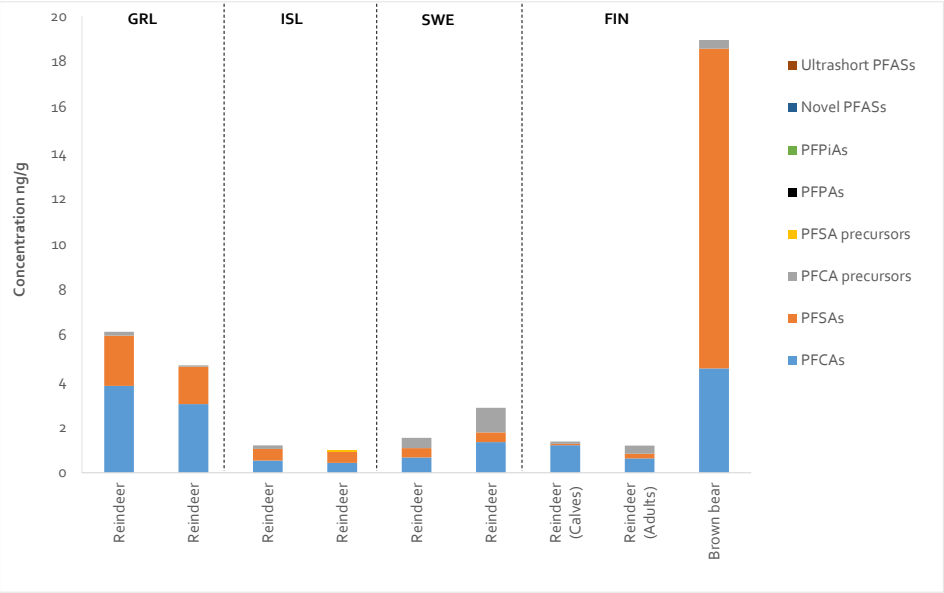
Terrestrial mammals

A total of nine terrestrial mammal samples, all livers, from Iceland (*n*=2), Sweden (*n*=2), Finland (*n*=3) and Greenland (*n*=2) were analyzed for EOF and PFASs. All samples were from reindeers, except one which was a brown bear fom Finland. In addition, the two reindeer samples from Finland were divided into calves and adults. Concentrations of individual compounds in the sample are provided in Appendix 5.

The average total PFAS concentrations in the reindeer samples in descending order were 5.4 ng/g for Greenland, 2.2 ng/g for Sweden, 1.3 ng/g for Finland and 1.1 ng/g

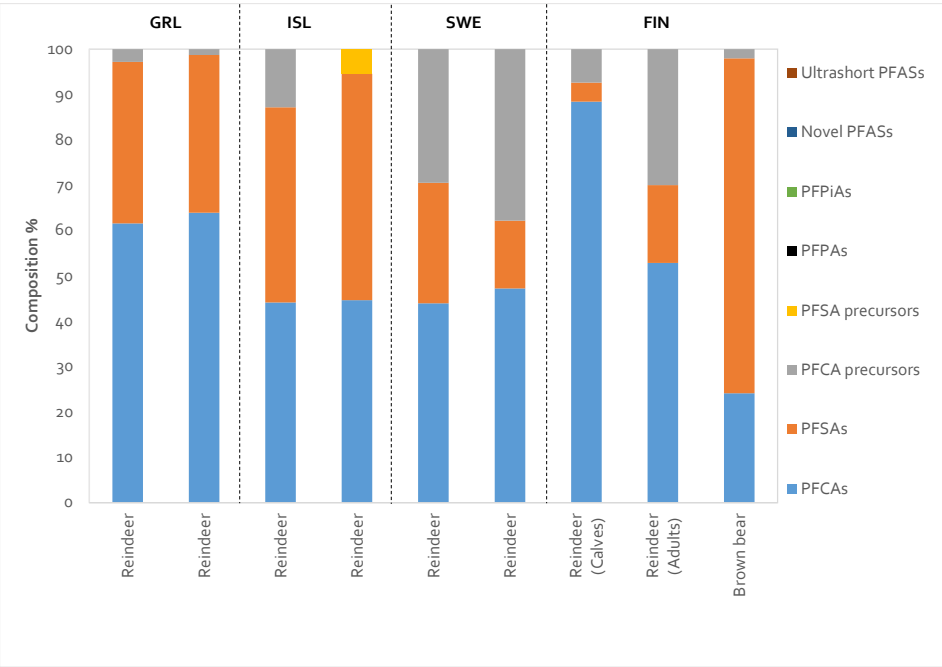
for Iceland (Figure 14). The individual brown bear sample from Finland had a total PFAS concentration of 18.9 ng/g. All terrestial mammal samples showed detectable PFCAs and PFSAs resulting in those two classes being the dominating ones. Detectable PFCA precursors were found in all the samples although in low concetrations. One sample from Sweden also contain detectable level of diPAPs, which belongs to the PFCA precursor group.

Figure 14: Concentration (ng/g w.w.) of different PFAS classes in reindeer and brown bear from the Nordic countries



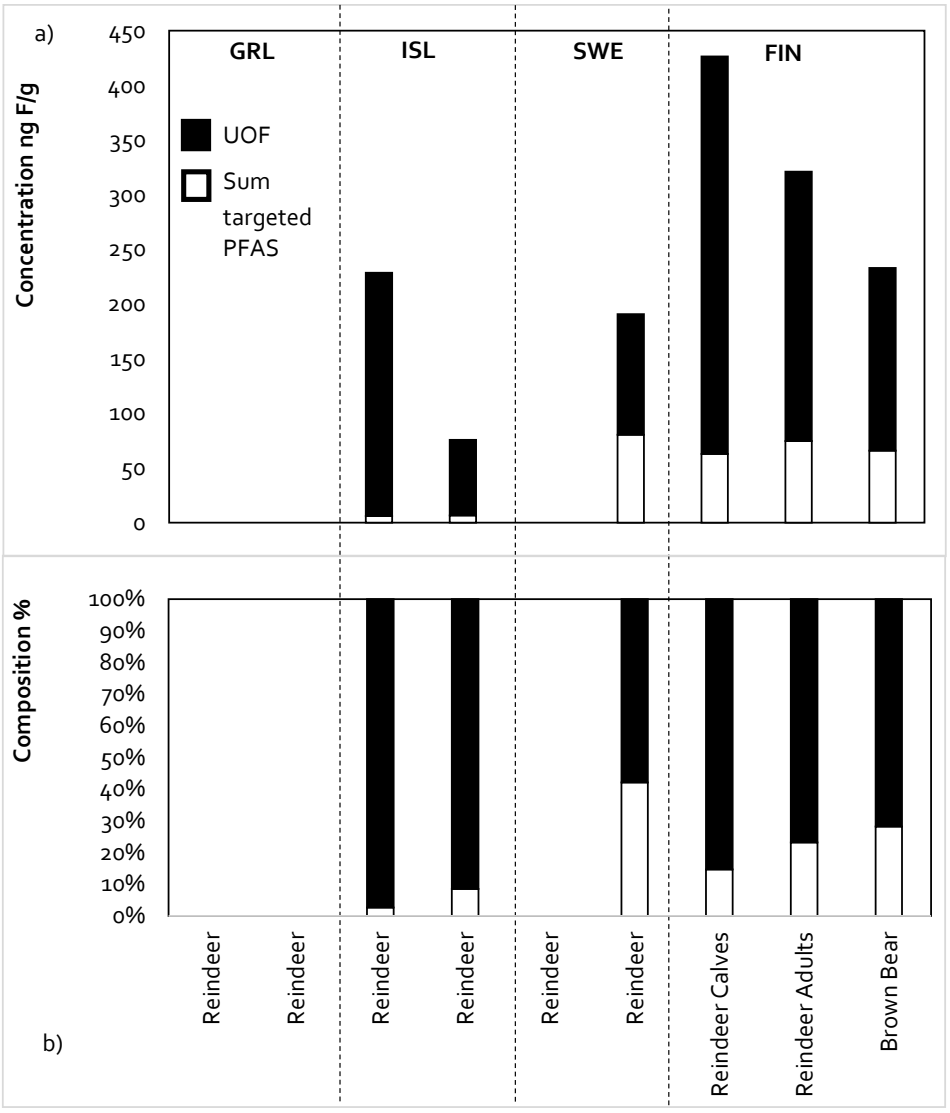
Terrestrial mammals from the different studied nations showed different contribution between PFSAs, PFCAs, and PFCA precursors (Figure 15). PFCAs was dominating the PFAS profile for reindeers from Greenland (~60%) and Finland (53–88%). Reindeer samples from Iceland showed almost equal proportion between PFCAs and PFSAs and reindeer samples from Sweden were dominated by PFCAs (46%) and PFCA precursors (34%). Although different contributions of PFCAs and PFSAs were noted, PFOS was representative for the PFSA class while long chain PFCAs dominated the PFCA class. The brown bear sample was dominated by PFOS (13.8 ng/g) resulting in the PFSA class being the major contribution to total PFASs.

Figure 15: Composition (%) of different PFAS classes in terrestial mammals



Six out of the nine samples, five reindeer and one brown bear, showed measurable extractable organofluorine (EOF), which ranged 76–427 ng F/g for all samples. In general, samples from Finland (321–427 ng F/g) showed relatively higher EOF levels than those of Iceland (76–229 ng F/g) and Sweden (<115–191 ng F/g). Three of the reindeer samples showed EOF that were below the blank levels, and mass balance analysis could not be conducted on these samples. Levels and composition of quantifiable PFASs and unidentified EOF are shown in Figure 16. Results showed that five terrestial mammal samples showed detectable unidentified EOF, which accounted for 58–97% of EOF.

Figure 16: a) Total concentration of EOF (ng F/g) in reindeers and brown bear divided into sum of targeted PFASs and unidentified organofluorine (UOF). b) composition of sum targeted PFASs and unidentified EOF in percentage of total EOF. Empty column indicates sample concentration below the limits of detection <76 ng F/g



Fish

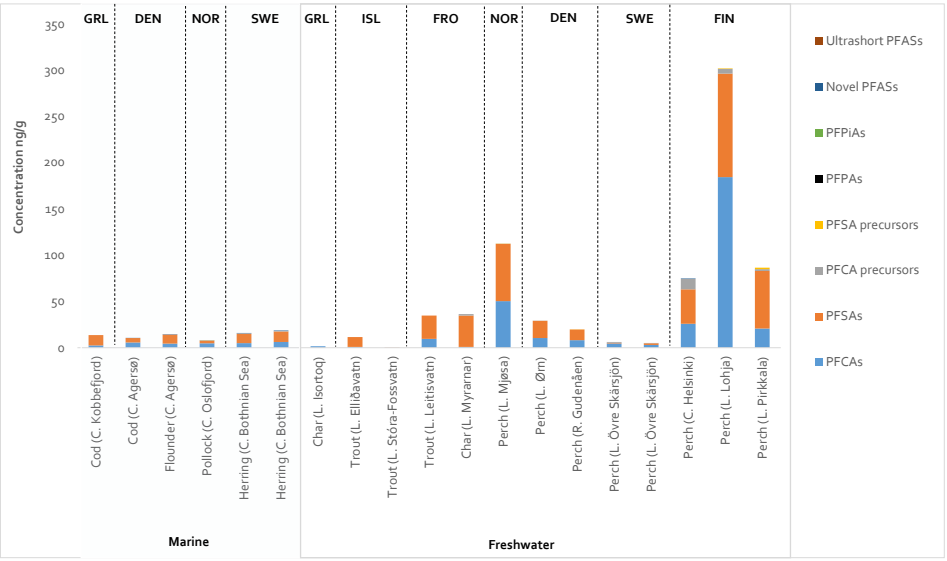
A total of six marine (Greenland n=1, Denmark n=2, Norway n=1, Sweden n=2) and thirteen freshwater fish samples (Greenland n=1, Iceland n=2, Faroe Islands n=2, Norway n=1, Denmark n=2, Sweden n=2, Finland n=3) were analyzed for EOF and PFASs. Concentrations of individual compounds in the samples are provided in Appendix 5.

The average total PFAS concentrations in the marine fish samples from the four countries were, in descending order, 17.2 (15.9–18.5) ng/g for Sweden, 13.7 for Greenland, 12.6 (10.6–14.6) ng/g for Denmark and 8.1 ng/g for Norway (Figure 17). All marine fish samples showed detectable PFCAs and PFASs, which contributed to over 91% of total PFASs. The marine fish samples from Denmark and Sweden showed detectable novel

PFAS (PFECHS) that contributed from 1.2 to 2.4% of the total PFASs. Precursors of PFCAs (i.e., 4:2, 6:2 FTSAs) accounted for up to 3.6% of the total PFASs. In general, PFSAs accounted for the majority of the total PFASs (32–82%), in which PFOS accounted for over 98% of the total PFSA. Long-chain PFCAs (PFNA, PFDA, and PFUnDA, and PFTrDA) together with PFOA accounted for all of the total PFCA in the samples.

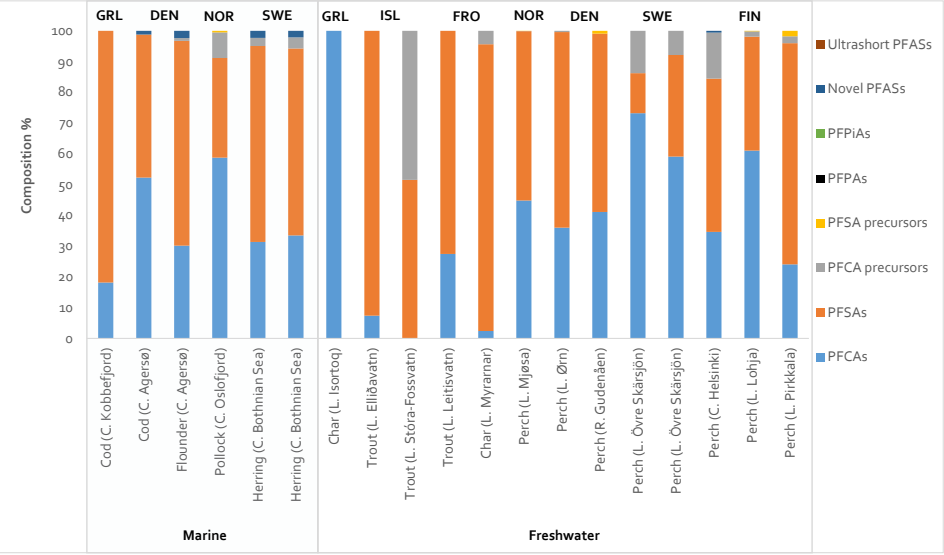
The total PFAS concentrations in the freshwater fish samples in descending order were 154 (74.7–302) ng/g for Finland, 112 ng/g for Norway, 35.4 (34.7–36.2) ng/g for Faroe Islands, 24.4 (19.8–29.1) ng/g for Denmark, 5.9 (0.3–11.5) ng/g for Iceland, and 5.7 (5.2–6.2) ng/g for Sweden (Figure 17).

Figure 17: Concentrations (ng/g w.w.) of different PFAS classes in fish liver samples by location (prefix C. indicate a coastal area, L. for lake and R. for river), and country



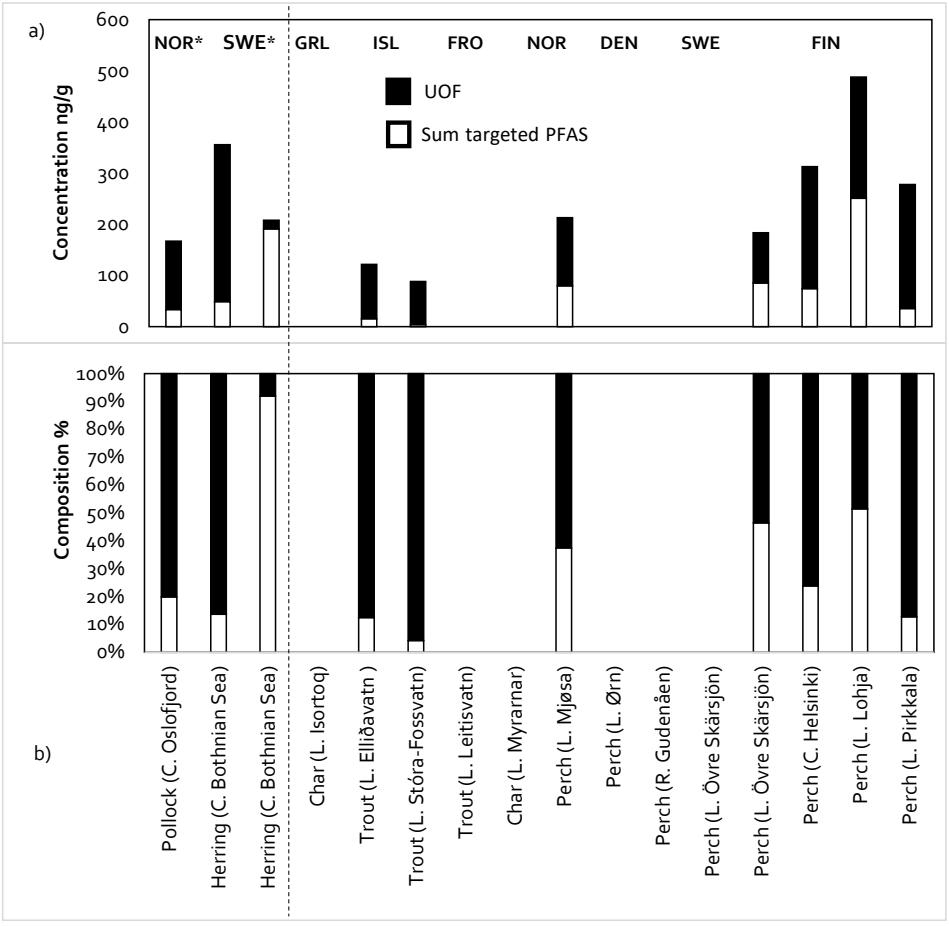
All freshwater fish samples showed detectable PFCAs and PFASs; in general PFSAs and PFCAs accounted for over 75% of the total PFASs (Figure 18). PFOS accounted for over 97% of the total PFSAs, while the long-chain PFCAs (PFOA, PFNA, PFDA, PFUnDA, PFDoDA, PFTrDA, and PFTeDA) accounted for over 99% of the total PFCAs. Precursors of PFCAs showed detectable levels up to 1.8% of the total PFASs, with the exception of one trout sample from Stóra-Fossvatn in Iceland which had an overall low total PFAS (0.3 ng/g) but had detectable levels of 6:2 diPAPs, 8:2 diPAPs and 6:2/8:2 diPAPs (total 0.15 ng/g). One novel PFAS was detected, PFECHS (0.44 ng/g), in one sample from Finland (Helsinki) constituting 0.6% of the total PFAS concentration in that specific sample.

Figure 18: Relative composition of different PFAS classes in fish samples grouped by locations (prefix C. indicate a coastal area, L. for lake and R. for river) and country



Three marine and seven freshwater fish samples showed measurable extractable organofluorine (EOF), which ranged <108–488 ng F/g for all samples. The highest concentrations of EOF was found in freshwater perch samples from Finland (278–488 ng F/g), followed by the marine herring from Sweden (208 ng F/g for males and 355 ng F/g for females), freshwater perch from Norway (213 ng F/g), freshwater perch from Sweden (<108–184 ng F/g), marine pollock from Norway (134 ng F/g) and freshwater trout from Iceland (88–121 ng F/g). Levels and composition of quantifiable PFASs and unidentified EOF are shown in Figure 19. The unidentified organofluorine varied between the samples, between only 8% UOF in one herring sample from Sweden (pooled from all male individuals), to 96% UOF in brown trout from Iceland. Notable is that the second herring sample from Sweden, consisting of all female individuals, resulted in a UOF of 86%. The difference between total PFAS for the two herring samples was not as large as the observed difference between UOF and the reason remains unknown.

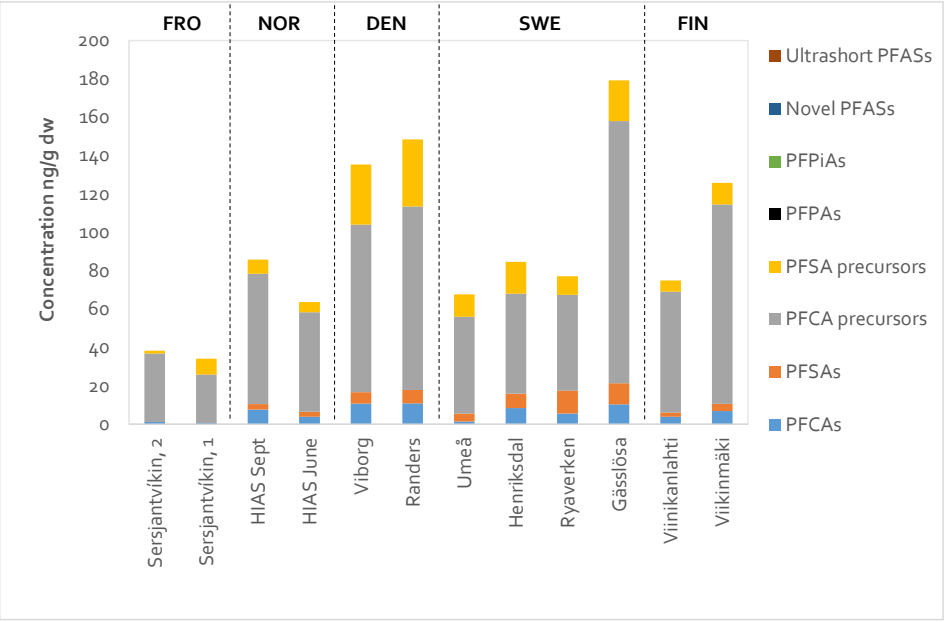
Figure 19: a) Total concentration of EOF (ng F/g) in fish divided into sum of targeted PFASs and unidentified organofluorine (UOF). b) composition of sum targeted PFASs and unidentified EOF in percentage of total EOF. (*) denotes marine fish. Marine fish samples from Greenland and Denmark were not reported due to high blank contamination. Empty column indicates sample concentration below the batchwise limits of detection (between <40 to <140 ng F/g



5.1.2 *WWTP sludge*

A total of 12 sludge samples from Faroe Islands (*n*=2), Norway (*n*=2), Denmark (*n*=2), Sweden (*n*=4) and Finland (*n*=2) were analyzed for EOF and PFASs. Concentrations of individual compounds in the sample are provided in Appendix 5. The sludge samples were freeze-dried before analysis (moisture content shown in Appendix 7), all results are therefore reported on dry weight (d.w.) basis.

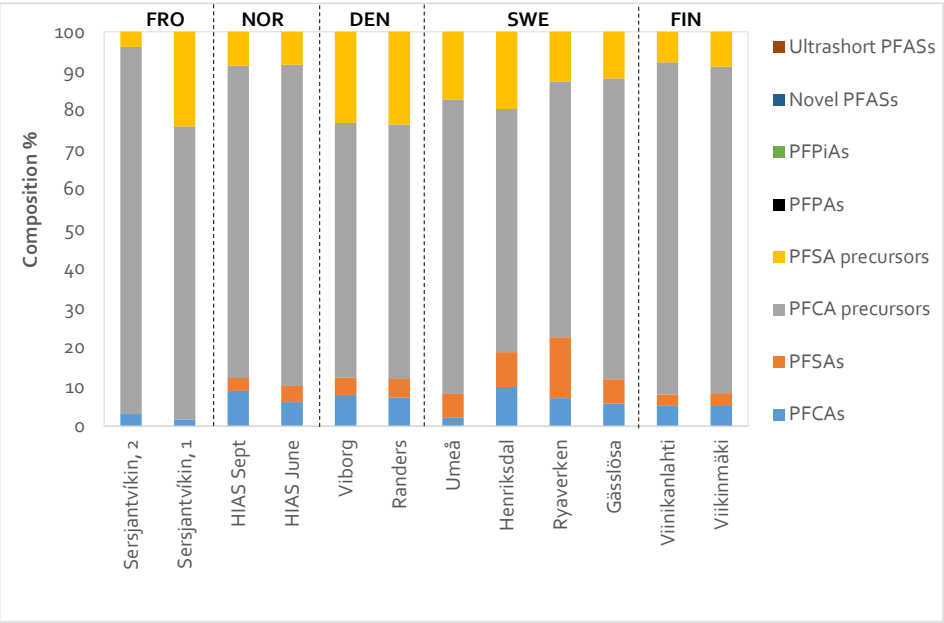
Figure 20: Concentration (ng/g dw) of different PFAS classes in sludge samples



The total PFAS concentrations in the sludge samples, in descending order, were 141.9 (135.3–148.4) ng/g for Denmark, 102.2 (67.7–179.2) ng/g for Sweden, 100.3 (74.9–125.8) ng/g for Finland, 74.7 (63.7–85.8) ng/g for Norway and 36.2 (34.1–38.3) ng/g for Faroe Islands (Figure 20). PFCAs, PFSAs, PFCA precursors and PFSA precursors were found in the sludge samples. PFCAs, PFCA precursors and PFSA precursors were found in all samples and made up between 84.5% and 100% of all identified PFASs. Faroe Islands samples differed from others as they did not show detectable levels of PFSAs, as for the other samples were PFSAs ranged from 2.2 ng/g in Finland to 11.9 ng/g in Sweden.

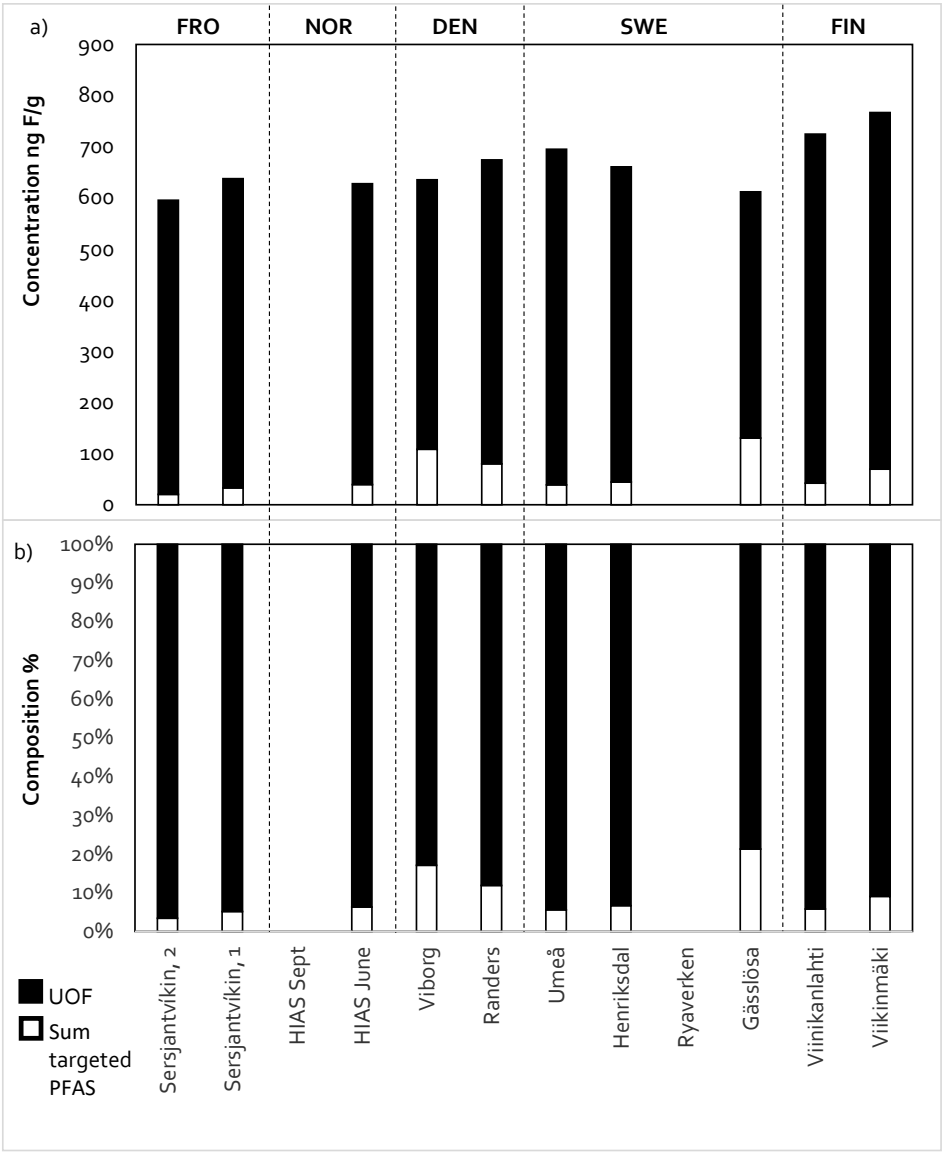
The homologue profiles of the sludge samples were dominated by PFCA precursors, on average accounting for 75.0% of all identified PFASs (Figure 21). This was mainly driven by 6:2 diPAP, 8:2 diPAP, 6:2/8:2 diPAP, 6:2/10:2 diPAP and 6:2/12:2 diPAP which were present in all samples. The second largest contributors were PFSA precursors with 14.0% of all identified PFASs. MeFOSAA and EtFOSAA accounted for about 90.0% of all PFSA precursors. PFCAs and PFSAs showed a smaller contribution to the total PFASs, 5.9% and 4.9% respectively. Although long-chain PFCAs dominated the PFCA class in most sludge samples, the Faroe Islands and Finland samples also had a significant contribution of short-chain PFCAs, 68% and 38% respectively.

Figure 21: Relative composition of different PFAS classes in sludge sampels



Ten out of twelve sludge samples showed measurable extractable organofluorine (EOF), which ranged <556–767 ng F/g for all samples. In general, sludge samples from Finland (724–767 ng F/g) showed relatively higher EOF levels than those from Sweden (<556–695 ng F/g), Denmark (636–674 ng F/g), Faroe Islands (575–638 ng F/g) and Norway (<556–628 ng F/g). Levels and composition of quantifiable PFASs and unidentified EOF are shown in Figure 22. The unidentified organofluorine part of EOF accounted for 79–97%, with the lowest UOF found in the sample from Sweden (Gässlösa) and the highest in Faroe Islands.

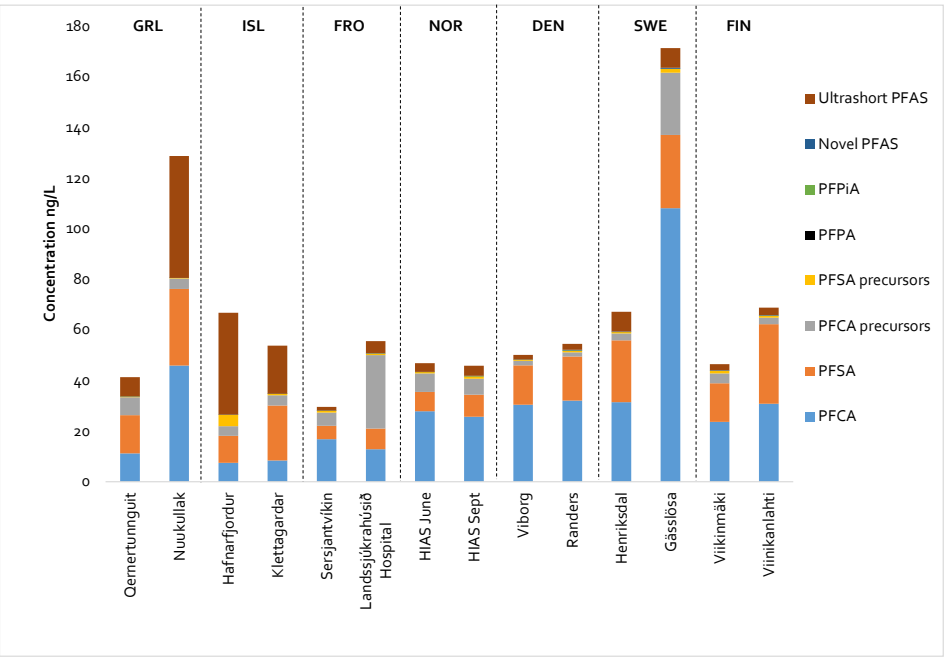
Figure 22: a) Total concentration of EOF (ng F/g) in sludge divided into sum of targeted PFASs and unidentified organofluorine (UOF). b) composition of sum targeted PFASs and unidentified EOF in percentage of total EOF. Empty column indicates sample concentration below the limits of detection (<556 ng F/g)



5.1.3 WWTP effluent

A total of 14 effluent samples from Greenland (n=2), Iceland (n=2), Faroe Islands (*n*=2), Norway (*n*=2), Denmark (*n*=2), Sweden (*n*=2) and Finland (*n*=2) were analyzed for EOF and PFASs. Samples were filtrated and the dissolved and particle phase were separately analyzed. The reported PFAS levels here (ng/L) were for sum of dissolved and particulate phase from each sample. Concentrations of individual compounds in the sample are provided in Appendix 5.

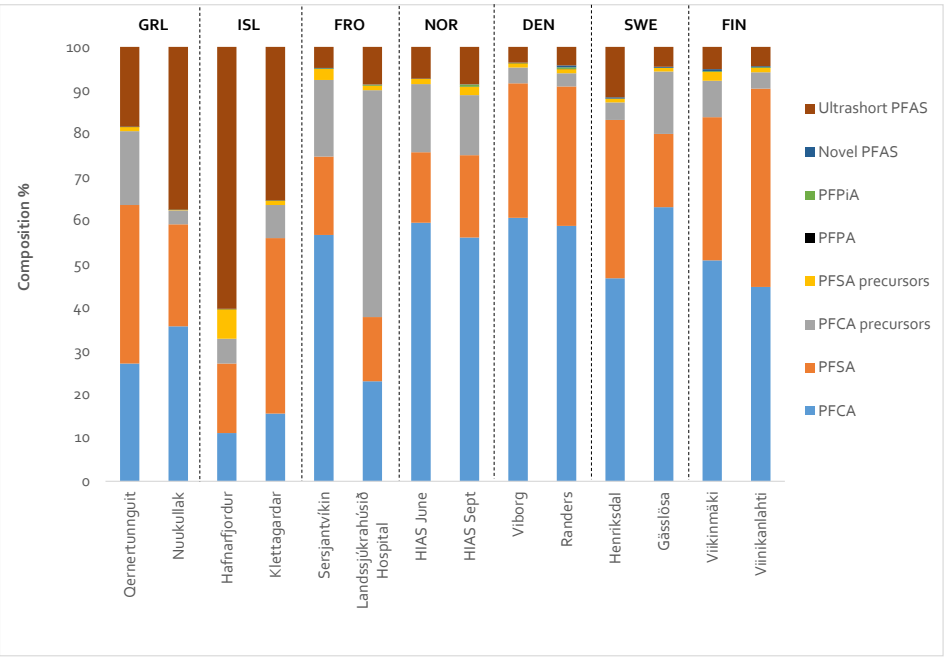
Figure 23: Concentration (ng/L) of different PFAS classes in effluent samples (dissolved + particle phase)



The average total PFAS concentrations in the effluent samples, in descending order, were 119 (67.1 and 171) ng/L for Sweden, 85.0 (41.3 and 129) ng/L for Greenland, 60.2 (53.7 and 66.7) ng/L for Iceland, 57.6 (46.4 and 68.8) ng/L for Finland, 52.3 (50.1 and 54.4) ng/L for Denmark, 46.3 (45.8 and 46.8) ng/L for Norway and 42.6 (29.6 and 55.6) ng/L for Faroe Islands (Figure 23). The total concentration were similar except for two samples with elevated concentrations, one sample from Sweden (Gässlösa) and one from Greenland (Nuukullak).

All samples showed detectable levels of PFCAs (C_4-C_{18}), PFSAs (C_4-C_{12}), PFCA precursors, PFSA precursors, novel PFASs and ultrashort PFASs (C_2-C_3). PFCAs were at the highest concentrations (average 29.4 ng/L, range 7.4–108) followed by PFSAs (average 17.2 ng/L, range 5.3–31.4), ultrashort PFASs (average 11.0 ng/L, range 1.4–48.2) and PFCA precursors (average 7.4 ng/L, range 1.7–29.0). Lower concentration was also detected for PFSA precursors (average 0.9 ng/L, range 0.2–4.5) and novel PFAS (PFECHS, average 0.10 ng/L, range 0.01–0.40).

Figure 24: Relative composition of different PFAS classes in effluent samples (dissolved + particle phase)



The homologue profiles of effluent samples from Finland, Sweden, Denmark and Norway were dominated by PFCAs, accounting for an average of 55% (range 45–63%) of total PFASs (Figure 24). The contribution from PFCAs was lower (average 28%, range 11–57%) in Faroe Islands, Iceland and Greenland. The breakdown of the PFCA group showed that in all samples the dominating compounds were short chain PFCAs with carbon chain length C_4–C_7, comprising on average 72% of all PFCAs. The most abundant short chain PFCAs were PFBA and PFHxA, accounting for 29% and 43% of short chain PFCAs, respectively.

PFSAs made up between 11% and 46% of total PFASs (27% on average). The predominant PFSA was PFBS, followed by L-PFOS and Br-PFOS. They were detected in all samples and had a percentage of the PFSA class on average 37%, 36% and 16%, respectively.

The ultrashort PFAS accounted for 6% of the total PFAS concentration in the samples from Finland, Sweden, Denmark, Norway and Faroe Islands. In the samples from Iceland and Greenland, the ultrashort PFASs were the most abundant class of PFASs, with a mean contribution of 39%. In all effluent samples the dominant ultrashort PFAS was PFPrA (C_3 PFCA), on average accounting for 90% of the ultrashort PFASs.

PFCA precursors accounted for 12% of total PFAS on average. The main PFCA precursors in effluent were 6:2 FTSA, 8:2 FTSA and 5:3 FTCA, together making up for 64% of all PFCA precursors.

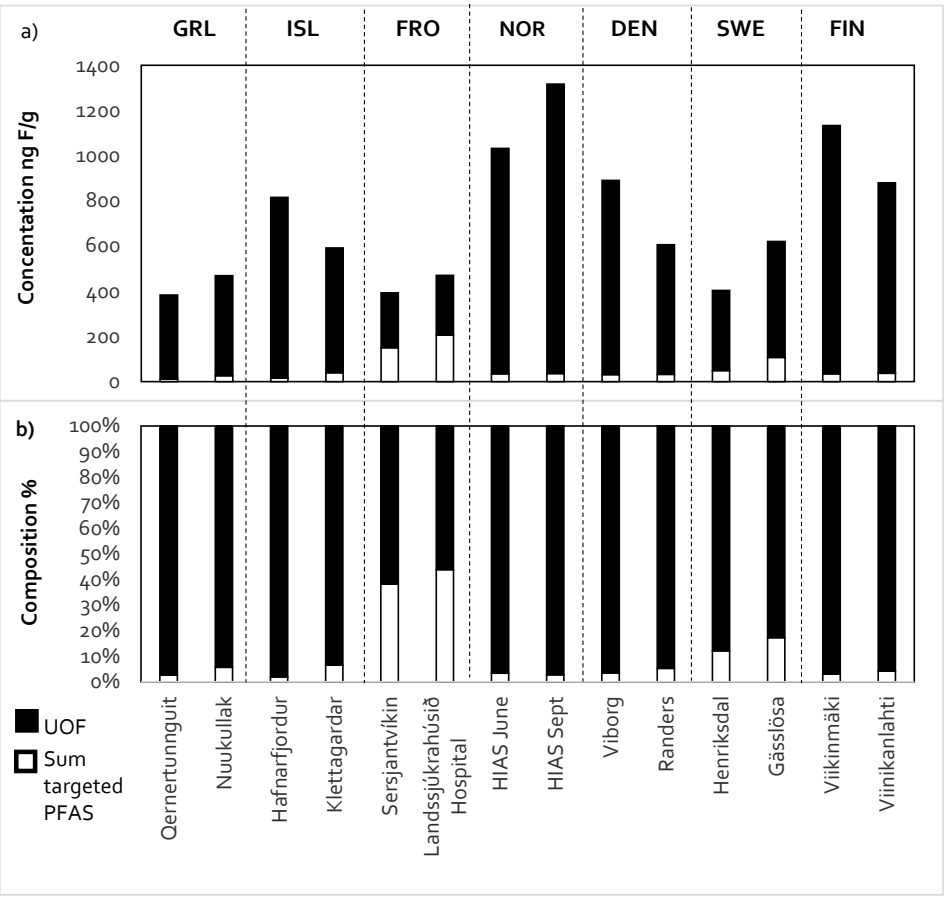
PFSA precursors had a smaller contributions towards the total PFAS, on average 2%. The only PFSA precursors detected were MeFOSAA and EtFOSAA, the latter was found in all samples.

Novel PFAS made up 0.1% of total PFAS on average,with the highest contribution in samples from Randers in Denmark (0.4% of total PFAS). From this class of PFAS only PFECHS was detected, in WWTP effluent from Denmark, Finland, and Sweden.

Only the dissolved phase was reported for EOF due to high blank contamination of the filter samples (for the particulate phase). Thirteen out of fourteen effluent samples showed measurable neutral extractable organofluorine (EOF) and all fourteen samples showed measurable anionic EOF. Neutral EOF (not displayed in the figure) ranged <123–898 ng F/L whereas anionic EOF ranged 383–1317 ng F/L. Relatively higher levels of neutral EOF were found in samples from Finland (636–893 ng F/L), followed by Denmark (541–734 ng F/L), Norway (331–527 ng F/L), Sweden (291–432 ng F/L), Faroe Islands (255–449 ng F/L), Greenland (<123–660 ng F/L) , and Iceland (170–215 ng F/L).

In contrast, Norway samples showed the highest anionic EOF (1032–1317 ng F/L), followed by Finland (880–1134 ng F/L), Denmark (606–890 ng F/L), Iceland (591–816 ng F/L), Sweden (404–620 ng F/g), Faroe Islands (392–471 ng F/L), and Greenland (383–470 ng F/L) (see Figure 25). No observable relationship between neutral and anionic EOF were found. In the current investigation, no target analytes were measured in the neutral faction, and the mass balance analysis was focused on the anionic fraction from these fourteen samples. Levels and composition of quantifiable PFAS and unidentified EOF are shown in Figure 25. The unidentified organofluorine accounted for 56–98% of EOF.

Figure 25: Total dissolved concentration of EOF (ng F/g) in effluent divided into sum of targeted PFAS and unidentified organofluorine (UOF). b) composition of sum targeted PFASs and unidentified EOF in percentage of total EOF

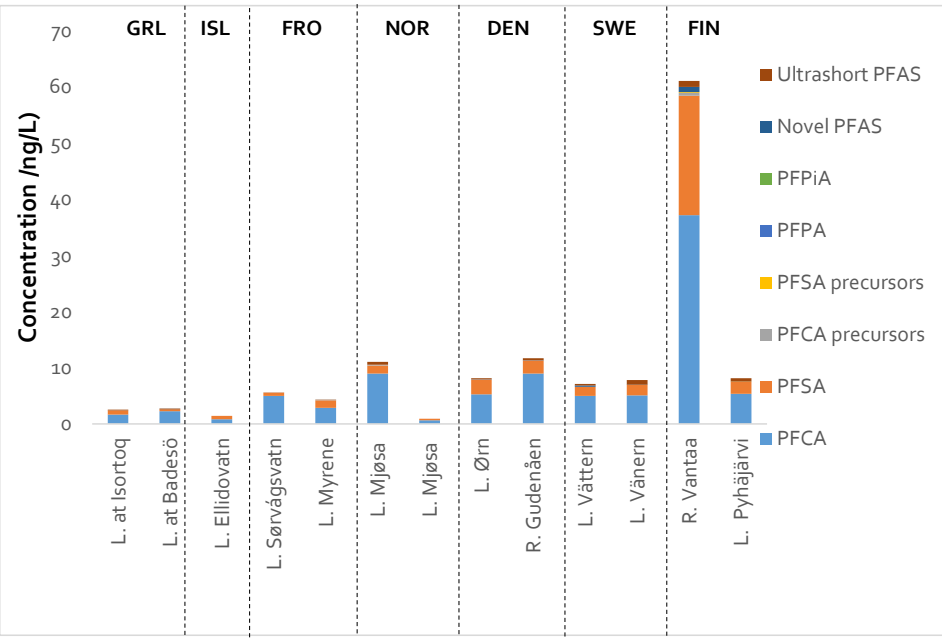


5.1.4 Surface water

A total of 12 effluent samples from Greenland (n=2), Iceland (n=1, one sample was lost during sample preparation), Faroe Islands (*n*=2), Norway (*n*=2), Denmark (*n*=2), Sweden (*n*=2) and Finland (*n*=2) were analyzed for EOF and PFAS. Samples were filtrated prior analysis and reported here is the dissolved PFAS levels. Concentrations of individual compounds in the sample are provided in Appendix 5.

The levels of total PFASs in surface water ranged between 0.93 ng/L and 61.1 ng/L, with a median of 11.0 ng/L. Lowest concentrations were found in samples from Norway, Iceland and Greenland (0.93–2.72 ng/L), and the highest concentration was found in one sample from Finland. The following PFAS classes were detected; PFCAs, PFSAs, FTSAs, FOSAAs and novel PFAS (PFCHSs) (Figure 26).

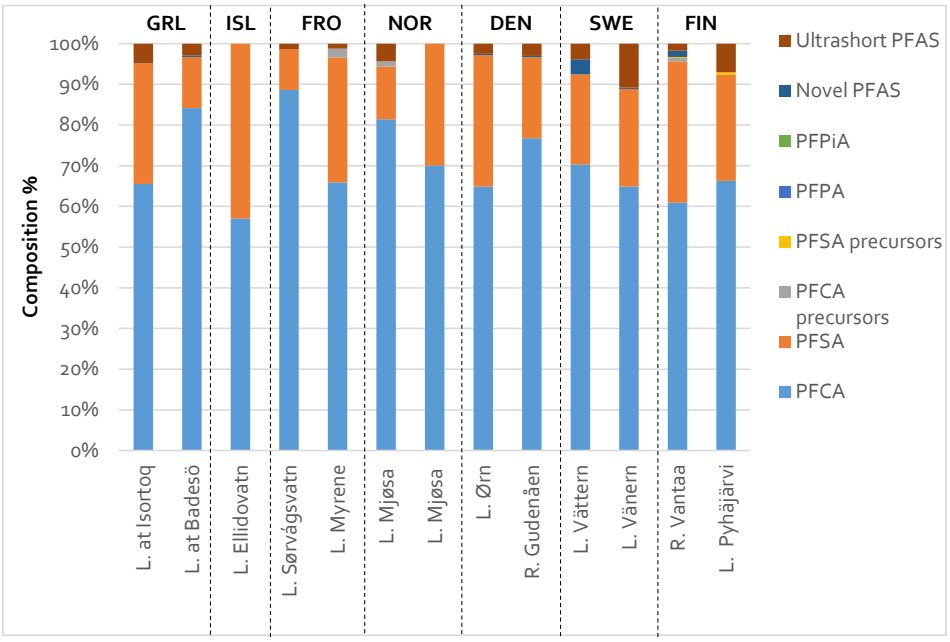
Figure 26: Concentration (ng/L) of different PFAS classes in surface water



In each sample, up to 20 individual PFAS homologues were detected, and in total 22 PFASs were detected in the surface water samples. The profiles were dominated by PFCAs (mean 71%) followed by PFSAs (mean 25%), and only minor contribution from other PFASs (Figure 27).

A majority (53–92%) of the PFCAs in the surface water samples could be attributed to short-chain PFCAs (C<8). The PFCAs in the samples were dominated by PFHxA, followed by PFBA, PFOA, PFHpA, PFNA, PFPeA, PFPrA, PFDA, and PFUnDA.

Figure 27: Relative composition of different PFAS classes in surface water samples



One sample from Finland had a different profile, and also about one order of magnitude higher levels compared to other samples. The highest concentration in this sample was PFNA (12.1 ng/L), followed by PFHxA (10.8 ng/L), PFPeA (5.92 ng/L), L-PFOA (4.07 ng/L), and PFHpA (3.16 ng/L).

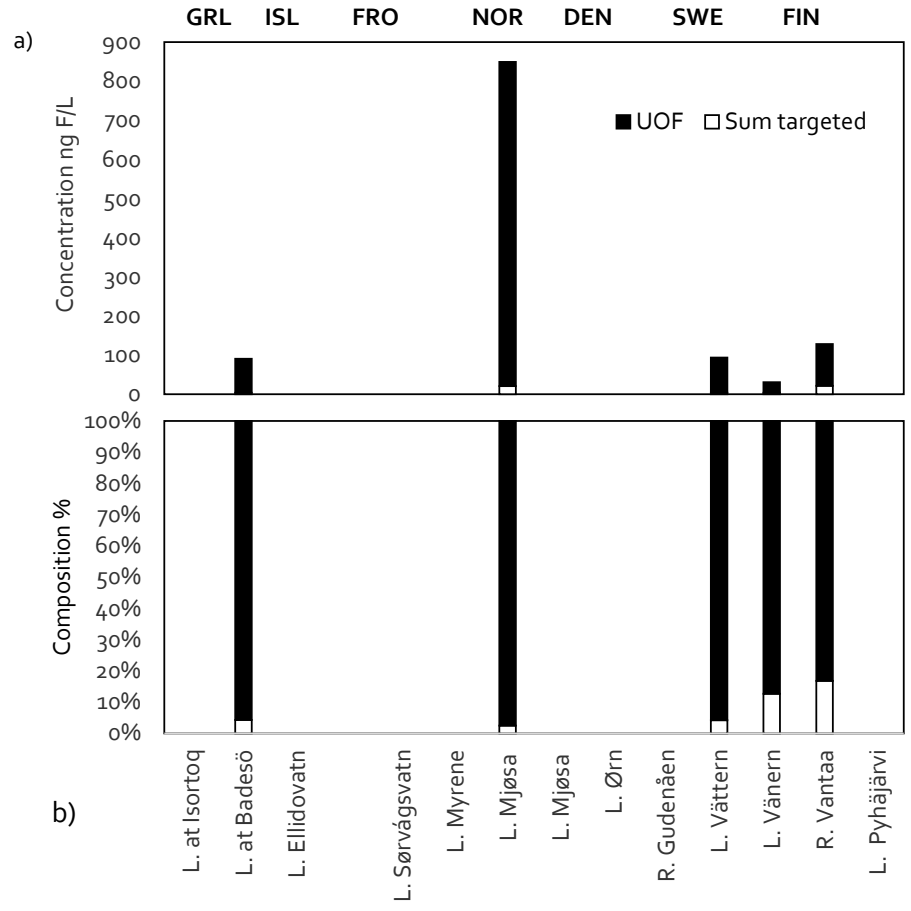
Branched isomers of PFOA were found above LOD in ten out of the 14 surface water samples,on average accounting for 17% of the sum of linear and branched PFOA. The presence of br-PFOA in the water samples indicates contribution from PFOA produced with the electrochemical fluorination (ECF) process. In ECF-produced PFOA, the proportion of br-PFOA is 22% (Reagen W *et al.*, 2007), which is higher than the samples in this study. This implicates that the main source of PFOA in the water samples stems from fluorotelomer-produced PFASs, which only generates the linear isomer. The composition of isomers is also influented by other factors such as different sorption behaviour, thus leading to enhancement of br-PFOA in water compared to technical products.

The PFSAs were mainly dominated by PFOS, followed by ultrashort chain PFEtS, and thereafter PFBS and PFHxS. The ultrashort chain PFPrS and PFPeS were also found in two and three samples, respectively. L-PFOS ranged from 0.27 ng/L to 10.4 ng/L. The proportion of br-PFOS ranged between 11.1% and 38.9%.

The PFOS precursor compound EtFOSAA was found in two samples, both from Finland, at concentrations of 0.05 ng/L and 0.16 ng/L. EtFOSAA is an oxidation product of EtFOSA, which has been used as a building block for diSAmPAP and applied in paper and packaging products (Olsen *et al.*, 2004). The observation is interesting since these compounds were expected to be phased out together with PFOS in 2001.
One of the novel PFASs, PFECHS, was observed in samples from Finland (0.94 ng/L) and Sweden (0.24 ng/L).

The concentrations and compositions of the EOF in the surface water samples are shown in Figure 28. The EOF content in the anionic fraction was above LOD in five of the water samples. Highest level was found in a sample from Norway (849 ng F/L), which was collected close to the effluent discharge point of the HIAS wastewater treatment plant. Lower levels of EOF were observed in Finland (<41–128 ng F/L), Sweden (31–94 ng F/L), and Greenland (<30–91 ng F/L). No EOF above LOD (30 ng F/L) could be determined in samples from Iceland, Denmark, Faroe Islands and the second sample from Norway (approximately 40 km downstream of the HIAS plant). The proportion of unidentified PFAS was similar in all samples and ranged between 83 and 98%.

Figure 28: a) Total concentration of EOF (ng F/g) in surface water divided into sum of targeted PFAS and unidentified organofluorine (UOF). b) composition of sum targeted PFASs and unidentified EOF in percentage of total EOF



5.1.5 Air

Conventional PFASs

In all samples, very low PFAS concentrations were found. The highest concentrations were found for PFOS and PFOA in Greenland samples (Table 6). Only Norway (No03) and Iceland (Ice01 & 02 only GFF) provided field blank samples for quality control purposes (Table A1-2). Therefore only for those samples potential contamination can be assessed. No conventional PFAS concentrations were confirmed for Icelandic atmospheric samples above LOD. Moderate field blank contamination was found for the Norwegian samples, therefore all PFOS and PFOA levels found in the Andøya sample set must be considered qualitative only. The GFF samples (Swe01, Swe02) from Råö in Sweden were found in the same order of magnitude as reported for the Norwegian air samples. The highest conventional PFAS concentrations were found in Greenland samples with maximum PFOS concentration of 15 pg/m^3 in the Gre03 sample (collected 26.06.–06.07.2017).

The concentration profile in this study corresponds to earlier reported literature data from similar locations in Northern Europe and the Arctic (Barber *et al.*, 2007, Jahnke *et al.*, 2007a, Shoeib *et al.*, 2004) Wong *et al.* 2018).

Table 6: Conventional PFAS levels in atmospheric samples form the recent Nordic screening (pg/m^3), <LOD = below Limit of detection. All values reported are above the method limit of quantification (LOQ), For details on the LC/MS method, see (Skaar *et al.*, 2018).

Tabel 6: Conventional PFAS levels in atmospheric samples from the recent Nordic screening (pg/m3), <LOD = below Limit of detection. All values reported are above the method limit of quantification (LOQ), For details on the LC/MS method, see (Skaar *et al.*, 2018)

Sample	Blank	Swe01	Swe02	No01	No01	No02	No02	No03	No03	Gre01	Gre01	Gre02	Gre02	Gre03	Gre03	Ice01	Ice02	Ice03	Ice04	Ice05	Ice06	Ice07	Ice08
Com-pount	PUF/ GFF	GFF	GFF	GFF	PUF	GFF	PUF	GFF	PUF	GFF	PUF	GFF	PUF	GFF	PUF	GFF	GFF	GFF	GFF	GFF	GFF	GFF	GFF
PFBS	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	3.39	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
PFHxA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
PFHpA	<LOD	<LOD	0.44	0.65	<LOD	<LOD	<LOD	<LOD	<LOD	0.21	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
PFHxS	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	1.74	<LOD	4.29	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
PFOA	<LOD	1.23	1.10	1.11	<LOD	0.68	<LOD	0.45	<LOD	0.56	<LOD	<LOD	3.24	<LOD	12.28	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
PFOS	<LOD	<LOD	1.20	<LOD	<LOD	<LOD	<LOD	3.34	<LOD	<LOD	<LOD	<LOD	5.14	<LOD	15.53	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Br-PFOS	<LOD	<LOD	0.99	0.00	<LOD	<LOD	<LOD	1.82	<LOD	<LOD	<LOD	<LOD	3.01	<LOD	10.83	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
PFNA	<LOD	0.66	0.60	0.68	<LOD	<LOD	<LOD	<LOD	<LOD	0.23	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
PFDA	<LOD	0.27	0.43	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
PFUdA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
PFDoDA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
FOSA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
PFTrDA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
PFTeDA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD

Sample	Blank	Swe01	Swe02	No01	No01	No02	No02	No03	No03	Gre01	Gre01	Gre02	Gre02	Gre03	Gre03	Ice01	Ice02	Ice03	Ice04	Ice05	Ice06	Ice07	Ice08
MeFOSA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
MeFOSE	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
EtFOSE	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
EtFOSA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Comments								Blank	Blank							Blank	Blank						

Gasesous phase samples

Novel emerging volatile PFAS (vPFASs) were analysed and quantified with a method that was developed and validated as described in the method section. The method was developed for both particulate phase (GFF) and gaseous phase (PUF/XAD-2/PUF). Specific requirements for sampling and sample handling was available for all participating institution in the comprehensive sampling manual. This included also a complete sample form and protocol for documenting the sampling, storage and analytical procedures for all individual samples.

Gas phase atmospheric samples (PUF/XAD-2/PUF) were only provided for Greenland (Aarhus University) and Andøya, Norway (NILU) and field blanks were only available for the Norwegian gaseous phase samples (Table 7).

Table 7: Concentrations of PFAS (pg/m³) in gaseous PUF/XAD-2/PUF samples (shortened as PUF) from Norway and Greenland. Field blanks were only provided for the Norwegian samples. CAS numbers and additional information can be found in the appendix Table A2-3

Sample name	*Norway*	NO01	NO02	NO03	*Greenland*	Gre01	Gre02	Gre03
Type	**Drechsel**	**PUF**	**PUF**	**PUF**	**Drechsel**	**PUF**	**PUF**	**PUF**
Recovery (%)	*0*	105	67	*45*	*0*	*35*	42	56
FTET	+	<LOD	63.1	*<LOD*	-	6.0	<LOD	<LOD
BPFB	-	2.3	3.2	*0.0*	-	<LOD	1.6	1.5
BTFBB	+	3.8	458.4	*444.1*	+	0.3	122.7	166.3
FHET	-	5.4	0.6	*3.2*	-	0.8	0.5	2.2
FOET	+	9.0	19.3	*8.3*	+	1.3	2.0	0.2
EtfFOSA	+	1.4	2.1	*2.3*	+	0.3	1.3	2.4
TTFMCS	-	<LOD	<LOD	*<LOD*	+	1.4	2.7	<LOD
ETDHSA	+	3.3	2.5	*0.7*	+	0.3	<LOD	0.8
MeFBSA	-	n.d.	n.d.	*n.d.*	-	n.d.	n.d.	n.d.
TDFMSA	-	n.d.	n.d.	*n.d.*	-	n.d.	n.d.	n.d.
FOSA	-	n.d.	n.d.	*n.d.*	-	n.d.	n.d.	n.d.
EtFOSE	-	1.5	2.2	*1.3*	-	0.3	2.1	4.0
LPFBS	-	n.d.	n.d.	*n.d.*	-	n.d.	n.d.	n.d.
Comments				*Blank*		*Low recovery*		

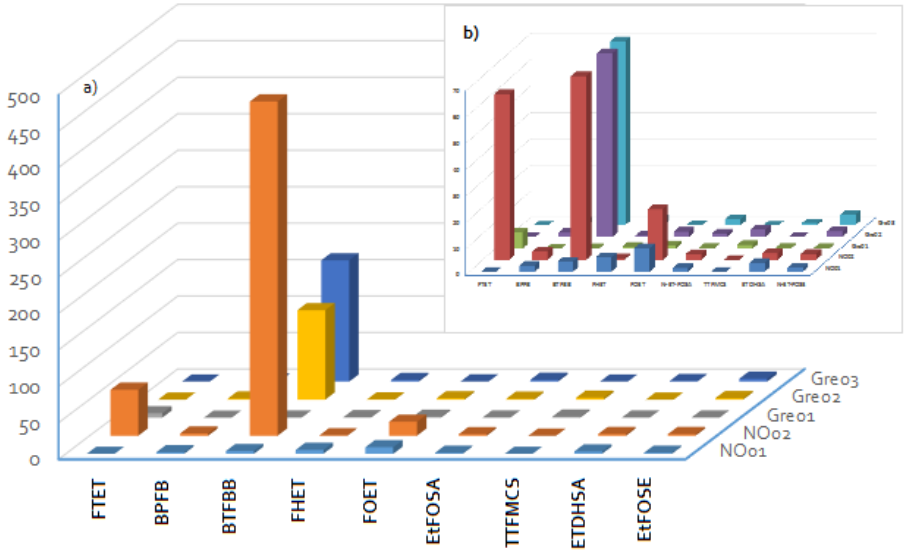
Note: "+": Detected in Drechsel gas washing flask (breakthrough assumed). "-": no breakthrough. <LOD: below limit of detection. All red marked numbers are below the LOQ from Norwegian samples which were calculated based on blank values (<LOQ = only qualitatively confirmed). n.d.: not detected.

Sample specific recovery rates between 35 and 105% were determined for all gaseous samples (Table A4-6). For FTET (4:2 FTOH, Norway only), BTFBB, FOET, EtFOSA, TTFMCS (Greenland only) and ETDHSA traces were confirmed in the Drechsel gas washing flask extract and, thus, potential breakthrough for these compounds was confirmed and quantitative results should be considered as semi-quantitative. MeFBSA, TDFMSA, FOSA and L-PFBS were not detected in all samples. For the

Norwegian field blank, considerable contamination with BTBB and minor contamination for FOET, FHET, EtFOSE and EtFOSA was confirmed. For all samples, except Gre01, BTFBB was found to be the predominant vPFAS substance. However, at least for the Norwegian samples, field blank contamination was confirmed and the concentrations determined should, thus, be considered as semi-quantitatively only.

In general, the Andøya gaseous samples showed higher vPFAS levels (2–8 fold) compared to the Greenland samples.

Figure 29: vPFAS levels in Norwegian and Greenland gaseous air samples (pg/m³). a) y-axis maximum = 500 pg/m³, b) y-axis maximum = 70 pg/m³



For both Norwegian and Greenlandic samples, BTFBB was the predominant vPFAS with more than 90% of the total vPFASs (Figure 29(a)). However, whereas FTET and FOET were found in low pg/m3 levels in Norwegian samples, only ultra-traces (<3 pg/m³) of all other vPFASs were found in Greenland samples (Figure 29(b)).

Particle phase samples

The particulate phase was collected on GFF according to well established methods at the respective national institutes. Samples from Greenland, Norway, Sweden and Iceland were received for quantitative analysis. Sampling procedures as well as quality control (QC) requirements are comprehensively described in the sampling manual which was provided to all participating institutions. Recovery rates between 45 and 102% were determined for all GFF particulate atmospheric samples. Similar as already reported for the gaseous samples, considerable BTFBB contamination was confirmed in the Norwegian field blank sample (900 pg/m³). Therefore, the here quantified BTFBB levels (at least for the Norwegian location) must be considered as semi-quantitative only. Also the laboratory blank was contaminated with BTFBB. Since the Icelandic field GFF blanks (Ice01 &

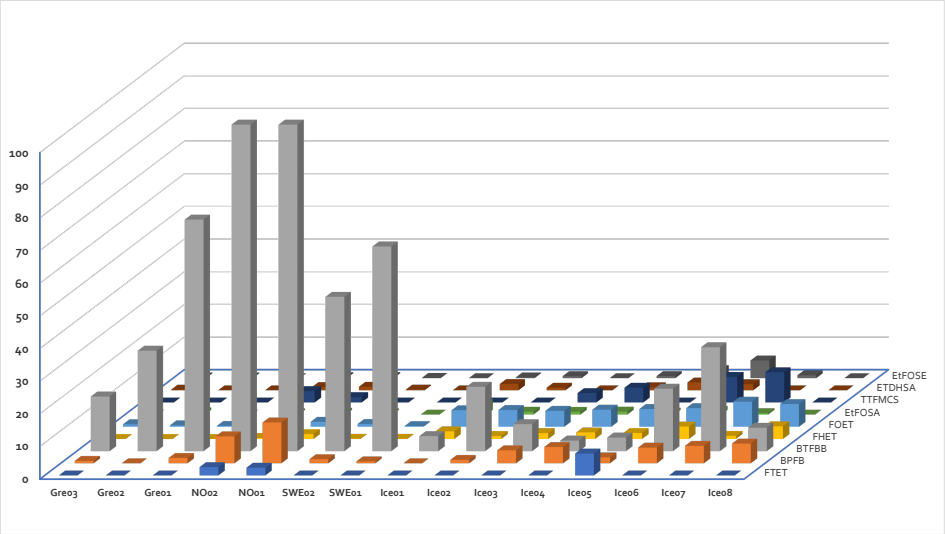
Ice02) showed only minor (but quantifiable) BTFBB contamination (Table 8), it was assumed that a combination of laboratory and field contamination might have led to the elevated levels found in the Norwegian (and partially in Greenlandic) samples.

Table 8: Concentrations of volatile PFASs (pg/m³) in particulate atmospheric samples (GFF) from Sweden, Iceland, Norway and Greenland. Field blanks were only provided for the Norwegian and Icelandic samples. <LOD: below limit of detection. All red marked numbers are below the LOQ from Norwegian samples which were calculated based on blank values (<LOQ = only qualitatively confirmed). n.d.: not detected

	Gre03	Gre02	Gre01	NO02	NO01	SWE02	SWE01	Ice01	Ice02	Ice03	Ice04	Ice05	Ice06	Ice07	Ice08
FTET	0.0	0.0	0.0	2.6	2.4	0.0	0.0	0.0	0.0	0.0	0.0	6.7	0.0	0.0	0.0
BPFB	0.7	0.0	1.6	8.3	12.5	1.3	0.6	0.0	1.0	4.0	5.0	1.8	4.8	5.4	6.0
BTFBB	16.7	30.8	70.9	828.6	319.2	47.3	62.7	4.6	19.7	8.3	3.2	4.2	19.1	31.8	7.2
FHET	0.0	0.0	0.0	0.3	1.5	0.0	0.0	2.3	0.9	1.8	2.0	1.8	3.8	0.9	3.9
FOET	0.8	0.4	0.3	0.2	1.5	0.9	0.2	5.1	5.2	4.9	5.2	5.4	5.7	7.7	7.0
EtFOSA	0.0	0.7	0.0	0.4	0.6	0.4	0.0	3.2	0.9	0.9	0.9	0.6	1.2	0.4	0.0
TTFMCS	0.0	0.0	0.0	3.5	1.7	0.0	0.0	0.0	0.0	2.9	4.5	0.0	7.8	9.3	0.0
ETDHSA	0.2	0.0	0.0	1.0	1.1	0.2	0.0	1.9	0.8	0.0	0.9	2.4	1.9	<LOD	0.0
EtFOSE	0.2	0.2	0.0	0.4	0.4	0.1	0.0	0.2	0.6	0.0	0.6	2.5	5.4	0.9	0.0

Further efforts need to be invested in the proper identification of the BTFBB contamination source(s). Only low but dominating BTFBB levels were found in Icelandic GFF samples (max. 32 pg/m3) indicating minor contamination issues (Figure 30).

Figure 30: vPFAS levels in particulate atmospheric samples (GFF) from four Nordic countries (pg/m³). No02 and No01: BTFBB values > 100 pg/m³ (possible contamination)



BTFBB was dominating all GFF samples (60–90% of total vPFASs). Whereas only few other compounds like BPFB and TTFMCS were found in Greenlandic, Norwegian and Swedish GFF samples. On the other hand a higher abundance of vPFAS was identified in Icelandic samples. This indicates different source distribution profiles for Iceland compared to the other more Northern locations (Greenland, Norway, Sweden).

1,3-Bis(trifluoromethyl)-5-bromo-benzene (BTFBB) is used as reactant in various chemical process and thus must be considered as potential industrial pollutant. BTFBB may be present as impurity in various chemical fluoro-containing products. However the potential contamination profile is not yet sufficiently explored.

6. Discussion and recommendations

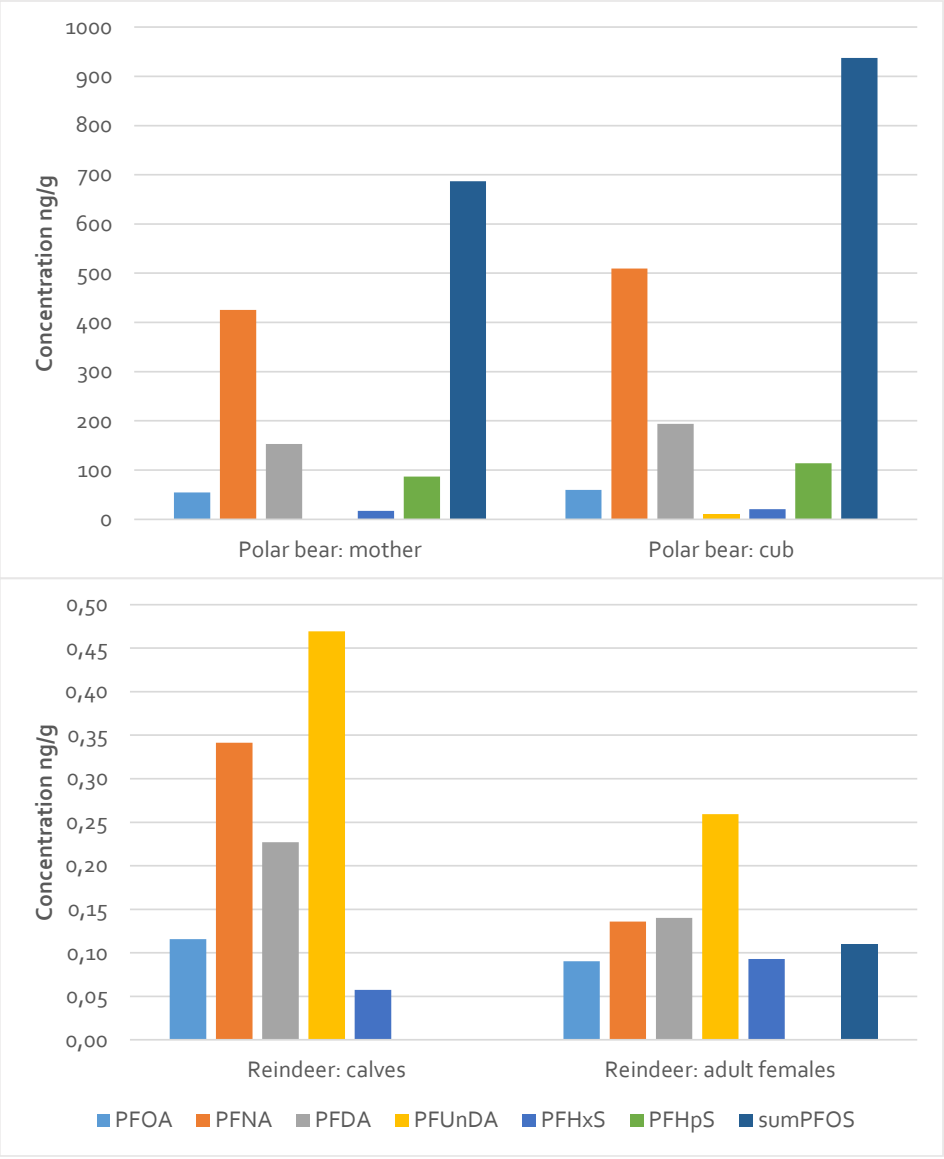
6.1 Conventional PFAS

The historical use and release of PFASs, resulting in environmental contamination of persistent PFCAs and PFSAs, is still dominating the PFAS class distribution and homologue pattern in this study even though decreasing environmental trends have been reported in recent years (Riget *et al.*, 2013). The PFAS profiles in the biota samples from fish, marine- and terrestrial mammals were dominated by PFCAs and PFSAs. There was a difference between the marine and terrestial environment which has been reported previously (Eriksson *et al.*, 2016, Letcher *et al.*, 2015). The contamination profile for marine fish, bird eggs and mammals was dominated by PFOS but longer chain PFCAs were also present in notable concentrations. In the terrestrial biota, long chain PFCAs can even be observed in higher concentrations compared to PFOS. Higher ratios of odd versus the next shortest even-carbon PFCA homolog could be indicative of atmospheric degradation of precursor compounds and is thus indicative of the importance of long-range transport as source (Armitage *et al.*, 2009).

Differences in concentrations and patterns between the Nordic countries included in this study were observed but can be attributed to differences in the selection of study location, closeness to point sources, and different collected species. It can be noted however that the egg samples from the Baltic Sea (Sweden) showed much higher contamination compared to other countries, and some fish samples and surface water from Finland were also elevated compared to the other countries.

The two polar bear samples from Greenland were taken from a mother and cub, and reindeer samples from Finland were divided into adults and calves. Figure 31 demonstrates the concentrations and homologue pattern of the PFASs present at highest concentrations. Even though this only represents a few samples, the difference between marine and terrestrial environment can be visualized. The polar bear samples show PFOS and PFNA with the highest concentrations, with decreasing concentrations with higher and lower chain lenghts. The reindeer samples show an odd-even pattern for the PFCAs indicating that atmospheric exposure might be of importance. Polar bear cub and reindeer calves showed higher concentrations of PFASs compared to polar bear mother and adult female reindeers, which could indicate maternal transfer and/or influence of body weight on the PFAS concentrations.

Figure 31: Profile of the highest detected PFAS levels in polar bears from Greenland (n=2) and reindeers (n=2 pools) from Finland. The sumPFOS refers to total concentration of linear and branched PFOS



6.2 Novel PFAS

The novel PFASs included in this present study are known to have been used in industrial and technical applications, but environmental levels are suspected to be low in the remote areas. Included in this study were a few samples from top predators that potentially could have been exposed to and accumulated detectable levels of biomagnifying novel PFASs. Novel PFASs were detected in marine mammals, fish, surface water, and effluent water. The brown bear and reindeer samples included in the study did not show any detectable levels of the novel PFASs.

PFECHS was identified in the surface water, WWTP effluent, fish and marine mammals (Appendix 5). PFECHS has previosuly been reported in the Great Lakes as a possible consequence after usage as an anticorrosive additive in aircraft hydraulic fluids (De Silva *et al.*, 2011). Other information indicates that it could also be a raw product for cosmetics (as adsorbent, anticaking, skin conditioning, binding, emulsion stabilising), and as semiconductors and actives (Fischer, March 2018). The relatively high concentration of PFECHS (0.94 ng/L) in surface water in Vantaanjoki of Finland in comparison to the other sites could therefore likely be due to the close vicinity to Helsinki Vantaa International Airport. PFECHS was also detected in Lake Vättern (0.24 ng/L), Sweden which also can be affected by civil and military airport activities. Concentrations of PFECHS in surface water (<MDL–0.94 ng/L), WWTP effluents (0.01–0.35 ng/L), fish (<MDL–0.44 ng/g) and marine mammals (<MDL–0.87 ng/g) from the present study from Nordic countries were consistent with those previously reported levels (Table 9). For example, De Silva *et al.* has reported the concentration of PFECHS in surface water (0.16–5.65 ng/L) and top predator fish (<MDL–3.7 ng/g ww in whole body homogenate) from the Great Lakes in Canada (De Silva *et al.*, 2011). Houde *et al.* measured PFECHS in the surface water (1.04–1.38 ng/L) and fish (liver, 0.54±0.25 ng/g ww and plasma, 5.07±4.72 ng/g downstream the WWTP in the St. Lawrence river in Canada (Houde *et al.*, 2013, Houde *et al.*, 2016). The median surface water (0.13 ng/L) and fish liver (69.6 ng/g ww) concentrations of PFECHS was also been reported at a pond downstream of the Beijing Capital International Airport in China (Wang *et al.*, 2016). The observation of PFECHS in WWTP effluents in Nordic countries indicates potential sources from consumer products other than aircraft hydraulic fluids. Moreover, PFECHS was detected in herring gull eggs collected in the Great Lakes in Canada with a concentration range of 0.09–1.56 ng/g ww (Letcher *et al.*, 2015), while no PFECHS was detected in the bird eggs in this study. A recent Norwegian screening study found PFECHs in small amounts in sparrowhawk eggs, fox liver and badger liver, with the highest level in one fox liver sample at 5 ng/g (Heimstad *et al.*, 2018). PFECHS has also been detected in the liver of Canadian Arctic polar bears with the concentration range of 0.09–1.45 ng/g ww (Letcher *et al.*, 2018). The polar bear cub liver in our study showed higher PFECH levels (0.22 ng/g) than the polar bear mother (0.11 ng/g).

Table 9: PFECHS concentrations reported from different studies

Location	Matrix	PFECHS	Reference
Great Lakes in Canada	Surface water	0.16–5.65 ng/L	(De Silva *et al.* 2011)
	Top predator fish	(<MDL–3.7 ng/g ww	
Downstream the WWTP in the St. Lawrence river in Canada	Surface water	1.04–1.38 ng/L	(Houde *et al.* 2013, Houde *et al.* 2016)
	Fish liver	0.54±0.25 ng/g ww	
	Fish plasma	5.07±4.72 ng/g	
Downstream of the Beijing Capital International Airport	Surface water	0.13 ng/L	(Wang *et al.* 2016)
	Fish liver	69.59 ng/g ww	
Canadian Arctic	Polar bear	0.09–1.45 ng/g ww	(Letcher *et al.* 2018)
Nordic screening	Surface water	<MDL–0.94 ng/L	(This study)
	WWTP effluent	0.01–0.35 ng/L	
	Fish liver	<MDL–0.44 ng/g ww	
	Marine mammals	<MDL–0.87 ng/g ww	

HFPO-DA, with the commercial name GenX, as well as ADONA were not detected in any of the samples from the Nordic countries (Appendix 5). Gebbink *et al.* detected HFPO-DA in river water one km downstream of a fluorochemical production facility in Netherland with the concentration range of 1.7–812 ng/L (Gebbink *et al.*, 2017). Moreover, Pan *et al.* measured HFPO-DA in surface water collected around the world (Pan *et al.*, 2018), and reported a median concentration of 0.95 ng/L in 160 samples from China, Korea, Sweden, US and UK, which demonstrates that HFPO-DA distribution is ubiquitous. However important information regarding its annual production volume, emission sources and toxicity remains unclear. More studies regarding its occurrence and distribution in biota, its toxicity and its bioaccumulation potential are warranted.

6.3 Volatile PFAS

The air sampling of volatile PFAS using active sampling gives a snapshot picture of the current profile in air. However it must be taken into consideration which PFASs sorb to particles and which ones are in the gaseous phase. In general, volatile PFASs are usually collected on sandwich samplers containg PUF/XAD-2/PUF filter collectors. Consequently, most of the here quantified vPFAS compounds are predominately found on PUF filters (Table 10). However, variable distribution profiles as indicated here for FTET, TTFMCS and FOET show that the adsorption properties of the particulate phase may contribution to the distribution profile (Table 10).

Table 10: Relative distribution of vPFASs (%) between GFF and PUF/XAD-2/PUF filters in Norwegian and Greenlandic samples

	FTET	BPFB	BTFBB	FHET	FOET	EtFOSA	TTFMCS	ETDHSA	EtFOSE
NO01 PUF	0	15	1	78	85	70	0	75	80
NO01 GFF	100	85	99	22	15	30	100	25	20
NO02 PUF	96	28	36	68	99	84	0	71	86
NO02 GFF	100	0	4	12	21	5	24	5	5
Gre01 PUF	100	0	0	100	82	100	100	100	100
Gre01 GFF	0	100	100	0	18	0	0	0	0
Gre02 PUF	0	100	80	100	82	64	100	0	90
Gre02 GFF	0	0	20	0	18	36	0	0	10
Gre03 PUF	0	67	91	100	13	100	0	80	95
Gre03 GFF	0	33	9	0	87	0	0	20	5

The here reported screening results demonstrates analysis of some novel vPFASs but must be considered as indicative due to the following reasons:

1. GFF based air samples only cannot be considered as representative for the screening of volatile gaseous compounds;
2. only for Norwegian samples, a complete documentation of sampling and storage documentation was available. Thus possible contamination issues cannot be sufficiently evaluated based on the available documents; and
3. the analytical methods need further optimization. Especially the MMI injection system on the GC/MS seems to be a potential error source for analysis of vPFASs. The relatively high injection temperatures (MMI, 250 °C) may cause thermal degradation and loss of sensitive vPFASs as demonstrated in the QC section.

6.4 EOF

Mass balance of fluorine between EOF and target PFAS allows better understanding on how much unidentified organofluorine that might be present in the sample. The measurements of OF using CIC are considered reproducible (RSD 14.4%, details please see QA/QC section). However, extraction blanks varied. For most of the samples (except for sludge samples), the detectable EOF levels were at least 2-fold higher that those of the extraction blanks. Relatively high extraction blank levels (475 ng/g) were found in the batch with sludge samples. However, several samples showed lower levels than those of the extraction blanks. The source(s) of contamination in these extraction blanks is currently not known, as no detectable PFASs were found in the extraction blank. We compared the detectable EOF levels of sludge samples from Sweden to those in our former report (Yeung *et al.*, 2017), and the levels of EOF and the percentage of identifial PFAS to EOF between studies were comparable. Therefore, we consider that the EOF results for sludge is reliable. However, special care should be given to the interpreation of the mass balance analysis because of the uncertainty.

In the current investigation, different amounts and proportion of unidentified extractable organofluorine (UEOF) were demonstrated in all studied matrices. In general, the measured levels of UEOF were at most within one order of magnitude difference within the matrices.

Marine mammals showed relative greater amounts of EOF (average: 707 ng F/g) than those of other biota samples (average: 221 ng F/g– bird eggs to 282 ng F/g marine fish). Measurable PFASs in bird egg samples accounted for the most EOF (average 68%) among biota samples, whereas PFASs in reindeers explained the least EOF (average: 18%) (Table 11). Although a larger number (n=78) of target analytes were included in the mass balance calculation, the percentage of unidentified EOF in marine mammals were similar to those of Indo-Pacific humpback dolphin (*Sousa chinensis*) and finless porpoise (*Neophocaena phocaenoides*) from South China (Yeung *et al.*, 2009b). In this study only long chain PFSAs and PFCAs were measured, leaving approximately 70% of the EOF unidentified.

WWTP sludge and effluent analysis showed that target PFAS could only explain a low percentage of the total EOF (Table 11). A relatively high background level of EOF for sludge was observed in the present study. The results of EOF corresponds well to a study of four WWTPs in Sweden from 2015 where the EOF was measured to between 606 and 2610 ng F/g, resulting in a mass balance of sludge between 5 and 11% (Yeung *et al.*, 2017). The previous study did not include ultra-short chain substances in the target analysis.

The ultra-short chain substances are generally not included in PFAS monitoring when looking at the scientific literature. This study initially included four ultra-short PFASs, however TFA could not be confirmed in any of the analysis due to relatively high background levels. Interestingly, the three remaining ultra-short PFAS does not seem to be major candidates for the unidentified portion of EOF as discussed in previous reports (Yeung *et al.*, 2009a, Loi *et al.*, 2011, Yeung *et al.*, 2009b). However, significant challenges remains in the analysis of ultrashort chain PFASs due to contamination from solvents, reagents and laboratory materials as well as quantification issues. Data from the present study should be considered as semi-quantitative, as corresponding mass-labelled standards were not available for quantification and surrogate mass-labelled standards using the PFAS with closest retention time were used.

Table 11: Extractable organic fluorine (EOF, ng F/g) detected in different matrices from the Nordic countries and the comparison between target PFAS and EOF, expressed as mass balance (%)

	Average F (ng/g) (range)	Average mass balance, target PFAS/EOF (range)
Marine mammals	707 (<40–2056)	37% (10–62%)
Reindeer	249 (<76–427)	18% (3–42%)
Brown bear	233	28%
Bird eggs	221 (<40–649)	68% (33–102%)
Marine fish	243 (<132–355)	42% (14–92%)
Fresh water fish	241 (<140–488)	26% (5–51%)
Sludge	663 (<556–767)	9% (3–21%)
Effluent	437 (<123–893)	11% (2–44%)
Surface water	239 (<30–849)	8% (2–17%)

The observed percentage of identified organofluorine is depending on the number of PFASs included in the mass balance, and will consequently be affected by not quantified values due to quality aspects such as ion suppression or recovery losses. The proportion of measurable PFAS in relation to EOF may therefore be related to the types of tissues analyzed. In current study, a relatively larger proportion of measurable PFAS in bird eggs could account for EOF; whereas the other biota samples were liver samples and showed relatively less proportion of measurable PFAS in relation to EOF. In addition to analytical difficulties, biological processess could be hypotized to play a role in the unidentified fraction. Although persistent PFCAs, PFSAs and PFPiAs would not undergo biotransformation in biological systems, some of the precursor PFSAs and PFCAs can as well as PFPiAs. Some conjugated products, such as FTOH-sulfate, FTOH-glucuronide and different FTUCA-glutathione (GSH) conjugates that have been observed in animal exposure of PFCA precursors (e.g., diPAP or FTOH) (Rand and Mabury, 2014), were not measured in current investigation. The detection of some intermediates such as 5:3 and 7:3 FTCAs in the samples suggested the biotransformation of FTOH in the biological system. Since liver is responsible for a number of enzyme for detoxification (Grant, 1991), other sample preparation methods using enzyme may be needed to have a better evaluation of the conjugated products.

The identy of the unidentified fraction could not be revelad in the present study. Further extraction of samples into different polarity and charge fractions prior to EOF may help in the identification of those unidentified PFAS. In contrast to biota samples, extraction of surface water and effluent samples used solid phase extraction with a weak ion exchange cartridge. Using this method, neutral and anionic PFAS were separated into two fractions. The neutral target compounds were not separately measured in the current study, and the proportion of measurable PFAS to EOF could therefore not be determine. Several shorter chain homologues of neutral sulfonamides (perfluorohexanesulfonamide and perfluorobutanesulfonamide including their respective methyl-substituted sulfonamides) were recently detected in the environment (Chu *et al.*, 2016, Kabore *et al.*, 2018), and these compounds should be measured in future studies. Relatively lower contribution (<10%) of measurable PFASs to EOF were observed in the anionic fraction of the water samples in the present study. Fluorinated pesticides, pharmaceuticals and other low-fluorinated substances could be responsible for the unidentified portion and should be included in future studies in order to reach a complete mass balance of EOF.

The identity of substances resulting in the measured EOF in environmental samples needs to be revealed to further assess environmental and human health risks. A large number of highly fluorinated substances (>4000) are present on the global market which puts a large demand on environmental monitoring studies (Swedish Chemicals Agency, 2015, OECD, 2018). One of the major sources of PFAS in the environment is related to the use of AFFFs; a number of studies demonstrated more than 100 fluorinated chemicals present in old (PFOS-based) and new (fluorotelomer-based) foams (D'Agostino and Mabury, 2014, Place and Field, 2012). These compounds can be included in a "suspect screening" list using high resolution mass spectrometry, or the total oxidizable precursor (TOP) assay. The latter method can be used to reveal any PFCA or PFSA precursors present in the sample (Houtz and Sedlak, 2012a). The TOP assay is

an oxidation process where the formation of hydroxyl radical oxidizes any precursors of PFSA or PFCA to measurable persistent PFCA or PFSA. This oxidation process might however be affected by the matrix of a sample. The combination of total fluorine analysis with oxidation product analysis, that is CIC-TOF and TOP, might help understand the contribution of unidentified PFCA/PFSA precursors in a sample that can further help explain the unidentified PFAS.

6.5 Sources and environmental implications

A large number of substances that are classified as PFASs are never monitored for in environmental studies. To the best of our knowledge, this is the first report of PFECHS occurence in marine mammals other than polar bear, in this study harbour porpoise and grey seal, and the first report on occurence in the Nordic countries. It has been discussed that sources of PFECHS are connected to aviator activities. The observation of PFECHS in WWTP effluents in Nordic countries indicates sources other than aircraft hydraulic fluids. However, more data are needed and PFECHS should be included in more studies on WWTPs before conclusions can be drawn regarding the sources and emission pathways. The concentration of PFECHS could also have been underestimated in the present study due to the many isomer forms that can exist for PFECHS. Even though environmental fate and toxicity is mostly lacking, there is a need to include highly fluorinated cycloalkanes in regulatory framworks. Results from this study highlight the importance of further investigation of PFECHS worldwide.

Precursor compounds contributed to the total PFASs in the present study and were frequently detected in many matrices. It is therefore important to not only include stable end-products in environmental monitoring, or regulatory discussions aiming at reducing PFAS exposure sources. The groups that were most frequently detected were FTCA/FTUCAs, FTSAs and diPAPs. As an example, FTCA/FTUCAs were detected in 54% of the marine mammals. Homologues detected was for example 7:3 FTCA (38%) which is a semi-stable intermediate product in the biodegradation of a wide range of PFASs that contain a part based on the 8:2 chemistry (8 perfluorinated carbons-2 carbons with hydrogens). 7:3 FTCA is a precursor and can be biologically degraded to PFOA and shorter PFCAs. Furthermore, diPAPs were also detected in biota. One fish from Helsinki achipelago (Finland) showed diPAPs constituting 11% of the total PFAS concentration. They are also potential precursors to persistent PFCAs and known sources are consumer products such as fodd packaging, cosmetics, floor finishing and paints (Klepeis *et al.*, 2001).

The PFOS precursor compound EtFOSAA was found in two surface water samples, both from Finland, at concentrations of 0.05 ng/L and 0.16 ng/L. EtFOSAA is an oxidation product of EtFOSA, which has been used as a building block for diSAmPAP and applied in paper and packaging products (Olsen *et al.*, 2004). The observation is interesting since these compounds were expected to be phased out together with PFOS in 2001.

Wastewater treatment plants have been identified as sources for environmental contamination of PFASs. This study show that PFCA precursors have a significant part

of the total PFAS in sludge and partly also in effluent. One PFAS class that were of significance in WWTP effluents are the ultrashort PFASs. While accounting for on average 7% of the total PFAS in effluents from Greenland, Faroe Islands, Norway and Denmark, the average contribution was 42% in effluents from Iceland.

The consequences of emission of highly fluorinated substances to the environment is not fully understood. While shorter chain PFASs, and especially ultrashort PFASs, are poor bioaccumulators, they are highly mobile which facilitates long range transport in the environment. As a consequence of the low molecular weight of ultrashort chain PFASs, the molar concentration is lower relative an equal weight concentration of, for example, a C8 PFAS resulting in lower toxicological relevant concentration. Nevertheless, the persistence of short chain PFASs should be equal to those long chain homologues and the the continuing emissions of all PFASs could therefore pose serious environmental problems.

7. Conclusions

This screening study demonstrated the need to include more PFAS classes in environmental assessments. Shorter chain PFASs with carbon chain lengths of 2–4 were frequently detected in surface water and WWTP effluent. Although poor bioaccumulators, their high persistency might lead to unknown future effects. Precursor compounds contributed to the total PFASs in the present study and were frequently detected in many matrices. It is therefore important to not only include stable end-products in environmental monitoring aiming at identifying sources. Several novel PFASs were detected in biota, water and air in the present study. Considering the large number of PFASs on the global market it can be expected that more PFASs are yet to be discovered in environmental samples. Extractable organic fluorine analysis showed that there is a large proportion of unknown extractable organofluorine in the Nordic environment. The identity of the additional organofluorine substances contributing to the measured extractable fluorine in environmental samples needs to be elucidated to further assess future risks.

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Svensk sammanfattning

I rapporten presenteras en undersökning av både konventionella och nya per- och polyfluoralkyl substanser (PFAS) i den nordiska miljön. PFAS är en omfattande klass av ämnen som har blivit ett miljöproblem på grund av deras extrema persistens och potentiella toxiska effekter hos biota och människor. Mer än 4 000 PFAS uppskattas finnas på den globala marknaden men det är inte klarlagt hur de sprids i miljön. Denna screeningsstudie omfattar totalt nittionio (99) PFAS från olika undergrupper samt analys av extraherbart organiskt fluor (EOF). EOF visar på mängden organiskt fluor i proverna, som i sin tur kan användas för att beräkna en massbalans mellan kända och okända PFAS. Studien initierades av Nordic Screening Group och finansierades av Nordiska ministerrådet genom Chemicals Group samt nationella organ och institut som finns representerade i Nordic Screening Group.

Sammanlagt 102 prover analyserades i studien, inklusive havsfågelägg, fisk, marina däggdjur, terrestra däggdjur, ytvatten, avloppsvatten och slam, vatten och luft. Prover samlades in av olika institut från de deltagande länderna och självstyrande områdena; Danmark, Färöarna, Finland, Grönland, Island, Norge och Sverige. Majoriteten av proverna samlades in 2017. PFAS analyserades genom vätske-, superkritisk vätske-, och gaskromatografi kopplad till masspektrometri. EOF analyserades genom förbränningsjonkromatografi.

PFAS-profilen hos havsfågelägg och marina däggdjur dominerades av perfluoralkylkarboxylsyror (PFCA) och perfluoralkylsulfonsyror (PFSA), främst perfluoroktansulfonsyra (PFOS) och långkedjiga PFCAs (> C8). Summan av de totala PFAS-halterna i ägg var 627 - 707 ng / g våtvikt (vv) för de svenska proverna, 44,9 - 99,9 ng / g vv för Island, och 56,9 - 81,4 ng / g vv för Färöarna. I isbjörnslever (Ursus maritimus) från Grönland uppmättes den högsta summan av PFAS (1426 - 1890 ng / g) samt även den högsta halten EOF (1782 - 2056 ng fluorid / g). Den totala PFAS-halten i övriga prover från marina däggdjur varierade mellan 35,1 ng / g i Gråsäl (Halichoerus grypus) från Danmark till 123 ng / g i Vikare (Phocoena phocoena), också från Danmark.

I leverprover från ren (Rangifer tarandus), abborre (Perca fluviatilis), öring (Salmo trutta) och röding (Salvelinus alpinus) dominerade PFCA och PFSA men även föregångarämnen till PFCA utgjorde en betydande del av summan PFAS. Summan PFAS i ren i fallande ordning var 5,4 ng / g för Grönland, 3,3 ng / g för Sverige, 1,4 ng / g för Finland och 1,1 ng / g för Island. Björn (Ursus arctos) från Finland hade en totalhalt PFAS av 18,9 ng / g. Leverprover från Pollock (Pollachius pollachius), Grönlandstorsk (Gadus ogac), Atlanttorsk (Gadus morhua), Skrubbskädda (Platichthys flesus) och sill (Clupea harengus) varierade från 10,6 ng / g till 18,2 ng / g. Medelhalten av summan PFAS (min-max) i sötvattenfisk var i fallande ordning 154 (74,7 - 302) ng / g för abborre (Perca fluviatilis) från Finland, 112 ng / g för abborre från Norge, 35,4 (34,7 - 36,2) ng / g för öring (Salmo trutta)och röding (Salvelinus alpinus) från Färöarna, 24,5 (19,8 - 29,1) ng / g för

abborre från Danmark, 5,9 (0,30 - 11,47) ng / g för öring från Island och 5,7 (5,2 - 6,2) ng / g för abborre från Sverige.
Slam från reningsverk dominerades av föregångarämnen till PFCA, som i genomsnitt stod för 75% av alla identifierade PFAS. Dessa utgjordes huvudsakligen av olika isomerer av polyfluoralkylfosfonsyra diestrar (diPAPs). Medelvärdet (min-max) av alla PFAS i slamproverna var i fallande ordning 142 (136 - 149) ng / g för Danmark, 103 (67,8 - 180) ng / g för Sverige, 100 (74,9 - 126) ng / g för Finland, 75,2 (64,1 - 86,2) ng / g för Norge och 36,8 (34,9 - 38,8) ng / g för Färöarna.

Utgående vatten från reningsverk innehöll en blandning av PFAS från olika klasser inklusive PFCAs, PFSAs, ultrakorta PFAS (huvudsakligen perfluorpropansyra, PFPrA) och föregångarämnen till PFCA. Den genomsnittliga totala PFAS-halten i proverna var 113 ng / L för Sverige, 75,4 ng / L för Grönland, 55,4 ng / L för Island, 49,7 ng / L för Finland, 48,2 ng / L för Danmark, 44,0 ng / L för Norge och 34,2 ng / L för Färöarna.
I sötvatten varierade den totala PFAS-halten mellan 1 och 10 ng / L, med ett undantag av 61 ng / L i Helsingfors vilket tyder på en stark påverkan från punktkällor. PFCAs dominerade totalhalten, där den högsta koncentrationen var för perfluorhexansyra (PFHxA) följt av perfluorbutansyra (PFBA).

Luft provtogs med glasfiberfilter (GFF) tillsammans med PUF / XAD-2 / PUF, och både konventionella samt nya PFAS undersöktes. De konventionella PFAS som detekterades i luftproverna inkluderade perfluoroktansyra (PFOA), perfluorbutansulfonsyra (PFBS), perfluorhexansulfonsyra (PFHxS) och PFOS. Nya PFAS, exemplevis 1,3-bis (trifluormetyl) -5-brom-bensen (BTFBB), detekterades också men halterna behöver bekräftas i ytterligare studier.

Ytterligare en av de nya PFAS som upptäcktes i denna studie var perfluoretylcyklohexansulfonsyra (PFECHS). PFECHS detekterades i lever från fisk och marina däggdjur, men även i ytvatten och utgående vatten från reningsverk.

Halten av de PFAS-ämnen som mättes kan förklara mellan 2% och 102% av den uppmätta EOF. Den genomsnittliga förklaringsgraden för proverna var 8% för ytvatten, 9% för reningsverksslam, 11% för utgående vatten, 18% för ren, 26% för sötvattenfisk, 28% för björn, 37% för marina däggdjur, 42 % för marina fiskar och 68% för fågelägg.

Studien visar på behovet av att inkludera fler PFAS-klasser i miljöbedömningar. PFAS med kolkedjelängder mellan 2-4 upptäcktes ofta i ytvatten och i ett urval av prover av utgående vatten från reningsverk. Även om de kortkedjiga PFAS har låg bioackumuleringspotential, är de sannolikt långlivade och deras långsiktiga effekter på miljön och människor är okända. Föregångarämnen bidrog också till den totala PFAS-halten i många provmatriser. Det är därför viktigt att inte bara inkludera de stabila slutprodukterna i miljöövervakning eller regleringar som syftar till att minska utsläppskällorna för PFAS. Den stora andelen okända fluorföreningar i de flesta miljöproverna i den nordiska miljön kräver också ytterligare studier. Vilka ämnen som ligger till grund för det uppmätta extraherbara fluoret i miljöproverna måste undersökas för att ytterligare kunna bedöma riskerna för miljön och människors hälsa.

Appendix 1: Sample characteristics as provided by the participating countries

Table A1-1: Sample information for water, sludge and biota

SAMPLE TYPE	LOCATION	SAMPLING DATE	COUNTRY
Bird eggs			
Black guillemot (Cepphus grylle)	Scoresbysund	2017-09-01	Greenland
Black guillemot (Cepphus grylle)	Koltur	2016-06	Faroe Islands
Northern fulmar (Fulmarus glacialis)	Skuvoy	2017-05	Faroe Islands
Northern fulmar (Fulmarus glacialis)	Skuvoy	2017-05	Faroe Islands
Northern fulmar (Fulmarus glacialis)	Skuvoy	2017-05	Faroe Islands
Northern fulmar (Fulmarus glacialis)	Skuvoy	2017-05	Faroe Islands
Northern fulmar (Fulmarus glacialis)	Skuvoy	2017-05	Faroe Islands
Common guillemot (Uria aalge)	Grimse		Iceland
Common guillemot (Uria aalge)	Bjarnarey		Iceland
Common guillemot (Uria aalge)	Stora Karlsö, Baltic Sea	2017-09-12	Sweden
Common guillemot (Uria aalge)	Stora Karlsö, Baltic Sea	2017-09-12	Sweden
Marine fish			
Atlantic cod (Gadus morhua)	Agersø Sund	2017-09-22	Denmark
European flounder (Platichthys flesus)	Agersø Sund	2017-09-15	Denmark
Greenland cod (Gadus ogac)	Kobbefjord, Nuuk	2017-09-15	Greenland
Atlantic pollock (Pollachius pollachius)	Oslofjord	2017-06-19	Norway
Atlantic herring (Clupea harengus)	Bothnian Sea	2016-09-24	Sweden
Atlantic herring (Clupea harengus)	Bothnian Sea	2016-09-24	Sweden
Fresh water fish			
European perch (Perca fluviatilis)	Lake Ørn	2017-08-29	Denmark
European perch (Perca fluviatilis)	Lake Silkeborg	2017-09-07	Denmark
Brown trout (Salmo trutta)	Leitisvatn		Faroe Islands
Arctic char (Salvelinus alpinus)	Myrarnar		Faroe Islands
European perch (Perca fluviatilis)	Pihlajasaari, Helsinki archipelago, Gulf of Finland	2017-09-08	Finland
European perch (Perca fluviatilis)	Lohjanjärvi, western Uusimaa	2017-09-29	Finland
European perch (Perca fluviatilis)	Pirkkalan Pyhäjärvi, downstream Tampere	2017-09-29	Finland
Arctic char (Salvelinus alpinus)	Isortoq	2017-09-07	Greenland
Brown trout (Salmo trutta)	Elliðavatn	2017-09-27	Iceland
Brown trout (Salmo trutta)	Stóra-Fossvatn	2017-08-01	Iceland
European perch (Perca fluviatilis)	Mjøsa	2017-06-01	Norway

SAMPLE TYPE	LOCATION	SAMPLING DATE	COUNTRY
Fresh water fish			
European perch (Perca fluviatilis)	Övre Skärsjön, Västmanland	2016-09-17	Sweden
European perch (Perca fluviatilis)	Övre Skärsjön, Västmanland	2016-09-17	Sweden
Marine mammals			
Harbour porpoise (Phocoena phocoena)	Flensbjorg Fjord	2015	Denmark
Grey seal (Halichoerus grypus)	Åbenrå fjord	2017	Denmark
Pilot whale (Globicephala melas)	Torshavn	2017-06-16	Faroe Islands
Pilot whale (Globicephala melas)	Torshavn	2017-06-16	Faroe Islands
Pilot whale (Globicephala melas)	Hvalvik	2017-06-26	Faroe Islands
Pilot whale (Globicephala melas)	Hvalvik	2017-06-26	Faroe Islands
Pilot whale (Globicephala melas)	Tjornuvik	2017-06-29	Faroe Islands
Humpback whale (Megaptera novaeang-liae)	West Greenland	2013-05-25, 2011-06-02	Greenland
Ringed seal (Pusa hispida)	Ilulissat Ice fjord	2016-09-15	Greenland
White-beaked dolphin (Lagenorhynchus albirostris)	Tassilaq	2016-09-30	Greenland
Polar bear (Ursus maritimus), mother	Tassilaq area	2017-08-14	Greenland
Polar bear (Ursus maritimus), cub	Tassilaq area	2017-08-14	Greenland
Terrestrial mammals			
Brown bear (Ursus arctos)	Kuusamo, Sotkamo		Finland
Reindeer (Rangifer tarandus)	Ylitornio	2017-10-09	Finland
Reindeer (Rangifer tarandus)	Ylitornio	2017-10-09	Finland
Reindeer (Rangifer tarandus)	Eastern region	2017-08-01-2017-09-20	Iceland
Reindeer (Rangifer tarandus)	Eastern region	2017-08-01-2017-09-20	Iceland
Reindeer (Rangifer tarandus)	Girjas and Sirges, Norrbotten	2017-09-11	Sweden
Reindeer (Rangifer tarandus)	Girjas and Sirges, Norrbotten	2017-09-11	Sweden
Reindeer (Rangifer tarandus)	Isortoq	2017-09-05	Greenland
Reindeer (Rangifer tarandus)	Nuuk area (64.306144 / -50.010555)	2017-10-20	Greenland
Fresh surface water			
Lake Ørn (Ørnsø)	Silkeborg	2017-08-29	Denmark
Lake Silkeborg	Silkeborg	2017-09-07	Denmark
Lake Leitisvatn	Sørvágsvatn	2017-09-24	Faroe Islands
Lake Myrene	Vestmanna	2017-09-25	Faroe Islands
River Vantaa	Helsinki archipelago (influ-enced by river)	2017-08-24	Finland
Lake Pirkkalan Pyhäjärvi	Tampere	2017-08-23	Finland
Lake at Isortoq		2017-09-07	Greenland
Lake at Badesö Kobbefjord	Nuuk	2017-09-14	Greenland
Lake Elliðavatn		2017-09-28	Iceland
Lake Mjøsa	Close to discharge of Hias WWTP	2017-08-08	Norway
Lake Mjøsa	~40 km downstream of Hias	2018-03-02	Norway
Lake Vättern	Central (58.19506 / 14.30541)	2017-05-29	Sweden
Lake Vänern	Mariestadssjön	2017-05-31	Sweden

SAMPLE TYPE	LOCATION	SAMPLING DATE	COUNTRY
WWTP sludge			
Viborg	Viborg	2017-08-31	Denmark
Randers	Randers	2017-08-31	Denmark
Sersjantvíkin	Torshavn	2017-09-26	Faroe Islands
Sersjantvíkin	Torshavn	2017-09-05 20:45	Faroe Islands
Viinikanlahti	Tampere	2017-09-05	Finland
Viikinmäki	Helsinki	2017-09-04	Finland
Hias	Ottestad	2017-08-28–2017-09-01	Norway
Hias	Ottestad	2017-06-19–2017-06-20	Norway
Umeå	Umeå		Sweden
Henriksdal	Stockholm	2017-10-9–2017-10-13	Sweden
Ryaverken	Gothenburg	2017-10-03	Sweden
Gässlösa	Borås	2017-10-19	Sweden
WWTP effluent			
Viborg	Viborg	2017-08-31	Denmark
Randers	Randers	2017-08-31	Denmark
Sersjantvíkin	Torshavn	2017-09-26	Faroe Islands
Landssjúkrahúsið, LSH, Main Hospital	Torshavn	2017-09-26	Faroe Islands
Viikinmäki	Helsinki	2017-09-04	Finland
Viinikanlahti	Tampere	2017-09-05	Finland
Qernertunnguit	Nuuk	2017-09-13	Greenland
Nuukullak	Nuuk	2017-09-13	Greenland
Hafnarfjordur	Hafnarfjordur		Iceland
Klettagardar	Reykjavik		Iceland
Hias	Ottestad	2017-06-27	Norway
Hias	Ottestad	2017-09-05	Norway
Umeå	Umeå	2017-10-17–2017-10-23	Sweden
Henriksdal	Stockholm	2017-10-09–2017-10-15	Sweden
Ryaverken	Gothenburg	2017-10-02–2017-10-03	Sweden
Gässlösa	Borås	2017-10-19	Sweden

Table A1-2: Sample characteristics for the atmospheric samples collected for this project. GPXP: GFF-PUF-XAD2-PUF

Sample name	Sample info	Sampling time	Sampling location	Sample type	QC	Country	Sample volume [m³]
SWE01	2	27/11/2017–01/01/2018	Råö	GFF		Sweden	6117
SWE02	3	29/5/2017–3/7/2017	Råö	GFF		Sweden	5736
NO01	17/2029	26/07/2017–28/07/2017	Andøya	GPXP		Norway	1315
NO02	17/2030	31/07/2017–02/08/2017	Andøya	GPXP		Norway	1268
NO03	17/2031	31/07/2017	Andøya	GPXP	Field Blank	Norway	1000
Gre01	ATPR 2016-14795	29/06/2017–06/07/2017	Station Nord	GPXP		Greenland	5000
Gre02	ATPR 2016-14799	27/7/2017–03/08/2017	Station Nord	GPXP		Greenland	5000
Gre03	ATPR 2016-14795	29/06/2017–06/07/2017	Station Nord	GPXP		Greenland	5000
Ice01	6EM18014 Ust 1	Nov-17	Norðurhella, Hafnarfjörður	GFF	Field Blank	Iceland	720
Ice02	6EM18014 Ust 2	Nov-17	Norðurhella, Hafnarfjörður	GFF	Field Blank	Iceland	720
Ice03	12	25/11/2017	Norðurhella, Hafnarfjörður	GFF		Iceland	720
Ice04	13	26/11/2017	Norðurhella, Hafnarfjörður	GFF		Iceland	720
Ice05	14	27/11/2017	Norðurhella, Hafnarfjörður	GFF		Iceland	720
Ice06	15	28/11/2017	Norðurhella, Hafnarfjörður	GFF		Iceland	720
Ice07	16	29/11/2017	Norðurhella, Hafnarfjörður	GFF		Iceland	720
Ice08	17	30/11/2017	Norðurhella, Hafnarfjörður	GFF		Iceland	720

Appendix 2. Full list of target PFASs and their abbreviations

Table A2-1: List of abbreviations of target PFASs for the water, sludge and biota samples

Class	Subgroup	Acronym	Name
PFSA	Ultra-short chain	PFEtS	Perfluoroethane sulfonic acid
	Ultra-short chain	PFPrS	Perfluoropropane sulfonic acid
	Short-chain	PFBS	Perfluorobutane sulfonic acid
	Short-chain	PFPeS	Perfluoropentane sulfonic acid
	Long-chain	PFHxS	Perflurohexane sulfonic acid
	Long-chain	PFHpS	Perfluoroheptane sulfonic acid
	Long-chain	PFOS	Perfluorooctane sulfonic acid
	Long-chain	PFNS	Perfluorononane sulfonic acid
	Long-chain	PFDS	Perfluorodecane sulfonic acid
	Long-chain	PFDoS	Perfluorododecane sulfonic acid
PFCA	Ultra-short chain	TFA	Trifluoroacetic acid
	Ultra-short chain	PFPrA	Perfluoropropanoic acid
	Short-chain	PFBA	Perfluorobutanoic acid
	Short-chain	PFPeA	Perfluoropentanoic acid
	Short-chain	PFHxA	Perfluorohexanoic acid
	Short-chain	PFHpA	Perfluoroheptanoic acid
	Long-chain	PFOA	Perfluorooctanoic acid
	Long-chain	PFNA	Perfluorononanoic acid
	Long-chain	PFDA	Perfluorodecanoic acid
	Long-chain	PFUnDA	Perfluoroundecanoic acid
	Long-chain	PFDoDA	Perfluorododecanoic acid
	Long-chain	PFTrDA	Perfluorotridecanoic acid
	Long-chain	PFTDA	Perfluorotetradecanoic acid
	Long-chain	PFHxDA	Perfluorohexadecanoic acid
	Long-chain	PFOcDA	Perfluorooctadecanoic acid
FTCA	Precursor	5:3 FTCA	5:3 Fluorotelomer carboxylic acid
	Precursor	7:3 FTCA	7:3 Fluorotelomer carboxylic acid
FTUCA	Precursor	6:2 FTUCA	6:2 Fluorotelomer unsaturated carboxylic acids
	Precursor	8:2 FTUCA	8:2 Fluorotelomer unsaturated carboxylic acids
	Precursor	10:2 FTUCA	10:2 Fluorotelomer unsaturated carboxylic acids
FTSA	Precursor	4:2 FTSA	4:2 Fluorotelomer sulfonic acid
	Precursor	6:2 FTSA	6:2 Fluorotelomer sulfonic acid
	Precursor	8:2 FTSA	8:2 Fluorotelomer sulfonic acid
monoPAP	Precursor	6:2 monoPAP	6:2 Fluorotelomer phosphate monoester
	Precursor	8:2 monoPAP	8:2 Fluorotelomer phosphate monoester
	Precursor	10:2 monoPAP	10:2 Fluorotelomer phosphate monoester
diPAP	Precursor	4:2 diPAP	4:2 Fluorotelomer phosphate monoester

Class	Subgroup	Acronym	Name
	Precursor	4:2/6:2 diPAP	4:2/6:2 Fluorotelomer phosphate diester
	Precursor	2:2/8:2 diPAP	2:2/8:2 Fluorotelomer phosphate diester
	Precursor	6:2 diPAP	6:2 Fluorotelomer phosphate diester
	Precursor	4:2/8:2 diPAP	4:2/8:2 Fluorotelomer phosphate diester
	Precursor	2:2/10:2 diPAP	2:2/10:2 Fluorotelomer phosphate diester
	Precursor	8:2 diPAP	8:2 Fluorotelomer phosphate diester
	Precursor	6:2/10:2 diPAP	6:2/10:2 Fluorotelomer phosphate diester
	Precursor	4:2/12:2 diPAP	4:2/12:2 Fluorotelomer phosphate diester
	Precursor	6:2/8:2 diPAP	6:2/8:2 Fluorotelomer phosphate diester
	Precursor	4:2/10:2 diPAP	4:2/10:2 Fluorotelomer phosphate diester
	Precursor	8:2/10:2 diPAP	8:2/10:2 Fluorotelomer phosphate diester
	Precursor	6:2/12:2 diPAP	6:2/12:2 Fluorotelomer phosphate diester
	Precursor	10:2 diPAP	10:2 Fluorotelomer phosphate diester
	Precursor	8:2/12:2 diPAP	8:2/12:2 Fluorotelomer phosphate diester
	Precursor	6:2/14:2 diPAP	6:2/14:2 Fluorotelomer phosphate diester
	Precursor	10:2/12:2 diPAP	10:2/12:2 Fluorotelomer phosphate diester
	Precursor	8:2/14:2 diPAP	8:2/14:2 Fluorotelomer phosphate diester
	Precursor	12:2 diPAP	12:2 Fluorotelomer phosphate diester
	Precursor	10:2/14:2 diPAP	10:2/14:2 Fluorotelomer phosphate diester
	Precursor	8:2/16:2 diPAP	8:2/16:2 Fluorotelomer phosphate diester
PFPA	Potential precursors	PFHxPA	Perfluorohexyl phosphonic acid
		PFOPA	Perfluorooctyl phosphonic acid
		PFDPA	Perfluorodecyl phosphonic acid
		PFTePA	Perfluorotetradecyl phosphonic acid
		PFHxDPA	Perfluorohexadecyl phosphonic acid
PFPiA	Potential precursors	C6/C6 PFPiA	Bis (perfluorohexyl) phosphinic acid
		C6/C8 PFPiA	Perfluoro (hexyloctyl) phosphinic acid
		C8/C8 PFPiA	Bis (perfluorooctyl) phosphinic acid
		C6/C10 PFPiA	Perfluoro (hexyldecyl) phosphinic acid
		C8/C10 PFPiA	Perfluoro (octyldecyl) phosphinic acid
		C6/C12 PFPiA	Perfluoro (hexyldodecyl) phosphinic acid
		C10/C10 PFPiA	Bis (perfluorodecyl) phosphinic acid
		C8/C12 PFPiA	Perfluoro (octyldodecyl) phosphinic acid
		C6/C14 PFPiA	Perfluoro (hexyltetradecyl) phosphinic acid
		C10/C12 PFPiA	Perfluoro (decyldodecyl) phosphinic acid
		C8/C14 PFPiA	Perfluoro (octycltetradecyl) phosphinic acid
		C12/C12 PFPiA	Bis (perfluorododecyl) phosphinic acid
		C10/C14 PFPiA	Perfluoro (decyltetradecyl) phosphinic acid
		C14/C14 PFPiA	Bis (perfluorotetradecyl) phosphinic acid
FASA	Precursor	FOSA	Perfluorooctane sulfonamide
FASAA	Precursor	FOSAA	Perfluorooctane sulfonamidoacetic acid
	Precursor	MeFOSAA	Methyl perfluorooctane sulfonamidoacetic acid
	Precursor	EtFOSAA	Ethyl perfluorooctane sulfonamidoacetic acid
PFCHS	Novel	PFECHS	Perfluoroethylcyclohexane sulfonic acid
PFECA	Novel	ADONA	3H-perfluoro-3-[(3-methoxy-propoxy)propanoic acid]
	Novel	HFPO-DA (GenX)	Hexafluoropropylene oxide dimer acid
PFESA	Novel	6:2 Cl-PFESA (F-53B)	6:2 chlorinated polyfluorinated ether sulfonate
	Novel	8:2 Cl-PFESA	8:2 chlorinated polyfluorinated ether sulfonate

Table A2-2: Conventional PFAS analysed and quantified in air samples

Compound	Acronym	CAS No.	Formula
PFCAs			
Perfluorohexanoic acid	PFHxA	307-24-4	$F(CF_2)_5COOH$
Perfluoroheptanoic acid	PFHpA	375-85-9	$F(CF_2)_6COOH$
Perfluorooctanoic acid	PFOA	335-67-1	$F(CF_2)_7COOH$
Perfluorononanoic acid	PFNA	375-95-1	$F(CF_2)_8COOH$
Perfluorodecanoic acid	PFDA	335-76-2	$F(CF_2)_9COOH$
Perfluoroundecanoic acid	PFUnDA	2058-94-8	$F(CF_2)_{10}COOH$
Perfluorododecanoic acid	PFDoDA	307-55-1	$F(CF_2)_{11}COOH$
PFSAs			
Perfluorobutanoic sulfonate	PFBS	29420-49-3 (potassium salt)	$F(CF_2)_4SO_3^- K^+$
Perfluorohexanoic sulfonate	PFHxS	3871-99-6 (potassium salt)	$F(CF_2)_6SO_3^- K^+$
Perfluorooctanoic sulfonate (Linear and branched isomers)	PFOS & Br-PFOS	1763-23-1 (sodium salt)	$F(CF_2)_8SO_3^- Na^+$
FASAs			
Perfluorooctane sulfonamide	FOSA	754-91-6	$F(CF_2)_8SO_3NH_2$
N-methyl-perfluorooctane sulfonamide	MeFOSA	31506-32-8	$F(CF_2)_8SO_3NHCH_3$
N-ethyl-perfluorooctane sulfonamide	EtFOSA	4151-50-2	$F(CF_2)_8SO_3NHCH_2CH_3$
FASEs			
N-methyl perfluorooctane sulfon-amidoethanol	MeFOSE	24448-09-7	$F(CF_2)_8SO_3NH(CH_3)CH_2CH_2OH$
N-ethyl perfluorooctane sulfon-amidoethanol	EtFOSE	1691-99-2	$F(CF_2)_8SO_3NH(CH_2CH_3)CH_2CH_2OH$

Table A2-3: Target vPFASs, PFASs, internal standards (ISTD) and recovery standard (RSTD) for air samples. Compound marked in bold are used as labelled standards. The "quant" column indicate wether or not the compound was included in the final quantification method

No	Quant	Compound (IUPAC)	Acronym	Provider	CAS
1	Y	1,3-Bis(trifluoromethyl)-5-bromo-benzene	BTFBB	Sigma Aldrich	328-70-1
2	Y	1,3,7-tetrakis(3,3,3-trifluoropropy)1,3,5,7-tetra-methylcyclosiloxane	TTFMCS	Sigma Aldrich	427-67-4
3	N	Bromopentafluorobenzene	BPFB	Sigma Aldrich	344-04-7
4	N	Perfluorotributylamine	PFTBA	ChemSupport AS	311-89-7
5	N	Perfluoroperhydrophenanthrene	PFPHP	ChemSupport AS	306-91-2
6	N	1,1,1,2,2,3,4,5,5,5-decafluoro-3-(1,2,2,2-tetrafluoro-1-(trifluoromethyl)ethyl)-4-(trifluoromethyl)pen-tane	DTFMP	ChemSupport AS	50285-18-2
7	N	1,1,2,2,3,3,4,4,5,5,6,6,6-tridecafluoro-n-methylhexane-1-sulfonamide	TDFMS	ChemSupport AS	68259-15-4
8	N	N-ethyl,1,1,2,2,3,3,4,4,5,5,6,6,6-tridecafluoro-N-(2-hydroxyethyl) hexane-1-sulfonamide	ETDFHS	ChemSupport AS	106443-63-4
9	N	N-(methyl) nonafluoro- butanesulfonamide	MeFBSA	ChemSupport AS	69298-12-4
10	N	1,1,2,2,3,3,4,4,5,5,6-undecafluoro-6-(nonafluorobu-tyl)cyclohexane	UDFBC	ChemSupport AS	374-60-7
11	N	1,2,3,4-tetrachloro-1,1,2,3,4,4-hexafluorobutane	TCHFB	ChemSupport AS	375-45-1
12	N	Perfluamine	PFA	ChemSupport AS	338-83-0
13	Y	1,1,2,2,3,3,4,4,5,5,6,6,6-tridecafluoro-N-methylhex-ane-1-sulfonamide	TDFMSA	ChemSupport AS	50285-18-2
14	Y	N- ethyltridecafluoro-N-(2-hydroxyethyl)hex-anesulphonamide	ETDHSA	ChemSupport AS	106443-63-4
15	Y	8:2 Fluorotelomer alcohol	FOET	Wellington	
16	Y	6:2 Fluorotelomer alcohol	FHET	Wellington	
17	Y	4:2 Fluorotelomer alcohol	FTET	Wellington	
18	*Y*	*2-Perfluorohexyl-[1,1-$^{2}H_2$]-[1,2-$^{13}C_2$]-ethanol (ISTD)*	*MFHET*	*Sigma Aldrich*	
19	*Y*	*N-methyl-$^{2}H_3$-perfluoro-1-ocanesulfonamide (ISTD)*	*d-MeFOSA*	*Sigma Aldrich*	
20	Y	Perfluorooctane sulfonamide	FOSA	Sigma Aldrich	
21	Y	N-methyl perfluorooctane sulfonamidoethanol	EtFOSE	Sigma Aldrich	
22	Y	Linear perfluoro butyl sulfonate	LPFBS	Sigma Aldrich	
23	*Y*	*$^{13}C_8$-perfluorooctanesulfonamide (ISTD)*	*M8FOSA*	*Wellington*	
24	*Y*	*Tetrachloronaphthalene (Recovery standard)*	*TCN*	*Sigma Aldrich*	

Appendix 3: Sampling manual

Screening of PFAS and total organic fluorine in Nordic countries 2017

Sampling and sample handling manual

Anna Kärrman (OrU), Thanh Wang (OrU), Roland Kallenborn (NMBU/KBM)

Prepared by
Roland Kallenborn,
Norwegian University of Life Sciences (NMBU),
Faculty of Chemistry, Biotechnology and Food Sciences (KBM)

Introduction and objectives of the study

These guidelines concern the sampling, sample handling and shipment of water, sediment, sludge, fish liver and seal liver for trace analysis of per and polyfluorinated organic substances (PFAS). They are suitable for perfluoroalkylated acids, perfluoroalkylated sulfonates and their derivatives. The institutes performing the chemical trace analysis do not take any responsibility for representativeness of samples or contamination problems during sampling, sample storage and shipment to the respective laboratories. These guidelines should be followed as precisely as possible and any deviations from the guidelines must be reported in the sampling protocols.

A variety of earlier studies identified novel PFAS in the here selected target media. As expansion of the current national PFAS monitoring, novel PFASs (according to the NCM Target list) will be analysed in air samples, water (freshwater, seawater, WWTP effluents), sediment, sludge, and selected biota from the Nordic countries (i.e. Denmark, Sweden, Finland, Norway, Iceland and Faeroe Islands). This will allow to assess the existing level of contamination (spatial distribution monitoring) possibly indicating regional differences. This screening project will enable to determine the representativeness of the current national monitoring sites regarding spatial variability in contaminant concentrations and will give information about the ubiquity of novel PFAS distribution in the Nordic countries.

Per- and polyfluoroalkyl substances (PFAS)

PFAS have been manufactured for more than 50 years (Buck *et al.* 2011). They are used for a large number of industrial applications such as protection of textiles, outdoor and recreational tools as well as in the production of Aqueous film forming foam (AFFF) based fire-fighting foams, herbicides and insecticides, lubricants, paints, adhesives and acid etching solutions (Anderson *et al.* 2016; Banzhaf *et al.* 2017; Chu *et al.* 2016; Houtz *et al.* 2016; Nguyen *et al.* 2016; Rotander *et al.* 2015). Their wide usage range is due upon their unique physico-chemical properties:

1. They are immiscible with most other liquids.
2. Fluoro-organics are non-flammable and non-corrosive.
3. Perfluorinated compounds have a very high insulation resistance.

These exceptional properties making man-made PFASs so attractive for industrial applications also impose a risk for the environment and ecological systems. The strength of the carbon-fluorine bond makes these compounds very persistent towards degradation. Recent publications indicated that PFASs and especially PFOS are widely distributed over the northern hemisphere, including remote areas such as the Arctic , (Bossi *et al.* 2015; Gronnestad *et al.* 2017; Lucia *et al.* 2015; Nost *et al.* 2014; Pedersen *et al.* 2016; Routti *et al.* 2016). However, this wide-ranging application range may also cause considerable contamination risk for ultra-trace analysis in environmental samples. In addition, the development of new PFAS products aiming at replacing regulated PFAS products is constantly evolving. Thus, new fluorinated chemicals are continuously identified as potential xenobiotics. The here planned screening identified 32 novel PFASs as potential priority contaminants or future extended monitoring. These substances will be included aside the already identified high priority compounds. For the here planned screening exercise, more than 50 PFASs including novel PFASs will be investigated.

A comprehensive sampling guideline is provided for avoiding and controlling possible contamination risk during sampling and sample handling. For detailed information on the target PFASs see Table A3-1, NMR-tender documentation.

General sampling strategy

Sampling should be performed in accordance with general sampling strategies for chemical trace analysis. In case of questions about the practicability of procedures or usability of special material and equipment NMBU/KBM or Örebro University must be contacted (Anna Kärrman, phone: +46 (0) 709780744, e-mail: Anna.karrman@oru.se; Roland Kallenborn, phone: +4767232497, e-mail: roland.kallenborn@nmbu.no). The sampling strategy should consider the specific objectives of the monitoring programme, including the quantitative objectives. Natural variability within the samples should be reduced by an appropriate sampling design. The sampling strategy is an intrinsic component of the data,

and may limit their use and interpretation. For sample characterisations, see Table A3-1. An overview of the sample handling in this project is given in Table A3-2.

Sampling site selection / representative sampling

The previous 2004 screening on the occurrence of PFASs revealed already considerable PFAS contamination in the Nordic environment (Kallenborn *et al.* 2004). However, during the past decade the number of relevant novel target poly- and perfluoroalkyl substances (Novel PFASs) in the environmental has exponentially increased due to the advancement of modern trace analytical procedures. Therefore, the here planned extended PFASs screening will investigate the current PFASs profile and assess whether regulation measures during the past decade were effective in preventing uncontrolled PFASs pollution in the Nordic environment. The detailed sampling site selection lies within the responsibility of the sampling institutes. Sampling sites must be indicated on the sampling protocols as accurate as possible (preferably with GPS coordinates and latitude/longitude data).

Homogeneity of samples

Primary sample amounts should be as large as feasible and homogenised on site to yield sub-samples of at least the required volume for analysis (see Chapter 5). Larger sample amounts are preferred (and mandatory for some samples of each matrix) to perform laboratory replicate studies. These as well as field replicate studies (see Chapter 7.2) are an integrated part of the quality assurance program of the planned study.

Documentation

The sample protocols (separate excel-file) must be filled in and sent to the laboratories. An explanation should be given if variables are left blank. There must be a clear connection between the labels on the sample containers and the documentation.

Sampling equipment / risk of contamination

All equipment, materials and containers expected to be in contact with the samples must be rinsed with high-purity water and methanol before use. Fluoropolymeric materials pose a significant risk of contamination with PFAS, especially for PFOA. Equipment made of or containing fluoropolymers such as PTFE ('Teflon') or Viton rubber (sealing rings etc.) must not be in direct contact with the samples and should completely be avoided when handling, storing or shipping samples. The target analytes are surface-active compounds. Due to their strong adsorbing properties on glass surfaces, glass containers should be avoided and replaced by polyethylene (PE) or polypropylene (PP) (not PTFE!).

NMBU/KBM or Örebro University must be contacted in case of questions about the usability of certain materials in contact with samples (Anna Kärrman, phone: +46 (0) 709780744, e-mail: Anna.karrman@oru.se; Roland Kallenborn, phone: +4767232497, e-mail: roland.kallenborn@nmbu.no). Samples should be collected in the same containers in which they are stored and shipped to the analysing laboratories to avoid losses due to adsorption and change of vessels.

Field sampling / required sample amounts

Water and sludge

General water sampling strategies for chemical trace analysis should be followed. Sample amounts of 2000 mL are required to guarantee good detection limits in low contaminated waters. For WWTP effluent 1000 mL is sufficient. A field blank must be pepared and provided with the samples (empty container that has been opened during sampling). The sampling depth in lakes and the sea is important information and should be recorded. Due to their surface-active properties, PFAS might form a layer on water surfaces or preferably bind to particles. Therefore, it is important to state if samples were collected on the water surface, several meters depth from the surface or close to the bottom. We recommend to sample surface water (approximately down to 30cm below surface). Water samples should be kept cool (but not frozen) and in darkness in order to avoid degradation of analytes. Sludge, minimum 10 g wet weight, should be kept in PP or PE containers in +4°C.

Air

All air samples will be collected with high volume air samples in collabaration with the local regulation and monitoring authorities. The high-volume air samples will be collected in glass- or stainless steal cartridges with glass fibre filter (GFF) particle collectors (without PTFE-rings) and PUF/XAD-2/PAH (PXP) polyurethane foam plugs. In case the chosen field stations/institutions have the opportunity to pack the PXP sampling cartridges, the anytical laboratry in charge will provide clean XAD-2 for sampling. However, the analytical laboratry offers to clean and prepack the cartridges. In this case, filterholders for the respective sampling units at the stations should be sent to the labortory in advance. The sample number is indicated in Table A3-2 of the tender document. Field blanks (cartridges placed in the sampling unit for 0.5–1 hour without air pumping) must be performed and in any other aspect treated in the same way as the samples.

The atmospheric samples collected (High- and low volume) must be sealed immediately after the collection using first aluminium foile and then plastic bags (type ziplock or equivalent) and kept frozen (-18 C) until shipped to the responsible laboratory for analysis. For sampling and storage, any contact with teflon surfaces must be avoided.

Biota

Fish, reindeer, marine mammals and sea bird eggs should be prepared immediately after collection (summer 2017) and tissue samples should be removed and frozen in closed PP or PE containers. The fish liver samples should be pooled samples prepared from at least 10 individuals of same specie and similar size (weight and length). The weight of the total pooled sample should in any case exceed 5 g. Fish caught during the non-spawning season is preferred over fish during spawning. The terrestrial as well as the marine tissue samples (liver) should preferably be prepared as individual samples. A minimum of 5 g liver tissue is requested for analysis. All biological samples must be frozen immediately after catch and preparation. The egg samples should be whole eggs and pooled from at least 5 individual eggs from the same specie. Samples are kept in containers (PP or PE) and frozen (-18 C) until shipping to the analytical laboratory. For sampling and storage, any contact with teflon surfaces must be avoided. An empty container should be sent to the laboratory together with the samples.

Storage and shipping of samples

Most of the listed PFASs (classical and novel) are very stable towards degradation. Therefore, the time between sampling and analysis is not expected to be crucial in this study. However, little is known about enzymatic degradation, therefore all samples should be kept cold and especially biological samples should be frozen (18 °C) immediately after collection.

All samples must be collected, stored and shipped in clean, fluoropolymer-free containers, preferably polyethylene vessels should be used (see Chapter 4). Containers should not be changed from the moment of sampling or preparation to the arrival at the analytical laboratories. Containers must be clearly and unmistakably marked with a sample name and sent together with their sampling protocols by an express delivery service (TNT, DHL, EMS or similar) to the following address:

Air samples:

Roland Kallenborn
Faculty of Chemistry,Biotechnology and Food Sciences (KBM)
Norwegian University of Life Sciences (NMBU)
Chrstian M.Falsen veg 1
NO-1432 Aas, Norway
Email: roland.kallenborn@nmbu.no

All others:

Anna Kärrman
ÖREBRO UNIVERSITY
MTM Research Centre
School of Science and Technology
Fakultetsgatan 1, SE-701 82 ÖREBRO, Sweden
e-mail: anna.karrman@oru.se

To assure that samples reach the destination within short time (usually within the same day), they should be sent early in the morning and not on a Friday (preferably Monday to Wednesday). When sending the samples a notice including the airway bill number (AWB) of the package must be sent to the corresponding email address (see above). The delivery should be marked with "samples NMR-PFAS screening study" to avoid unnecessary delay during the registration procedure at the analysing institute.

Water and sludge samples

Water, sediment and sludge samples must be cooled (< 4 °C) after collection. Water samples should not be frozen. All samples should be stored and shipped at low temperatures and in darkness.

Air samples

High (and low) volume samples must be kept frozen during storage (< -18 °C). During transportation, an insulated box should be used to ensure that the temperature does not exceed thawing temperature (< 0 °C).

Other samples

Biological samples (reindeer, egg, fish and marine mammals) as well as sediment/soil and sludge must be kept frozen during storage (< -18 °C). During transportation, an insulated box should be used to ensure that the temperature does not exceed thawing temperature (< 0 °C).

Sampling quality assurance

Quality assurance is a management scheme required to ensure the consistent delivery of quality controlled data. To minimise the risk of contamination or the loss of analytes (and so to avoid the generation of false positive and/or negative data) all procedures including sampling, storage and shipping must be evaluated and controlled. This is partly done by analysing field blanks and replicates. Furthermore, sample replicates allow to assess the precision of the complete analytical method. Field blank and replicate samples must be included in the sampling procedure and will be analysed and reported in addition to the

environmental samples without additional costs. The steering group of the Nordic Chemicals Group decides where blank and duplicate samples will be taken and is responsible for the distribution of these tasks (see also *Field Blanks* and *Field replicates*).

Field blanks

Field blanks must be taken parallel to the samples for all matrices. The purpose of the blanks is to controll possible contamination introduced during sampling and handling before the samples arrives in the analytical laboratory. This is done by allocating containers without samples that are treated in exactly the same way as the real samples from the moment of sampling in the field.

Field replicates

In addition to the blank and real samples, duplicate samples must be taken for all matrices at a minimum of three different sampling sites (preferably three different countries). These samples will be used to assess the repeatability and representativeness of the sampling procedures. The duplicates must in each case be two independent samples simultaneously taken from the same site and not two aliquots from the same primary sample homogenate. It has to be indicated on the sampling protocols which samples belong together as field duplicates.

Table A3-1: Samples to be taken in the screening project as described in the tender.

Nordic Country where the sample is collected	Matrix	Number of samples analyzed
Finland, Denmark, Norway, Sweden	Sludge WWTP	8
Faroe Islands, Greenland, Finland, Denmark, Norway, Sweden, Iceland	Effluent WWTP	14
Greenland, Iceland, Norway, Sweden	Air	6
Faroe Islands, Greenland, Finland, Denmark, Norway, Sweden, Iceland	Fresh water	14
Faroe Islands, Greenland, Finland, Denmark, Norway, Sweden, Iceland	Fresh water fish	14
Finland, Denmark, Norway, Sweden	Marine fish	8
Faroe Islands, Greenland, Iceland, Sweden	Sea bird eggs	8
Greenland, Iceland, Finland, Norway, Sweden	Reindeer	10
Faroe Islands, Greenland, Iceland, Denmark	Marine mammals	8

Table A3-2: Overview of the sampling instructions. For more details, please see sections 3-7.

	Water	Fresh fish	Marine fish	Eggs	Reindeer Marine M	Air	WWTP water/ sludge
Specie	-	Perch or eq.	Cod or eq.			-	-
Matrix	-	liver	liver	whole	liver	-	-
Pool or Individual	I	P (n=10)	P (n=10)	P (n=5)	I	I	I or P
Amount	2000mL	≥5g wet weight	≥5g wet weight	≥5g wet weight	≥5g wet weight	Contact the lab*	W:1000mL S: ≥10g wet weight
Container	PE or PP	PE or PP	PE or PP	PE or PP	PE or PP	Alu-foil	PE or PP
Storage	+4°C	-20°C	-20°C	-20°C	-20°C	-20°C	+4°C
Shipment	Isolated box with ice packs with express courier						

Note: (Anna Kärrman, phone: +46 (0) 709780744, e-mail: anna.karrman@oru.se; Roland Kallenborn, phone: +4767232497, e-mail: roland.kallenborn@nmbu.no)

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Appendix 4. Details on method development for volatile PFAS

Analytical method

A new and optimized method was developed for the here conducted atmospheric screening. A list of 21 target substances (Table A4-1) was selected based on the recommendations of the NMR pollutant screening group and outlined in the tender documentation. In addition, two isotope labeled internal standards and target contaminant quantification and one recovery standard (Tetrachloronaphthalene = TCN) were selected and validated (table 1). The principle method validation was performed according to internationally accepted QC strategies (Asmund and Cleemann, 2000, Asmund *et al.*, 2004, Mitchum and Donnelly, 1991).

Quantitative determination is based on internal standard (ISTD) quantification and sample specific recovery determination. For the here performed method validation, key components like linear response range for quantitative determination (Rel. response factor +/- 10%) and overall and sample specific recovery range (minimum: 40%) were determined. In addition method precision and overall uncertainty was estimated based on repeated quantification of samples and standards.

Table A4-1: Target vPFAS, internal standards (ISTD) and recovery standard (RSTD)

No	Compound (IUPAC)	Acronym	Provider	CAS
1	1,3-Bis(trifluoromethyl)-5-bromo-benzene	BTFBB	Sigma Aldrich	328-70-1
2	1,3,7-tetrakis(3,3,3-trifluoropropy)1,3,5,7-tetramethylcy-closiloxane	TTFMCS	Sigma Aldrich	427-67-4
3	Bromopentafluorobenzene	BPFB	Sigma Aldrich	344-04-7
4	Perfluorotributylamine	PFTBA	ChemSupport AS	311-89-7
5	Perfluoroperhydrophenanthrene	PFPHP	ChemSupport AS	306-91-2
6	1,1,1,2,2,3,4,5,5,5-decafluoro-3-(1,2,2,2-tetrafluoro-1-(trifluoro-methyl)ethyl)-4-(trifluoromethyl)pentane	DTFMP	ChemSupport AS	50285-18-2
7	1,1,2,2,3,3,4,4,5,5,6,6,6-tridecafluoro-n-methylhexane-1-sulfonamide	TDFMS	ChemSupport AS	68259-15-4
8	N-ethyl,1,1,2,2,3,3,4,4,5,5,6,6,6-tridecafluoro-N-(2-hydroxy-ethyl) hexane-1-sulfonamide	ETDFHS	ChemSupport AS	106443-63-4
9	N-(methyl) nonafluoro- butanesulfonamide	MNFBS	ChemSupport AS	69298-12-4
10	1,1,2,2,3,3,4,4,5,5,6-undecafluoro-6-(nonafluorobutyl)cyclo-hexane	UDFBC	ChemSupport AS	374-60-7
11	1,2,3,4-tetrachloro-1,1,2,3,4,4-hexafluorobutane	TCHFB	ChemSupport AS	375-45-1
12	Perfluamine	PFA	ChemSupport AS	338-83-0
13	N-(Methyl)nonafluorobutanesulfonamide	MNFBSA	ChemSupport AS	68298-12-4
14	1,1,2,2,3,3,4,4,5,5,6,6,6-tridecafluoro-N-methylhexane-1-sul-fonamide	TDFMSA	ChemSupport AS	50285-18-2
15	N- ethyltridecafluoro-N-(2-hydroxyethyl)hexanesulphonamide	ETDHSA	ChemSupport AS	106443-63-4
16	8:2 Fluorotelomer alcohol	FOET	Wellington	
17	6:2 Fluorotelomer alcohol	FHET	Wellington	
18	4:2 Fluorotelomer alcohol	FTET	Wellington	
19	*2-Perfluorohexyl-[1,1-$^{2}H_2$]-[1,2-$^{13}C_2$]-ethanol (ISTD)*	*MFHET*	*Sigma Aldrich*	
20	*N-methyl-$^{2}H_3$-perfluoro-1-ocanesulfonamide (ISTD)*	*d-N-MeFOSA*	*Sigma Aldrich*	
21	Perfluoroocante sulfonamide	FOSA	Sigma Aldrich	
22	N-methyl perfluorooctane sulfonamidoethanol	N-Et-FOSE	Sigma Aldrich	
23	Linear perfluoro butyl sulfonate	LPFBS	Sigma Aldrich	
24	*$^{13}C_8$-perfluorooctanesulfonamide (ISTD)*	*M8FOSA*	*Wellington*	
25	*Tetrachloronaphthalene (Recovery standard)*	*TCN*	*Sigma Aldrich*	

For unambiguous identification, all single standards were injected in scan mode at concentrations between 1–5 ng/µL. A scan range between 50–600 amu was chosen. Based upon the identified separation characteristics, an optimized multimode inlet (MMI) injection and chromatographic separation program including temperature program was developed. The characteristic retention times (RT) are listed in Table A4-2.

Table A4-2: Compounds identified in GC/MS EI-SCAN of standard solution (1ng/µL single standard injected) using MMI pulsed injection (250 °C) on DB5MS (30 m, 0.25 µm FT,0.25 mm ID) capillary column

No	Compound	RT [min]
4	Perfluorotrobutylamine	3.5
11	1,2,3,4-tetrachlorohexafluorobutane	5.8
1	1,3- bis (trifluoromethyl)-5-bromo-benzene	7.1
3	Bromopentafluorobenzene	8.5
2a	*Isomer* 1: 1,3,5,7-tetrakis(3,3,3-trifluoropropyl) 1,3,5,7-tetramethylcyclosiloxanes	21.2
2b	*Isomer* 2: 1,3,5,7-tetrakis(3,3,3-trifluoropropyl) 1,3,5,7 tetramethylcyclosiloxanes	21.3
2c	*Isomer* 3: 1,3,5,7-tetrakis(3,3,3-trifluoropropyl) 1,3,5,7 tetramethylcyclosiloxanes	21.6
9	N-(methyl)nonafluorobutanesulfonamide	26.7
14	1,1,2,2,3,3,4,4,5,5,6,6,6-tridecafluoro-N-methylhexane-1-sulfonamide	27.0
5	Perfluoroperhydrophenanthrene	28.4
16	8:2 FTOH	13.1
19	MFHET (ISTD)	11.1
20	d-NMeFOSA (ISTD)	27.4
22	N-Et-FOSE	29.4
21	FOSA	26.0
25	TCN (RSTD)	44.6

Gas chromatographic parameters and conditions

Gas chromatograph: 7890B (Agilent, Santa Clara, USA)
Injector parameters

Table A4-3: Injector parameters

Mode	Pulsed
Heater	280 C
Pressure	160 kPA
Total Flow	64 mL/min
Septum Purge Flow	3 ml/min
Injection Pulse Pressure	172 kPa until 0,75 min
Purge Flow to Split Vent	60 mL/min at 2,5 min

For GC separation a Agilent 7890B high resolution Gas chromatograph and a 50 m DB5MS (Agilent 0,25mm ID, 0.25 µm FT) was applied.
A MMI with pressure pulse injection at 250 °C (2 min SSL time) was used for injection on an Agilent Autosampler 7693A.

Table A4-4: Settings for the GC method

Initial temperature	70 °C (Isotherm 3 min)
#1 Rate	5 °C/min
Temp 1	250 °C
Isotherm	5 min
#2 Rate	30 °C/min
Temp 2	280 °C
Isotherm	20 min
Equilibration Time	0.25 min
Max Temperature	280 °C

Mass spectrometer parameters

The quantification was performed on a Agilent (Santa Clara, USA) triple Quadrupole (QQQ) 7000C instrument.

Table A4-5: Settings for the mass spectrometry method

Mass spectrometer	7000C Triple Quadrupole (Agilent, Santa Clara, USA)
Ionisation	Electron ionization (MRM)
High vacuum	5×10^{-6} kPa
Temperature Q1	200C
Temperature Q2	200C
Collision energy	30 eV (for all compounds)
Scan modus	MRM

An optimized MRM program was developed for multi target analysis for all selected vPFAS. Two characteristic transition were chosen for all target compounds after comprehensive product ion scan (PIS). The characteristic MRM transition are listen in Table A4-3.

Table A4-3: GC/MS mass transitions for MRM quantification for volatile emerging PFASs

No	Compound	RT [min]	Transition 1	Transition 2
4	Perfluorotrobutylamine	3.5	219-131	131-69
11	1,2,3,4-tetrachlorohexafluorobutane	5.8	151-101	148-69
1	1,3- bis (trifluoromethyl)-5-bromo-benzene	7.1	292-213	213-273
3	Bromopentafluorobenzene	8.5	247-168	167-117
2a	Isomer 1: 1,3,5,7-tetrakis(3,3,3-trifluoropropyl) 1,3,5,7-tetra-methylcyclosiloxanes	21.2	215-159	137-107
2b	Isomer 2: 1,3,5,7-tetrakis(3,3,3-trifluoropropyl) 1,3,5,7 tetra-methylcyclosiloxanes	21.3	215-159	137-107
2c	Isomer 3: 1,3,5,7-tetrakis(3,3,3-trifluoropropyl) 1,3,5,7 tetra-methylcyclosiloxanes	21.6	215-159	137-107
9	N-(methyl)nonafluorobutanesulfonamide	26.7	131-69	94-65
14	1,1,2,2,3,3,4,4,5,5,6,6,6-tridecafluoro-N-methylhexane-1-sulfona-mide	27.0	131-69	94-65
5	Perfluoroperhydrophenanthrene	28.4	257-111	129-55
16	8:2 FTOH	13.1	231-131	181-69
19	MFHET (ISTD)	11.1	349-96	298-79
20	D_3-NMeFOSA (ISTD)	27.4	434-131	219-69
22	N-Et-FOSE	29.4	540-448	448-378
21	FOSA	26.0	512-169	448-119
25	TCN (RSTD)	44.6	266-196	266-194

Sensitivity testing

All 21 target volatile poly- and perfluoroalkyl substances (vPFAS) were tested for method and instrument sensitivity where modified multi-mode injection (MMI, pulsed pressure injection) was applied with an adjusted temperature program on a 60 m DB5 MS column (0.25 mm ID, 0,32 µm film thickness). Both Electron impact (EI) and Negative Ion Chemical ionization (NICI) was tested. The final instrument method for the quantitative determination of vPFAS in atmospheric samples is described in detail in the method chapter.

The list of target compounds with sufficient sensitivity for MMI-GC/MS (EI-MRM) are listed in Table A4-4.

Table A4-4: List of target compounds with sufficient sensitivity with current analytical method

No	Compound (IUPAC)	Acronym	Sensitivity	remarks
1	1,3-Bis(trifluoromethyl)-5-bromo-benzene	BTFBB	Detected (d)	
2	1,3,7-tetrakis(3,3,3-trifluoropropy)1,3,5,7-tetra-methylcyclosiloxanes	TTFMCS (1-3)	d	3 isomers separated in the standard solution
3	Bromopentafluorobenzene	BPFB	d	
4	Perfluorotributylamine	PFTBA	d	
5	Perfluoroperhydrophenanthrene	PFPHP	d	
6	1,1,1,2,2,3,4,5,5,5-decafluoro-3-(1,2,2,2-tetrafluoro-1-(trifluoromethyl)ethyl)-4-(trifluoromethyl)pentane	DTFMP	d	
7	1,1,2,2,3,3,4,4,5,5,6,6,6-tridecafluoro-n-methylhexane-1-sulfonamide	TDFMS	d	
8	N-ethyl,1,1,2,2,3,3,4,4,5,5,6,6,6-tridecafluoro-N-(2-hydroxyethyl) hexane-1-sulfonamide	ETDFHS	d	
9	N-(methyl) nonafluoro- butanesulfonamide	MNFBS	d	
10	1,1,2,2,3,3,4,4,5,5,6-undecafluoro-6-(nonafluorobu-tyl)cyclohexane	UDFBC	d	
11	1,2,3,4-tetrachloro-1,1,2,3,4,4-hexafluorobutane	TCHFB	d	
12	Perfluamine	PFA	d	
13	N-(Methyl)nonafluorobutanesulfonamide	MNFBSA	d	
14	1,1,2,2,3,3,4,4,5,5,6,6,6-tridecafluoro-N-methylhex-ane-1-sulfonamide	TDFMSA	d	
15	N- ethyltridecafluoro-N-(2-hydroxyethyl)hexanesul-phonamide	ETDHSA	d	
16	8:2 Fluorotelomer alcohol	FOET	d	
17	6:2 Fluorotelomer alcohol	FHET	d	
18	4:2 Fluorotelomer alcohol	FTET	d	
21	Perfluoroocante sulfonamide	FOSA	d	
22	N-methyl perfluorooctane sulfonamidoethanol	N-Et-FOSE	d	
23	Linear perfluoro butyl sulfonate	LPFBS	d	

Internal standards

Two potential isotope labeled internal standards (ISTD) were selected and validated for the here developed quantitative analytical method for volatile poly- and perfluoroalkyl substances (vPFAS): 2-perfluorohexyl-[1,1-$^{2}H_2$]-[1,2-$^{13}C_2$]-ethanol (MFHET) and N-methyl-$^{2}H_3$-perfluoro-1-ocanesulfonamide (d-N-MeFOSA). However, the first recovery tests revealed a considerable loss of d-N-MeFOSA (recovery between 15 and 30%). Therefore, MFHET (with acceptable overall recovery (60–80%) was further used as internal standard for all selected target vPFAS as a first approach. For MFHET, an acceptable linear response was determined in the concentration range 10 pg/µL–900 pg/µL and 2 µL injected) with $r^2 = 0.89$.

Linearity of target volatile poly- and perfluoroalkyl substances (vPFAS)

For the determination of a validated internal standard quantification method, the linearity range of the single target vPFAS compounds was assessed. The linearity range for the selected vPFAS is summarized in Table A4-5.

Table A4-5: Linearity and sensitivity of target compounds in the vPFAS method

No	Acronym	Detection	Sensitivity (within the lowest quarter of the linear range)	Linear range [pg/µL]	Comment
1	BTFBB	Detected (d)	yes	10–900	
2	TTFMCS 1	d	yes	10–900	
	TTFMCS 2	d	yes	10–900	
	TTFMCS 3	d	yes	10–900	
3	BPFB	d	yes	10–900	
4	PFTBA	d	no	no	
5	PFPHP	d	no	no	Thermal decomposition in injector expected
6	DTFMP	d	no	no	Thermal decomposition in injector expected
7	TDFMS	d	no	no	Thermal decomposition in injector expected
8	ETDFHS	d	no	no	Thermal decomposition in injector expected
9	MNFBS	d	no	no	Thermal decomposition in injector expected
10	UDFBC	d	no	no	Thermal decomposition in injector expected
11	TCHFB	d	no	no	Thermal decomposition in injector expected
12	PFA	d	no	no	Thermal decomposition in injector expected
13	MNFBSA	d	yes	10–900	
14	TDFMSA	d	yes	10–900	
15	ETDHSA	d	yes	10–900	
16	FOET	d	yes	10–900	
17	FHET	d	no	no	
18	FTET	d	no	no	
21	FOSA	d	yes	10–900	
22	N-Et-FOSE	d	yes	10–900	
23	LPFBS	d	yes	10–900	

No sufficient sensitivity and/or no linearity response for the here selected detector system could be established for 10 out of 23 target substances. The method validation for the remaining compounds continued with the determination of response factors (RF) and recovery determination.

Method effectivity

For an overall method efficiency test, a mix of the remaining 13 target vPFAS (5 ng in total compound) including the internal standard (MFHET) was spiked on a precleaned GFF (particulate phase) and PUF/XAD-2/PUF sandwich (gaseous phase) and prepared according to the vPFAS method described in the method section.

Table A4-6: Results from spiked recovery tests

Glass Fiber filters				
No	**Acronym**	**Recovery**	**Acceptable**	**comment**
1	BTFBB	>30%	N	loss
2	TTFMCS 1	60	Y	Breakthrough suspected,
	TTFMCS 2	60	Y	
	TTFMCS 3	60	Y	
13	MNFBSA	60	Y	
14	TDFMSA	64	Y	
15	ETDHSA	62	Y	
16	FOET	91	Y	
17	FHET	81	Y	
18	FTET	<20%	N	loss
21	FOSA	70	Y	
22	N-Et-FOSE	60	Y	
23	LPFBS	60	Y	
PUF/XAD-2/PUF				
No	**Acronym**	**Recovery**	**Acceptable**	**comment**
1	BTFBB	>30%	N	loss
2	TTFMCS 1	70	Y	Breakthrough suspected,
	TTFMCS 2	75	Y	
	TTFMCS 3	75	Y	
13	MNFBSA	70	Y	
14	TDFMSA	75	Y	
15	ETDHSA	72	Y	
16	FOET	91	Y	
17	FHET	81	Y	
18	FTET	<20%	N	loss
21	FOSA	55	Y	
22	N-Et-FOSE	81	Y	
23	LPFBS	60	Y	

For the TTFMCS standards, three isomers (presumably diastereomers) were identified in the standard solution. For simplicity, those three components were attributed with a similar response in the GC/MS and were quantified as sum TTFMCS in the results section.

Quantification and detection limits

Limit of detection (LOD) defines the minimum level of the compound which can be reliably detected. Thus, the limit of quantification (LOQ) is the minimum level of which a compound can be quantified. LOD is based on a minimum signal (S) in relation to baseline noise (N) of the chromatogram and as S/N ratio to be minimum 3:1 in the lowest quantifiable standard solution. The LOQ is determined as S/N= 10:1 in case no blank

contamination (field blank, lab-blank, solvent blank) was detected. In case a blank contamination was detected, the LOQ was determined as blank value + 10 * standard deviation (SD). For more information please refer to (Klang and Williams, 2016, Rustichelli *et al.*, 2013, Anonymous, 1998).

Table A4-7: Limit of detection (LOD) and Limit of Quantification for target vPFAS

Compound	LOD [pg/m3]	LoQ (pg/m3] PUF	LoQ [pg/m3] GFF	Comment
FTET	1	8/ 65 (PUF Nor)	6	Field blank
BPFB	0,5	5	12	
BTFBB	0,1	3/ 600 (PUF Nor)	900 (PUF Nor)	Field blank
FHET	0,2	16	5	
FOET	0,1	18	15	Field blank
N-ET-FOSA	0,2	11	7	
TTFMCS	1	3	6	
ETDHSA	0,1	4	4	
MNFBSA	0,1	1	1	
TDFMSA	0,1	1	1	
FOSA	0,1	1	1	
N-ET-FOSE	0,1	1	2	
LPFBS	0,1	1	1	

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Appendix 5: Tables with measured concentrations

n.q. = not quantified (not fullfilling quality control criterias).
* = semi-quantified.
<value = below method detection limit

Table A5-1): Bird egg concentrations (ng/g w.w.) of PFSAs and PFCAs

Species	Black guillemot	Common guillemot	Common guillemot	Black guillemot	Northern fulmar	Northern fulmar	Northern fulmar	Northern fulmar	Northern fulmar	Common guillemot	Common guillemot
Country	Green land	Iceland	Iceland	Faroe Islands	Faroe Islands	Faroe Islands	Faroe Islands	Faroe Islands	Faroe Islands	Sweden	Sweden
Location	Scoresbysund	Grimse	Bjarnarey	Koltur	Skuvoy	Skuvoy	Skuvoy	Skuvoy	Skuvoy	Stora Karlsö	Stora Karlsö
PFPrA	<21	<25	<25	<25	<25	<25	<25	<25	<25	<25	<25
PFBA	0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.26	<0.2	<0.2	<0.2	<0.2
PFPeA	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
PFHxA	<0.32	< 0.32	< 0.32	< 0.32	0.54	< 0.32	< 0.32	0.35	< 0.32	0.38	< 0.32
PFHpA	0.19	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
L-PFOA	0.56	< 0.24	< 0.24	< 0.24	0.31	< 0.24	< 0.24	0.30	< 0.24	0.40	0.54
Br-PFOA	<0.21	<0.21	<0.21	<0.21	<0.21	<0.21	<0.21	<0.21	<0.21	<0.21	<0.21
PFNA	1.60	1.55	1.08	2.01	2.23	1.26	1.78	2.25	1.82	5.61	7.13
PFDA	1.32	2.83	2.98	1.91	2.82	2.51	4.47	3.39	2.52	10.1	11.4
PFUnDA	5.01	18.9	27.7	7.19	8.75	9.07	14.9	10.4	8.60	27.9	28.9
PFDoDA	0.81	4.97	7.35	1.74	2.32	2.45	3.77	2.82	2.28	8.12	8.44
PFTrDA	1.89	5.62	17.6	3.79	8.11	7.38	12.7	8.57	9.08	13.9	15.8
PFTDA	n.q	<0.04	4.13	0.91	2.86	2.10	5.13	3.46	3.32	2.05	<0.04
PFHxDA	n.q	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
PFOcDA	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
PFEtS	<0.2	n.q.	n.q.	<0.2	<0.2	<0.2	<0.2	n.q.	n.q.	n.q.	n.q.
PFPrS	<0.04	n.q.	n.q.	<0.04	<0.04	<0.04	<0.04	n.q.	n.q.	n.q.	n.q.
PFBS	n.q	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
PFPeS	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.09	0.05
L-PFHxS	0.33	< 0.20	< 0.20	0.31	0.21	0.24	< 0.20	0.29	0.23	1.58	1.65
Br-PFHxS	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
PFHpS	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	5.20	6.80
L-PFOS	51.9	9.90	38.7	42.8	29.3	31.9	35.9	49.4	39.8	476	528
Br-PFOS	0.55	1.12	0.43	2.08	< 0.09	< 0.09	< 0.09	< 0.09	< 0.09	75.7	98.3
PFNS	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
PFDS	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
PFDoDS	n.q.	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04

Table A5-2: Bird egg concentrations (ng/g w.w.) of PFCA precursors

Species	Black guillemot	Common guillemot	Common guillemot	Black guillemot	Northern fulmar	Northern fulmar	Northern fulmar	Northern fulmar	Northern fulmar	Common guillemot	Common guillemot
Country	Greenland	Iceland	Iceland	Faroe Islands	Faroe Islands	Faroe Islands	Faroe Islands	Faroe Islands	Faroe Islands	Sweden	Sweden
Location	Scoresbysund	Grimse	Bjarnarey	Koltur	Skuvoy	Skuvoy	Skuvoy	Skuvoy	Skuvoy	Stora Karlsö	Stora Karlsö
4:2 FTSA	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
6:2 FTSA	n.q.	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.15	<0.04	<0.04	<0.04
8:2 FTSA	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
5:3 FTCA	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
6:2 FTUCA	<0.04	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
7:3 FTCA	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
8:2 FTUCA	n.q.	n.q	n.q	<0.04	<0.04	<0.04	<0.04	n.q	n.q	n.q	n.q
10:2 FTUCA	n.q.	n.q	n.q	<0.04	<0.04	<0.04	<0.04	n.q	<0.04	n.q	n.q
SAmPAP	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
diSAmPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
6:2 monoPAP	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
8:2 monoPAP	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
10:2 monoPAP	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
4:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
4:2/6:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
2:2/8:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
6:2 diPAP	<0.04	0.05	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
4:2/8:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
2:2/10:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
8:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
6:2/10:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
4:2/12:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
6:2/8:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
4:2/10:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
8:2/10:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04

Species	Black guillemot	Common guillemot	Common guillemot	Black guillemot	Northern fulmar	Northern fulmar	Northern fulmar	Northern fulmar	Northern fulmar	Common guillemot	Common guillemot
Country	Greenland	Iceland	Iceland	Faroe Islands	Faroe Islands	Faroe Islands	Faroe Islands	Faroe Islands	Faroe Islands	Sweden	Sweden
Location	Scoresbysund	Grimse	Bjarnarey	Koltur	Skuvoy	Skuvoy	Skuvoy	Skuvoy	Skuvoy	Stora Karlsö	Stora Karlsö
6:2/12:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
6:2/12:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
10:2 diPAP	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
8:2/12:2 diPAP	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
6:2/14:2 diPAP	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
10:2/12:2 diPAP	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
8:2/14:2 diPAP	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
12:2 diPAP	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
10:2/14:2 diPAP	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
8:2/16:2 diPAP	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2

Table A5-3: Bird egg concentrations (ng/g w.w.) of PFSA precursors

Species	Black guillemot	Common guillemot	Common guillemot	Black guillemot	Northern fulmar	Northern fulmar	Northern fulmar	Northern fulmar	Northern fulmar	Common guillemot	Common guillemot
Country	Greenland	Iceland	Iceland	Faroe Islands	Faroe Islands	Faroe Islands	Faroe Islands	Faroe Islands	Faroe Islands	Sweden	Sweden
Location	Scoresbysund	Grimse	Bjarnarey	Koltur	Skuvoy	Skuvoy	Skuvoy	Skuvoy	Skuvoy	Stora Karlsö	Stora Karlsö
FOSAA	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
MeFOSAA	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
EtFOSAA	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04

Table A5-4): Bird egg concentrations (ng/g w.w.) of PFPiA/PFPA

Species	Black guillemot	Common guillemot	Common guillemot	Black guillemot	Northern fulmar	Northern fulmar	Northern fulmar	Northern fulmar	Northern fulmar	Common guillemot	Common guillemot
Country	Greenland	Iceland	Iceland	Faroe Islands	Faroe Islands	Faroe Islands	Faroe Islands	Faroe Islands	Faroe Islands	Sweden	Sweden
Location	Scoresbysund	Grimse	Bjarnarey	Koltur	Skuvoy	Skuvoy	Skuvoy	Skuvoy	Skuvoy	Stora Karlsö	Stora Karlsö
PFHxPA	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
PFOPA	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
PFDPA	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
6:6 PFPiA	<0.04	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4
6:8 PFPiA	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
8:8 PFPiA	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4

Table A5-5: Bird egg concentrations (ng/g w.w) of novel PFASs

Species	Black guillemot	Common guillemot	Common guillemot	Black guillemot	Northern fulmar	Northern fulmar	Northern fulmar	Northern fulmar	Northern fulmar	Common guillemot	Common guillemot
Country	Greenland	Iceland	Iceland	Faroe Islands	Faroe Islands	Faroe Islands	Faroe Islands	Faroe Islands	Faroe Islands	Sweden	Sweden
Location	Scoresbysund	Grimse	Bjarnarey	Koltur	Skuvoy	Skuvoy	Skuvoy	Skuvoy	Skuvoy	Stora Karlsö	Stora Karlsö
PFECHS	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
ADONA	<0.50	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
HFPO-DA	<0.05	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4
6:2 Cl-PFESA	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
8:2 Cl-PFESA	n.q.	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04

Table A5-6: Marine fish concentrations (ng/g w.w) of PFCAs and PFSAs

Species	Atlantic cod	European flounder	Greenland cod	Atlantic pollock	Atlantic herring	Atlantic herring
Country	**Denmark**	**Denmark**	**Greenland**	**Norway**	**Sweden**	**Sweden**
Location	**Agersø Sund**	**Agersø Sund**	**Kobbefjord**	**Oslofjord**	**Bothnian Sea**	**Bothnian Sea**
PFPrA	n.q.	n.q.	<3.38	n.q.	<21	<21
PFBA	<0.2	<0.2	0.24	<0.2	<0.04	<0.04
PFPeA	<0.04	<0.04	<0.2	<0.04	<0.04	<0.04
PFHxA	<1.7	<1.7	n.q.	< 0.08	<0.04	<0.04
PFHpA	<0.04	<0.04	n.q.	<0.04	<0.04	<0.04
L-PFOA	0.27	0.33	n.q.	<0.21	0.64	1.17
Br-PFOA	<0.20	<0.20	n.q.	<0.20	<0.20	<0.20
PFNA	0.61	1.37	n.q.	<0.04	2.78	3.39
PFDA	0.68	0.84	n.q.	0.79	0.71	0.65
PFUnDA	1.05	0.86	n.q.	1.37	0.69	0.90
PFDoDA	<0.04	<0.04	n.q.	n.q	0.16	0.08
PFTrDA	2.25	1.01	n.q.	2.61	<0.04	<0.04
PFTDA	0.69	<0.1	n.q.	<0.04	n.q	n.q
PFHxDA	<0.7	<0.7	n.q.	<0.37	n.q	n.q
PFOcDA	<0.7	<0.7	n.q.	<0.04	<0.04	<0.04
PFEtS	<0.2	<0.2	n.q.	n.q.	<0.2	<0.2
PFPrS	<0.04	<0.04	n.q.	n.q.	<0.04	<0.04
PFBS	<0.04	<0.04	n.q.	<0.04	<0.04	<0.04
PFPeS	<0.04	<0.04	n.q.	<0.04	<0.04	<0.04
L-PFHxS	<0.2	0.34	n.q.	<0.19	0.32	0.39
Br-PFHxS	<0.1	<0.1	n.q.	<0.1	<0.1	<0.1
PFHpS	<0.04	<0.04	n.q.	<0.04	<0.04	<0.04
L-PFOS	4.93	8.22	n.q.	2.04	9.77	10.9
Br-PFOS	<0.09	1.17	n.q.	0.59	<0.09	<0.09
PFNS	<0.04	<0.04	n.q.	<0.04	<0.04	<0.04
PFDS	<0.04	<0.04	n.q.	<0.04	<0.04	<0.04
PFDoDS	<0.04	<0.04	n.q.	<0.04	<0.04	<0.04

Table A5-7: Marine fish concentrations (ng/g w.w) of PFCA precursors

Species	Atlantic cod	European flounder	Greenland cod	Atlantic pollock	Atlantic herring	Atlantic herring
Country	Denmark	Denmark	Greenland	Norway	Sweden	Sweden
Location	Agersø Sund	Agersø Sund	Kobbefjord	Oslofjord	Bothnian Sea	Bothnian Sea
4:2 FTSA	<0.04	<0.04	n.q.	<0.04	0.26	0.31
6:2 FTSA	<0.04	0.13	n.q.	<0.04	0.16	0.05
8:2 FTSA	<0.04	<0.04	n.q.	<0.04	<0.04	<0.04
5:3 FTCA	n.q.	n.q.	n.q.	n.q.	<0.04	<0.04
6:2 FTUCA	n.q.	n.q.	n.q.	<0.04	<0.04	<0.04
7:3 FTCA	<0.04	<0.04	n.q.	0.67	<0.04	0.32
8:2 FTUCA	<0.04	<0.04	n.q.	<0.04	<0.04	<0.04
10:2 FTUCA	n.q.	n.q.	n.q.	<0.04	<0.04	<0.04
SAmPAP	n.q.	n.q.	n.q.	<4	n.q.	n.q.
diSAmPAP	<0.04	<0.04	n.q.	<0.04	<0.04	<0.04
6:2 monoPAP	n.q.	n.q.	n.q.	<0.1	n.q.	n.q.
8:2 monoPAP	n.q.	n.q.	n.q.	<0.1	<0.1	<0.1
10:2 monoPAP	n.q.	n.q.	n.q.	<2	<2	<2
4:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
4:2/6:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
2:2/8:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
6:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
4:2/8:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
2:2/10:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
8:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
6:2/10:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
4:2/12:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
6:2/8:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
4:2/10:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
8:2/10:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
6:2/12:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
10:2 diPAP	<0.2	<0.2	n.q	<0.2	<0.2	<0.2
8:2/12:2 diPAP	<0.2	<0.2	n.q	<0.2	<0.2	<0.2
6:2/14:2 diPAP	<0.2	<0.2	n.q	<0.2	<0.2	<0.2
10:2/12:2 diPAP	<0.2	<0.2	n.q	<0.2	<0.2	<0.2
8:2/14:2 diPAP	<0.2	<0.2	n.q	<0.2	<0.2	<0.2
12:2 diPAP	<0.2	<0.2	n.q	<0.2	<0.2	<0.2
10:2/14:2 diPAP	<0.2	<0.2	n.q	<0.2	<0.2	<0.2
8:2/16:2 diPAP	<0.2	<0.2	n.q	<0.2	<0.2	<0.2

Table A5-8: Marine fish concentrations (ng/g w.w) of PFSA precursors

Species	Atlantic cod	European flounder	Greenland cod	Atlantic pollock	Atlantic herring	Atlantic herring
Country	**Denmark**	**Denmark**	**Greenland**	**Norway**	**Sweden**	**Sweden**
Location	**Agersø Sund**	**Agersø Sund**	**Kobbefjord**	**Oslofjord**	**Bothnian Sea**	**Bothnian Sea**
FOSAA	<4	<4	<2	<4	<4	<4
MeFOSAA	<0.04	<0.04	<0.02	<0.04	<0.04	<0.04
EtFOSAA	<0.04	<0.04	<0.02	0.05	<0.04	<0.04

Table A5-9: Marine fish concentrations (ng/g w.w) of PFPiA/PFPA

Species	Atlantic cod	European flounder	Greenland cod	Atlantic pollock	Atlantic herring	Atlantic herring
Country	**Denmark**	**Denmark**	**Greenland**	**Norway**	**Sweden**	**Sweden**
Location	**Agersø Sund**	**Agersø Sund**	**Kobbefjord**	**Oslofjord**	**Bothnian Sea**	**Bothnian Sea**
PFHxPA	<4	<4	n.q.	<4	<4	<4
PFOPA	<4	<4	n.q.	<4	<4	<4
PFDPA	<4	<4	n.q.	<4	<4	<4
6:6 PFPiA	<0.4	<0.4	n.q.	<0.4	<0.4	<0.4
6:8 PFPiA	<4	<4	n.q.	<4	<4	<4
8:8 PFPiA	<4	<4	n.q.	<4	<4	<4

Table A5-10: Marine fish concentrations (ng/g w.w) of novel PFASs

Species	Atlantic cod	European flounder	Greenland cod	Atlantic pollock	Atlantic herring	Atlantic her-ring
Country	**Denmark**	**Denmark**	**Greenland**	**Norway**	**Sweden**	**Sweden**
Location	**Agersø Sund**	**Agersø Sund**	**Kobbefjord**	**Oslofjord**	**Bothnian Sea**	**Bothnian Sea**
PFECHS	0.13	0.35	n.q.	<0.04	0.37	0.39
ADONA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
HFPO-DA	<0.4	<0. 4	<0.2	<0.4	<0.4	<0.4
6:2 Cl-PFESA	<0.04	<0.04	n.q	<0.04	<0.04	<0.04
8:2 Cl-PFESA	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.

Table A5-11: Fresh fish concentrations (ng/g w.w) of PFCAs and PFSAs

Species	European perch	European perch	Brown trout	Arctic char	European perch	European perch	European perch	Arctic char	Brown trout	Brown trout	European perch	European perch	European perch
Country	Denmark	Denmark	Faroe Islands	Faroe Islands	Finland	Finland	Finland	Greenland	Iceland	Iceland	Norway	Sweden	Sweden
Location	Lake Ørn	Lake Silkeborg	Leitisvatn	Myrarnar	Helsinki archipelago	Lohjanjärvi	Downstream Tampere	Isortoq	Elliðavatn	Stóra-Fossvatn	Mjøsa	Övre Skärsjön	Övre Skärsjön
PFPrA	n.q.	n.q.	n.q	n.q.	n.q.	n.q.	n.q.	<3.38	n.q.	n.q.	n.q.	<21	<21
PFBA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	n.q	<0.2	<0.04	<0.04
PFPeA	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.2	<0.04	n.q	<0.04	<0.04	<0.04
PFHxA	<1.7	<1.7	<1.7	<1	<1.7	<1.7	<1.7	<0.22	<1.7	< 0.09	< 0.08	n.q.	n.q.
PFHpA	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.85	<0.04	<0.04	<0.04	0.05	<0.04
L-PFOA	<0.25	<0.25	<0.25	0.19	<0.25	<0.25	<0.25	0.23	<0.25	<0.21	<0.21	0.10	0.11
Br-PFOA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
PFNA	0.31	0.17	0.83	<0.04	4.80	3.70	0.49	0.51	0.13	<0.04	1.59	0.10	0.06
PFDA	2.27	1.70	0.77	<0.04	3.09	68.2	3.06	n.q.	0.18	<0.11	5.73	0.37	0.38
PFUnDA	2.80	1.98	3.16	0.67	10.90	35.3	5.24	n.q.	0.41	<0.17	13.9	1.11	0.95
PFDoDA	2.45	2.20	1.03	n.q	0.91	23.1	3.56	n.q.	<0.04	<0.04	8.03	0.72	0.47
PFTrDA	1.58	1.08	2.78	<0.04	5.59	50.1	6.07	n.q.	0.13	<0.04	21.2	1.62	0.91
PFTDA	1.08	1.00	0.94	n.q	0.56	3.78	2.37	n.q.	<0.1	<0.04	n.q	0.47	n.q
PFHxDA	<0.7	<0.7	<0.7	n.q	<0.7	n.q.	<0.7	n.q.	<0.37	<0.37	<0.37	n.q	0.19
PFOcDA	<0.7	<0.7	<0.7	<0.04	<0.7	n.q.	<0.7	n.q.	<0.7	<0.04	<0.04	<0.04	<0.04
PFEtS	<0.2	<0.2	n.q	<0.2	<0.2	<0.2	<0.2	n.q.	<0.2	<0.2	n.q.	<0.2	<0.2
PFPrS	<0.04	<0.04	n.q	<0.04	<0.04	<0.04	<0.04	n.q.	<0.04	<0.04	n.q.	<0.04	<0.04
PFBS	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.12	<0.04	<0.04	<0.04	<0.04	<0.04
PFPeS	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.02	<0.04	<0.04	<0.04	<0.04	<0.04
L-PFHxS	<0.2	<0.2	<0.2	<0.04	0.28	<0.2	<0.2	<0.09	<0.19	<0.19	<0.19	0.02	0.05
Br-PFHxS	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
PFHpS	<0.04	<0.04	<0.04	<0.04	0.28	<0.04	<0.04	<0.2	<0.04	<0.04	<0.04	<0.04	<0.04
L-PFOS	18.1	11.3	25.0	33.8	34.0	108	61.0	n.q.	10.6	0.15	60.9	0.78	1.35
Br-PFOS	0.46	0.13	0.12	<0.09	2.64	4.13	1.17	n.q.	< 0.09	< 0.09	0.96	<0.09	0.31
PFNS	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	n.q.	<0.04	<0.04	<0.04	<0.04	<0.04

Species	European perch	European perch	Brown trout	Arctic char	European perch	European perch	European perch	Arctic char	Brown trout	Brown trout	European perch	European perch	European perch
Country	**Denmark**	**Denmark**	**Faroe Islands**	**Faroe Islands**	**Finland**	**Finland**	**Finland**	**Greenland**	**Iceland**	**Iceland**	**Norway**	**Sweden**	**Sweden**
Location	**Lake Ørn**	**Lake Silkeborg**	**Leitisvatn**	**Myrarnar**	**Helsinki archipelago**	**Lohjanjärvi**	**Downstream Tampere**	**Isortoq**	**Elliðavatn**	**Stóra-Fossvatn**	**Mjøsa**	**Övre Skärsjön**	**Övre Skärsjön**
PFDS	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	n.q.	<0.04	<0.04	<0.04	<0.04	<0.04
PFDoDS	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	n.q.	<0.04	<0.04	<0.04	<0.04	<0.04

Table A5-12: Fresh fish concentrations (ng/g w.w) of PFCA precursors

Species	European perch	European perch	Brown trout	Arctic char	European perch	European perch	European perch	Arctic char	Brown trout	Brown trout	European perch	European perch	European perch
Country	**Denmark**	**Denmark**	**Faroe Islands**	**Faroe Islands**	**Finland**	**Finland**	**Finland**	**Greenland**	**Iceland**	**Iceland**	**Norway**	**Sweden**	**Sweden**
Location	**Lake Ørn**	**Lake Silkeborg**	**Leitisvatn**	**Myrarnar**	**Helsinki**	**Lohjanjärvi**	**Tampere**	**Isortoq**	**Elliðavatn**	**Stóra-Fossvatn**	**Mjøsa**	**Övre Skärsjön**	**Övre Skärsjön**
4:2 FTSA	<0.04	<0.04	<0.04	0.93	<0.04	<0.04	<0.04	<0.02	<0.04	<0.04	<0.04	<0.04	0.29
6:2 FTSA	0.11	<0.04	<0.1	<0.04	<0.04	<0.04	<0.04	<0.1	<0.04	<0.04	<0.04	0.15	0.12
8:2 FTSA	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	n.q.	<0.04	<0.04	0.06	<0.04	<0.04
5:3 FTCA	n.q.	n.q.	n.q.	<0.04	n.q.	n.q.	n.q.	n.q.	n.q.	<0.04	<0.04	<0.04	<0.04
6:2 FTUCA	n.q.	n.q.	n.q.	<0.04	n.q.	n.q.	n.q.	n.q.	n.q.	<0.04	<0.04	0.46	<0.04
7:3 FTCA	<0.04	<0.04	<0.04	0.57	<0.04	5.18	1.96	n.q.	<0.04	<0.04	<0.04	0.24	<0.04
8:2 FTUCA	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	n.q.	<0.04	<0.04	<0.04	<0.04	<0.04
10:2 FTUCA	n.q.	n.q.	n.q.	<0.04	n.q.	n.q.	n.q.	n.q.	n.q.	<0.04	<0.04	<0.04	<0.04
SAmPAP	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	<4	<4	<4	n.q.	n.q.
diSAmPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	n.q.	<0.04	<0.04	<0.04	<0.04	<0.04

Species	European perch	European perch	Brown trout	Arctic char	European perch	European perch	European perch	Arctic char	Brown trout	Brown trout	European perch	European perch	European perch
Country	**Denmark**	**Denmark**	**Faroe Islands**	**Faroe Islands**	**Finland**	**Finland**	**Finland**	**Greenland**	**Iceland**	**Iceland**	**Norway**	**Sweden**	**Sweden**
Location	**Lake Ørn**	**Lake Silkeborg**	**Leitisvatn**	**Myrarnar**	**Helsinki**	**Lohjanjärvi**	**Tampere**	**Isortoq**	**Elliðavatn**	**Stóra-Fossvatn**	**Mjøsa**	**Övre Skärsjön**	**Övre Skärsjön**
6:2 monoPAP	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	<0.1	<0.1	<0.1	<0.1
8:2 monoPAP	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	<0.1	<0.1	<0.1	<0.1
10:2 monoPAP	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	<2	<2	<2	<2
4:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
4:2/6:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
2:2/8:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
6:2 diPAP	<0.04	<0.04	<0.04	0.07	0.90	<0.04	<0.04	<0.04	<0.04	0.05	<0.04	<0.04	<0.04
4:2/8:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
2:2/10:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
8:2 diPAP	<0.04	<0.04	<0.04	<0.04	0.95	<0.04	<0.04	<0.04	<0.04	0.05	<0.04	<0.04	<0.04
6:2/10:2 diPAP	<0.04	<0.04	<0.04	<0.04	1.42	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
4:2/12:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
6:2/8:2 diPAP	<0.04	<0.04	<0.04	<0.04	1.16	<0.04	<0.04	<0.04	<0.04	0.05	<0.04	<0.04	<0.04
4:2/10:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
8:2/10:2 diPAP	<0.04	<0.04	<0.04	<0.04	0.71	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
6:2/12:2 diPAP	<0.04	<0.04	<0.04	<0.04	0.45	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
10:2 diPAP	<0.2	<0.2	<0.2	<0.2	3.02	<0.2	<0.2	n.q	<0.2	<0.2	<0.2	<0.2	<0.2
8:2/12:2 diPAP	<0.2	<0.2	<0.2	<0.2	2.56	<0.2	<0.2	n.q	<0.2	<0.2	<0.2	<0.2	<0.2
6:2/14:2 diPAP	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	n.q	<0.2	<0.2	<0.2	<0.2	<0.2
10:2/12:2 diPAP	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	n.q	<0.2	<0.2	<0.2	<0.2	<0.2
8:2/14:2 diPAP	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	n.q	<0.2	<0.2	<0.2	<0.2	<0.2
12:2 diPAP	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	n.q	<0.2	<0.2	<0.2	<0.2	<0.2
10:2/14:2 diPAP	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	n.q	<0.2	<0.2	<0.2	<0.2	<0.2
8:2/16:2 diPAP	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	n.q	<0.2	<0.2	<0.2	<0.2	<0.2

Table A5-13: Fresh fish concentrations (ng/g w.w) of PFSA precursors

Species	European perch	European perch	Brown trout	Arctic char	European perch	European perch	European perch	Arctic char	Brown trout	Brown trout	European perch	European perch	European perch
Country	Denmark	Denmark	Faroe Islands	Faroe Islands	Finland	Finland	Finland	Greenland	Iceland	Iceland	Norway	Sweden	Sweden
Location	Lake Ørn	Lake Silkeborg	Leitisvatn	Myrarnar	Helsinki	Lohjanjärvi	Tampere	Isortoq	Elliðavatn	Stóra-Fossvatn	Mjøsa	Övre Skärsjön	Övre Skärsjön
FOSAA	<4	<4	<4	<4	<4	<4	<4	<2	<4	<4	<4	<4	<4
MeFOSAA	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	1.18	<0.02	<0.04	<0.04	<0.04	<0.04	<0.04
EtFOSAA	<0.04	0.18	<0.04	<0.04	<0.04	0.59	0.36	<0.02	<0.04	<0.04	0.06	<0.04	<0.04

Table A5-14: Fresh fish concentrations (ng/g w.w) of PFPiA/PFPA

Species	European perch	European perch	Brown trout	Arctic char	European perch	European perch	European perch	Arctic char	Brown trout	Brown trout	European perch	European perch	European perch
Country	Denmark	Denmark	Faroe Islands	Faroe Islands	Finland	Finland	Finland	Greenland	Iceland	Iceland	Norway	Sweden	Sweden
Location	Lake Ørn	Lake Silkeborg	Leitisvatn	Myrarnar	Helsinki	Lohjanjärvi	Tampere	Isortoq	Elliðavatn	Stóra-Fossvatn	Mjøsa	Övre Skärsjön	Övre Skärsjön
PFHxPA	<4	<4	<4	<4	<4	<4	<4	<0.04	<4	<4	<4	<4	<4
PFOPA	<4	<4	<4	<4	<4	<4	<4	<0.04	<4	<4	<4	<4	<4
PFDPA	<4	<4	<4	<4	<4	<4	<4	<0.04	<4	<4	<4	<4	<4
6:6 PFPiA	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.2	<0.4	<0.4	<0.4	<0.4	<0.4
6:8 PFPiA	<4	<4	<4	<4	<4	<4	<4	<0.2	<4	<4	<4	<4	<4
8:8 PFPiA	<4	<4	<4	<4	<4	<4	<4	<0.2	<4	<4	<4	<4	<4

Table A5-15: Fresh fish concentrations (ng/g w.w) of novel PFAS

Species	European perch	European perch	Brown trout	Arctic char	European perch	European perch	European perch	Arctic char	Brown trout	Brown trout	European perch	European perch	European perch
Country	Denmark	Denmark	Faroe Islands	Faroe Islands	Finland	Finland	Finland	Greenland	Iceland	Iceland	Norway	Sweden	Sweden
Location	Lake Ørn	Lake Silkeborg	Leitisvatn	Myrarnar	Helsinki	Lohjanjärvi	Tampere	Isortoq	Elliðavatn	Stóra-Fossvatn	Mjøsa	Övre Skärsjön	Övre Skärsjön
PFECHS	<0.04	<0.04	<0.04	<0.04	0.44	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
ADONA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
HFPO-DA	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.02	<0.4	<0.4	<0.4	<0.4	<0.4
6:2 Cl-PFESA	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
8:2 Cl-PFESA	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.

Table A5-16: Marine mammal concentrations (ng/g w.w) of PFCAs and PFSAs. * = semi-quantified (low recovery of internal standard)

Species	Harbour porpoise	Grey seal	Pilot whale	Pilot whale	Pilot whale	Pilot whale	Pilot whale	Humpback whale	Ringed seal	White-beaked dolphin	Polar bear cub	Polar bear mother
Country	Denmark	Denmark	Faroe Islands	Faroe Islands	Faroe Islands	Faroe Islands	Faroe Islands	Greenland	Green-land	Greenland	Greenland	Greenland
Location			Torshavn	Torshavn	Hvalvik	Hvalvik	Tjornuvik					Nuuk area
PFPrA	<1.5	<1.5	<1.5	<1.5	<1.5	<1.5	<1.5	<3.38	<3.38	<3.38	<3.38	<3.38
PFBA	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.2	<0.2	<0.2	<0.2	<0.2
PFPeA	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.2	<0.2	<0.2	<0.2	<0.2
PFHxA	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	4.10	<0.22	<0.22	<0.22	<0.22
PFHpA	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	2.30	0.59	0.95	4.00	2.85
L-PFOA	0.30	0.49	0.36	<0.04	<0.04	<0.04	<0.04	0.99	0.93	1.61	59.4	54.5
Br-PFOA	<0.24	<0.24	<0.24	<0.24	<0.24	<0.24	<0.24	<0.24	<0.24	<0.24	<0.24	<0.24

Species	Harbour porpoise	Grey seal	Pilot whale	Pilot whale	Pilot whale	Pilot whale	Pilot whale	Humpback whale	Ringed seal	White-beaked dolphin	Polar bear cub	Polar bear mother
Country	Denmark	Denmark	Faroe Islands	Faroe Islands	Faroe Islands	Faroe Islands	Faroe Islands	Greenland	Greenland	Greenland	Greenland	Greenland
Location			Torshavn	Torshavn	Hvalvik	Hvalvik	Tjornuvik					Nuuk area
PFNA	2.94	4.30	8.68	3.35	4.07	4.12	6.48	4.30	6.38	14.9	509*	425*
PFDA	4.69	2.11	8.88	6.11	4.91	6.32	8.48	16.0*	5.0*	14.0*	194*	153*
PFUnDA	4.40	1.69	18.4	10.9	8.44	13.7	14.9	28.9*	13.5*	42.5*	10.8*	n.q.
PFDoDA	0.99	0.34	2.38	1.30	0.95	2.27	2.02	n.q.	n.q.	n.q.	n.q.	n.q.
PFTrDA	0.52	0.96	6.23	2.11	3.73	5.05	10.4	n.q.	n.q.	n.q.	n.q.	n.q.
PFTDA	n.q.	<0.04	n.q.	<0.04	0.50	1.35	1.40	n.q.	n.q.	n.q.	n.q.	n.q.
PFHxDA	<0.04	<0.04	n.q	<0.04	<0.04	<0.37	<0.37	n.q.	n.q.	n.q.	n.q.	n.q.
PFOcDA	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	n.q.	n.q.	n.q.	n.q.	n.q.
PFEtS	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	n.q	n.q.	n.q.	n.q.	n.q.
PFPrS	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	n.q.	n.g.	n.q.	n.q.	n.q.
PFBS	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.12	<0.12	<0.12	<0.12	<0.12
PFPeS	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.02	<0.02	<0.02	<0.02	<0.02
L-PFHxS	2.29	0.21	<0.04	<0.04	0.25	<0.04	<0.04	0.46	0.15	1.15	20.4	17.3
Br-PFHxS	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
PFHpS	0.81	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.12*	<0.2	<0.2	114*	86.7*
L-PFOS	97.2	22.6	23.6	15.4	13.1	18.7	17.7	38.7*	27.5	61.4*	819*	567*
Br-PFOS	6.17	2.16	0.66	0.63	0.48	0.67	0.61	1.7*	4.03	3.2*	119*	120*
PFNS	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	n.q.	<0.04	n.q.	n.q.	n.q.
PFDS	0.12	0.13	<0.04	0.14	0.17	0.12	0.25	n.q.	<0.04	n.q.	n.q.	n.q.
PFDoDS	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	n.q.	n.q.	<0.02	n.q.	n.q.

Table A5-17: Marine mammal concentrations (ng/g w.w) of PFCA precursors

Species	Harbour porpoise	Grey seal	Pilot whale	Pilot whale	Pilot whale	Pilot whale	Pilot whale	Humpback whale	Ringed seal	White-beaked dolphin	Polar bear cub	Polar bear mother
Country	Denmark	Denmark	Faroe Islands	Faroe Islands	Faroe Islands	Faroe Islands	Faroe Islands	Greenland	Greenland	Greenland	Greenland	Greenland
Location			Torshavn	Torshavn	Hvalvik	Hvalvik	Tjornuvik					Nuuk area
4:2 FTSA	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.02	<0.02	<0.02	<0.02	<0.02
6:2 FTSA	<0.04	<0.04	n.q.	<0.04	n.q.	<0.04	<0.04	<0.1	1.02	<0.1	<0.1	<0.1
8:2 FTSA	<0.04	<0.04	<0.04	<0.04	n.q.	<0.04	0.06	n.q.	0.05	<0.01	<0.01	0.12
5:3 FTCA	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	n.q.	n.q.
6:2 FTUCA	<0.04	n.q.	<0.04	<0.04	n.q.	<0.04	<0.04	<0.04	0.09	0.09	n.q.	n.q.
7:3 FTCA	2.13	25.0*	<0.04	0.76	1.56	0.68	0.14	<0.04	<0.04	<0.04	n.q.	n.q.
8:2 FTUCA	<0.04	n.q.	<0.04	<0.04	n.q.	<0.04	<0.04	<0.04	<0.04	<0.04	n.q.	n.q.
10:2 FTUCA	<0.04	<0.04	n.q.	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	n.q.	n.q.
SAmPAP	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
diSAmPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	n.q.	n.q.	n.q.	n.q.	n.q.
6:2 monoPAP	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
8:2 monoPAP	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
10:2 monoPAP	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
4:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
4:2/6:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
2:2/8:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
6:2 diPAP	<0.04	<0.04	0.21	0.22	<0.04	0.74	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
4:2/8:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
2:2/10:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
8:2 diPAP	<0.04	<0.04	0.12	<0.04	<0.04	0.58	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
6:2/10:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	0.52	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
4:2/12:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
6:2/8:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	1.53	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
4:2/10:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
8:2/10:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	0.87	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04

Species	Harbour porpoise	Grey seal	Pilot whale	Pilot whale	Pilot whale	Pilot whale	Pilot whale	Humpback whale	Ringed seal	White-beaked dolphin	Polar bear cub	Polar bear mother
Country	Denmark	Denmark	Faroe Islands	Faroe Islands	Faroe Islands	Faroe Islands	Faroe Islands	Greenland	Greenland	Greenland	Greenland	Greenland
Location			Torshavn	Torshavn	Hvalvik	Hvalvik	Tjornuvik					Nuuk area
6:2/12:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	0.40	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
10:2 diPAP	<0.2	<0.2	<0.2	<0.2	<0.2	4.24	<0.2	n.q	n.q	n.q	n.q	n.q
8:2/12:2 diPAP	<0.2	<0.2	<0.2	<0.2	<0.2	0.75	<0.2	n.q	n.q	n.q	n.q	n.q
6:2/14:2 diPAP	<0.2	<0.2	<0.2	<0.2	<0.2	1.65	<0.2	n.q	n.q	n.q	n.q	n.q
10:2/12:2 diPAP	<0.2	<0.2	<0.2	<0.2	<0.2	1.60	<0.2	n.q	n.q	n.q	n.q	n.q
8:2/14:2 diPAP	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	n.q	n.q	n.q	n.q	n.q
12:2 diPAP	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	n.q	n.q	n.q	n.q	n.q
10:2/14:2 diPAP	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	n.q	n.q	n.q	n.q	n.q
8:2/16:2 diPAP	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	n.q	n.q	n.q	n.q	n.q

Table A5-18: Marine mammal concentrations (ng/g w.w) of PFSA precursors

Species	Harbour porpoise	Grey seal	Pilot whale	Pilot whale	Pilot whale	Pilot whale	Pilot whale	Humpback whale	Ringed seal	White-beaked dolphin	Polar bear cub	Polar bear mother
Country	Denmark	Denmark	Faroe Islands	Faroe Islands	Faroe Islands	Faroe Islands	Faroe Islands	Greenland	Greenland	Greenland	Greenland	Greenland
Location			Torshavn	Torshavn	Hvalvik	Hvalvik	Tjornuvik					Nuuk area
FOSAA	<4	<4	<4	<4	<4	<4	<4	<2	<2	<2	<2	<2
MeFOSAA	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.02	<0.02	<0.02	<0.02	<0.02
EtFOSAA	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.02	<0.02	<0.02	<0.02	<0.02

Table A5-19: Marine mammal concentrations (ng/g w.w.) of PFPiA/PFPA

Species	Harbour porpoise	Grey seal	Pilot whale	Pilot whale	Pilot whale	Pilot whale	Pilot whale	Humpback whale	Ringed seal	White-beaked dolphin	Polar bear cub	Polar bear mother
Country	**Denmark**	**Denmark**	**Faroe Islands**	**Faroe Islands**	**Faroe Islands**	**Faroe Islands**	**Faroe Islands**	**Greenland**	**Greenland**	**Greenland**	**Greenland**	**Greenland**
Location			**Torshavn**	**Torshavn**	**Hvalvik**	**Hvalvik**	**Tjornuvik**					**Nuuk area**
PFHxPA	<4	<4	<4	<4	<4	<4	<4	<0.04	<0.04	<0.04	<0.04	<0.04
PFOPA	<4	<4	<4	<4	<4	<4	<4	<0.04	<0.04	<0.04	<0.04	<0.04
PFDPA	<4	<4	<4	<4	<4	<4	<4	<0.04	<0.04	<0.04	<0.04	<0.04
6:6 PFPiA	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.2	<0.2	<0.2	<0.2	<0.2
6:8 PFPiA	<4	<4	<4	<4	<4	<4	<4	<0.2	<0.2	<0.2	<0.2	<0.2
8:8 PFPiA	<4	<4	<4	<4	<4	<4	<4	<0.2	<0.2	<0.2	<0.2	<0.2

Table A5-20: Marine mammal concentrations (ng/g w.w.) of novel PFAS

Species	Harbour porpoise	Grey seal	Pilot whale	Pilot whale	Pilot whale	Pilot whale	Pilot whale	Humpback whale	Ringed seal	White-beaked dolphin	Polar bear cub	Polar bear mother
Country	**Denmark**	**Denmark**	**Faroe Islands**	**Faroe Islands**	**Faroe Islands**	**Faroe Islands**	**Faroe Islands**	**Greenland**	**Greenland**	**Greenland**	**Greenland**	**Greenland**
Location			**Torshavn**	**Torshavn**	**Hvalvik**	**Hvalvik**	**Tjornuvik**					**Nuuk area**
PFECHS	0.87	0.18	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.22	0.10
ADONA	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
HFPO-DA	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.2	<0.2	<0.2	<0.2	<0.2
6:2 Cl-PFESA	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	n.q.	<0.04	n.q.	n.q.	n.q.
8:2 Cl-PFESA	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.

Table A5-21: Terrestrial mammal concentrations (ng/g w.w.) of PFCAs and PFSAs

Species	Brown bear	Reindeer	Reindeer	Reindeer	Reindeer	Reindeer	Reindeer	Reindeer	Reindeer
Country	Finland	Finland	Finland	Iceland	Iceland	Green-land	Green-land	Sweden	Sweden
Location	Kuusamo. Sotkamo	Ylitornio	Ylitornio	Eastern region	Eastern region	Isortoq	Nuuk area	Girjas and Sirges	Girjas and Sirges
PFPrA	<21	<21	<21	n.q.	n.q.	<3.38	<3.38	<21	<21
PFBA	<0.04	<0.04	<0.04	<0.2	<0.2	<0.2	<0.2	<0.04	0.21
PFPeA	<0.04	<0.04	<0.04	<0.04	<0.04	<0.2	<0.2	<0.04	<0.04
PFHxA	<0.04	<0.16	0.31	<0.16	<0.16	<0.22	<0.22	0.80	1.43
PFHpA	<0.04	<0.04	<0.04	<0.04	<0.04	1.05	1.46	<0.04	0.04
L-PFOA	1.99	0.12	0.09	<0.21	<0.21	0.36	0.19	0.09	0.09
Br-PFOA	<0.24	<0.24	<0.24	<0.24	<0.24	<0.24	<0.24	<0.24	<0.24
PFNA	1.05	0.34	0.14	0.34	0.26	1.46	0.78	0.18	0.35
PFDA	0.68	0.23	0.14	0.19	0.17	0.92	0.57	0.16	0.18
PFUnDA	0.60	0.47	0.26	<0.17	<0.17	<0.04	<0.04	0.20	0.23
PFDoDA	0.13	0.05	<0.04	<0.04	<0.04	n.q.	n.q.	0.05	<0.04
PFTrDA	0.11	<0.04	<0.04	<0.04	<0.04	n.q.	n.q.	<0.04	<0.04
PFTDA	<0.04	n.q	n.q	<0.04	<0.04	n.q.	n.q.	<0.04	0.24
PFHxDA	<0.04	<0.37	<0.37	<0.37	<0.37	n.q.	n.q.	<0.37	<0.37
PFOcDA	<0.04	<0.04	<0.04	<0.04	<0.04	n.q.	n.q.	<0.04	<0.04
PFEtS	<0.1	<0.2	<0.2	n.q.	n.q.	n.q.	n.q.	<0.2	<0.2
PFPrS	<0.02	<0.04	<0.04	n.q.	n.q.	n.q.	n.q.	<0.04	<0.04
PFBS	<0.04	<0.04	<0.04	<0.04	<0.04	<0.12	<0.12	<0.04	<0.04
PFPeS	<0.04	<0.04	<0.04	<0.04	<0.04	<0.02	<0.02	<0.04	<0.04
L-PFHxS	0.14	0.06	0.09	<0.19	<0.19	<0.09	0.11	0.07	0.05
Br-PFHxS	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
PFHpS	<0.04	<0.04	<0.04	<0.04	<0.04	n.q.	n.q.	<0.04	<0.04
L-PFOS	13.2	<0.04	0.11	0.52	0.48	2.20	1.53	0.33	0.37
Br-PFOS	0.68	<0.09	<0.09	<0.09	<0.09	n.q.	n.q.	<0.09	<0.09
PFNS	<0.04	<0.04	<0.04	<0.04	<0.04	n.q.	n.q.	<0.04	<0.04
PFDS	<0.04	<0.04	<0.04	<0.04	<0.04	n.q.	n.q.	<0.04	<0.04
PFDoDS	<0.04	<0.04	<0.04	<0.04	<0.04	<0.02	n.q.	<0.04	<0.04

Table A5-22: Terrestrial mammal concentrations (ng/g w.w) of PFCA precursors

Species	Brown bear	Reindeer	Reindeer	Reindeer	Reindeer	Reindeer	Reindeer	Reindeer	Reindeer
Country	Finland	Finland	Finland	Iceland	Iceland	Green-land	Green-land	Sweden	Sweden
Location	Kuusamo. Sotkamo	Ylitornio	Ylitornio	Eastern region	Eastern region	Isortoq	Nuuk area	Girjas and Sirges	Girjas and Sirges
4:2 FTSA	<0.04	<0.04	<0.04	<0.04	<0.04	<0.02	n.q.	<0.04	<0.04
6:2 FTSA	0.36	0.10	0.06	0.15	<0.04	<0.1	n.q.	0.24	0.10
8:2 FTSA	0.02	<0.04	<0.04	<0.04	<0.04	n.q.	<0.01	<0.04	<0.04
5:3 FTCA	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
6:2 FTUCA	<0.04	<0.2	0.30	<0.04	<0.04	0.17	0.06	0.20	<0.2
7:3 FTCA	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
8:2 FTUCA	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
10:2 FTUCA	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
SAmPAP	n.q.	n.q.	n.q.	<4	<4	n.q.	n.q.	n.q.	n.q.
diSAmPAP	<0.02	<0.04	<0.04	<0.04	<0.04	n.q.	n.q.	<0.04	<0.04
6:2 monoPAP	<0.1	<0.1	<0.1	<0.1	<0.1	n.q.	n.q.	<0.1	<0.1
8:2 monoPAP	<0.1	<0.1	<0.1	<0.1	<0.1	n.q.	n.q.	<0.1	<0.1
10:2 monoPAP	<2	<2	<2	<2	<2	n.q.	n.q.	<2	<2
4:2 diPAP	<0.02	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
4:2/6:2 di-PAP	<0.02	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
2:2/8:2 di-PAP	<0.02	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
6:2 diPAP	<0.02	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.10
4:2/8:2 di-PAP	<0.02	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
2:2/10:2 di-PAP	<0.02	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
8:2 diPAP	<0.02	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.08
6:2/10:2 di-PAP	<0.02	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.14
4:2/12:2 di-PAP	<0.02	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
6:2/8:2 di-PAP	<0.02	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.17
4:2/10:2 di-PAP	<0.02	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
8:2/10:2 di-PAP	<0.02	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.14
6:2/12:2 di-PAP	<0.02	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
10:2 diPAP	<0.1	<0.2	<0.2	<0.2	<0.2	n.q	n.q	<0.2	0.34
8:2/12:2 di-PAP	<0.1	<0.2	<0.2	<0.2	<0.2	n.q	n.q	<0.2	<0.2
6:2/14:2 di-PAP	<0.1	<0.2	<0.2	<0.2	<0.2	n.q	n.q	<0.2	<0.2
10:2/12:2 di-PAP	<0.1	<0.2	<0.2	<0.2	<0.2	n.q	n.q	<0.2	<0.2
8:2/14:2 di-PAP	<0.1	<0.2	<0.2	<0.2	<0.2	n.q	n.q	<0.2	<0.2
12:2 diPAP	<0.1	<0.2	<0.2	<0.2	<0.2	n.q	n.q	<0.2	<0.2
10:2/14:2 di-PAP	<0.1	<0.2	<0.2	<0.2	<0.2	n.q	n.q	<0.2	<0.2
8:2/16:2 di-PAP	<0.1	<0.2	<0.2	<0.2	<0.2	n.q	n.q	<0.2	<0.2

Table A5-23: Terrestrial mammal concentrations (ng/g w.w) of PFSA precursors

Species	Brown bear	Reindeer	Reindeer	Reindeer	Reindeer	Reindeer	Reindeer	Reindeer	Reindeer
Country	Finland	Finland	Finland	Iceland	Iceland	Green-land	Green-land	Sweden	Sweden
Location	Kuusamo. Sotkamo	Ylitornio	Ylitornio	Eastern region	Eastern region	Isortoq	Nuuk area	Girjas and Sirges	Girjas and Sirges
FOSAA	<2	<4	<4	<4	<4	<2	<2	<4	<4
MeFOSAA	<0.02	<0.04	<0.04	<0.04	<0.04	<0.02	<0.02	<0.04	<0.04
EtFOSAA	<0.02	<0.04	<0.04	<0.04	0.05	<0.02	<0.02	<0.04	<0.04

Table A5-24: Terrestrial mammal concentrations (ng/g w.w) of PFPiA/PFPA

Species	Brown bear	Reindeer	Reindeer	Reindeer	Reindeer	Reindeer	Reindeer	Reindeer	Reindeer
Country	Finland	Finland	Finland	Iceland	Iceland	Green-land	Green-land	Sweden	Sweden
Location	Kuusamo. Sotkamo	Ylitornio	Ylitornio	Eastern region	Eastern region	Isortoq	Nuuk area	Girjas and Sirges	Girjas and Sirges
PFHxPA	<4	<4	<4	<4	<4	<0.04	<0.04	<4	<4
PFOPA	<4	<4	<4	<4	<4	<0.04	<0.04	<4	<4
PFDPA	<4	<4	<4	<4	<4	<0.04	<0.04	<4	<4
6:6 PFPiA	<0.04	<0.4	<0.4	<0.4	<0.4	<0.2	<0.2	<0.4	<0.4
6:8 PFPiA	<0.04	<4	<4	<4	<4	<0.2	<0.2	<4	<4
8:8 PFPiA	<0.04	<4	<4	<4	<4	<0.2	<0.2	<4	<4

Table A5-25: Terrestrial mammal concentrations (ng/g w.w) of novel PFASs

Species	Brown bear	Reindeer	Reindeer	Reindeer	Reindeer	Reindeer	Reindeer	Reindeer	Reindeer
Country	Finland	Finland	Finland	Iceland	Iceland	Green-land	Green-land	Sweden	Sweden
Location	Kuusamo. Sotkamo	Ylitornio	Ylitornio	Eastern region	Eastern region	Isortoq	Nuuk area	Girjas and Sirges	Girjas and Sirges
PFECHS	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
ADONA	<0.1	<0.2	<0.2	<0.2	<0.2	<0.1	<0.1	<0.2	<0.2
HFPO-DA	<0.2	<0.4	<0.4	<0.4	<0.4	<0.2	<0.2	<0.4	<0.4
6:2 Cl-PFESA	<0.04	<0.04	<0.04	<0.04	<0.04	n.q.	n.q.	<0.04	<0.04
8:2 Cl-PFESA	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.

Table A5-26: Surface water concentrations (ng/L) of PFCAs and PFSAs

Country	Denmark	Denmark	Faroe Islands	Faroe Islands	Finland	Finland	Greenland	Greenland	Iceland	Norway	Norway	Sweden	Sweden
Location	**Lake Ørn**	**Lake Silkeborg**	**Lake Sørvágsvatn**	**Myrene Vestmanna**	**River Vantaa**	**Pirkkalan Pyhäjärvi**	**Isortoq**	**Badesö Kobbefjord**	**Elliðavatn**	**Lake Mjøsa**	**Lake Mjøsa**	**Lake Vättern.**	**Lake Vänern.**
PFPrA	<15	<15	<0.2	<0.2	<15	<15	<15	<0.2	<15	0.29	<5	<0.2	0.39
PFBA	2.64	3.52	2.38	2.05	<0.27	<0.27	1.09	1.51	0.45	<0.02	0.16	0.99	<0.02
PFPeA	<0.02	0.48	<0.02	<0.02	5.92	0.61	<0.02	<0.02	0.11	<0.02	0.10	0.53	<0.02
PFHxA	1.90	3.28	1.72	<1.70	10.8	2.50	<1.70	<1.70	<1.70	7.87	0.10	1.98	2.02
PFHpA	0.16	0.47	0.27	0.27	3.16	0.56	0.33	0.30	0.12	0.41	0.09	0.39	0.67
L-PFOA	0.38	0.85	0.28	0.23	4.07	0.89	0.13	0.19	0.14	0.31	0.1	0.81	1.34
Br-PFOA	0.07	0.11	0.05	0.04	0.55	0.08	<0.05	0.08	<0.05	0.13	n.q.	0.13	0.41
PFNA	0.09	0.15	0.18	0.21	12.1	0.41	0.12	0.11	<0.02	0.13	0.04	0.15	0.48
PFDA	0.06	0.10	0.06	0.06	0.23	0.23	<0.02	0.06	<0.02	0.10	0.03	0.03	0.11
PFUnDA	<0.02	<0.02	0.03	<0.02	0.29	0.11	<0.02	0.05	<0.02	0.04	0.02	<0.02	0.03
PFDoDA	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
PFTrDA	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
PFTDA	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
PFHxDA	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
PFOcDA	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
PFEtS	0.21	0.35	0.08	0.05	0.88	0.57	0.12	0.08	<0.06	0.19	n.q.	0.24	0.45
PFPrS	<0.02	<0.02	<0.02	<0.02	0.18	<0.02	<0.02	<0.02	<0.02	<0.02	n.q.	0.04	<0.02
PFBS	0.09	0.90	<0.02	<0.02	1.62	0.27	<0.02	<0.02	<0.02	<0.02	0.026	<0.02	0.27
PFPeS	<0.02	<0.02	<0.02	<0.02	0.47	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.09	0.09
L-PFHxS	0.07	0.18	<0.02	<0.02	4.29	0.21	<0.02	<0.02	<0.02	0.04	0.03	0.52	0.33
Br-PFHxS	<0.02	<0.02	<0.02	<0.02	0.77	<0.02	<0.02	<0.02	<0.02	<0.02	n.q.	0.06	0.06
PFHpS	<0.02	<0.02	<0.02	<0.02	0.25	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
L-PFOS	2.07	1.01	0.43	1.17	10.4	1.18	0.65	0.27	0.55	1.23	0.22	0.56	0.76
Br-PFOS	0.40	0.24	0.13	0.17	3.43	0.45	0.11	0.07	0.06	0.15	n.q	0.35	0.36
PFNS	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
PFDS	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
PFDoDS	<0.02	<0.02	n.q.	n.q.	<0.02	<0.02	<0.02	n.q.	<0.02	n.q.	<0.02	n.q.	n.q.

Table A5-27: Surface water concentrations (ng/L) of PFCA precursors

Country	Denmark	Denmark	Faroe Islands	Faroe Islands	Finland	Finland	Greenland	Greenland	Iceland	Norway	Norway	Sweden	Sweden
Location	**Lake Ørn**	**Lake Silkeborg**	**Lake Sørvágsvatn**	**Myrene Vestmanna**	**River Vantaa**	**Pirkkalan Pyhäjärvi**	**Isortoq**	**Badesö Kobbefjord**	**Elliðavatn**	**Lake Mjøsa**	**Lake Mjøsa**	**Lake Vättern.**	**Lake Vänern.**
4:2 FTSA	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
6:2 FTSA	<0.02	<0.02	<0.06	0.09	0.51	<0.02	<0.02	<0.06	<0.02	0.14	<0.06	<0.06	<0.06
8:2 FTSA	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
5:3 FTCA	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
6:2 FTUCA	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
7:3 FTCA	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
8:2 FTUCA	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
10:2 FTUCA	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
SAmPAP	<0.02	<0.02	n.q.	n.q.	<0.02	<0.02	<0.02	n.q.	<0.02	n.q.	n.q.	n.q.	n.q.
diSAmPAP	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
6:2 monoPAP	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	<0.02	n.q.	n.q.	n.q.	n.q.
8:2 monoPAP	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
10:2 monoPAP	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
4:2 diPAP	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	<0.02	<0.02	<0.02	n.q.	n.q.	n.q.	<0.02
4:2/6:2 diPAP	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	<0.02	<0.02	<0.02	n.q.	n.q.	n.q.	<0.02
2:2/8:2 diPAP	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	<0.02	<0.02	<0.02	n.q.	n.q.	n.q.	<0.02
6:2 diPAP	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	<0.02	<0.02	<0.02	n.q.	n.q.	n.q.	<0.02
4:2/8:2 diPAP	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	<0.02	<0.02	<0.02	n.q.	n.q.	n.q.	<0.02
2:2/10:2 diPAP	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	<0.02	n.q.	<0.02	n.q.	n.q.	n.q.	n.q.
8:2 diPAP	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
6:2/10:2 diPAP	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
4:2/12:2 diPAP	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
6:2/8:2 diPAP	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
4:2/10:2 diPAP	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
8:2/10:2 diPAP	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.

Country	Denmark	Denmark	Faroe Islands	Faroe Islands	Finland	Finland	Greenland	Greenland	Iceland	Norway	Norway	Sweden	Sweden
Location	Lake Ørn	Lake Silkeborg	Lake Sørvágsvatn	Myrene Vestmanna	River Vantaa	Pirkkalan Pyhäjärvi	Isortoq	Badesö Kobbefjord	Elliðavatn	Lake Mjøsa	Lake Mjøsa	Lake Vättern.	Lake Vänern.
6:2/12:2 diPAP	**n.q.**	**n.q.**	**n.q.**	**n.q.**	**n.q.**	**n.q.**	**n.q.**	**n.q.**	**n.q.**	**n.q.**	**n.q.**	**n.q.**	**n.q.**
10:2 diPAP	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
8:2/12:2 diPAP	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
6:2/14:2 diPAP	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
10:2/12:2 diPAP	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
8:2/14:2 diPAP	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
12:2 diPAP	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
10:2/14:2 diPAP	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
8:2/16:2 diPAP	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.

Table A5-28: Surface water concentrations (ng/L) of PFSA precursors

Country	Denmark	Denmark	Faroe Islands	Faroe Islands	Finland	Finland	Greenland	Greenland	Iceland	Norway	Norway	Sweden	Sweden
Location	**Lake Ørn**	**Lake Silkeborg**	**Lake Sørvágsvatn**	**Myrene Vestmanna**	**River Vantaa**	**Pirkkalan Pyhäjärvi**	**Isortoq**	**Badesö Kobbefjord**	**Elliðavatn**	**Lake Mjøsa**	**Lake Mjøsa**	**Lake Vättern.**	**Lake Vänern.**
FOSAA	<2	<2	<0.02	<0.02	<2	<2	<2	<0.02	<2	<0.02	<0.02	<0.02	<0.02
MeFOSAA	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
EtFOSAA	<0.02	<0.02	<0.02	<0.02	0.16	0.05	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02

Table A5-29: Surface water concentrations (ng/L) of PFPiA/PFPA

Country	Denmark	Denmark	Faroe Islands	Faroe Islands	Finland	Finland	Greenland	Greenland	Iceland	Norway	Norway	Sweden	Sweden
Location	**Lake Ørn**	**Lake Silkeborg**	**Lake Sørvágsvatn**	**Myrene Vestmanna**	**River Vantaa**	**Pirkkalan Pyhäjärvi**	**Isortoq**	**Badesö Kobbefjord**	**Elliðavatn**	**Lake Mjøsa**	**Lake Mjøsa**	**Lake Vättern.**	**Lake Vänern.**
PFHxPA	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
PFOPA	<2	<2	n.q.	n.q.	<2	<2	<2	n.q.	<2	n.q.	n.q.	n.q.	n.q.
PFDPA	<2	<2	n.q.	n.q.	<2	<2	<2	n.q.	<2	n.q.	n.q.	n.q.	n.q.
6:6 PFPiA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
6:8 PFPiA	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
8:8 PFPiA	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2

Table A5-30: Surface water concentrations (ng/L) of novel PFAS

Country	Denmark	Denmark	Faroe Islands	Faroe Islands	Finland	Finland	Greenland	Greenland	Iceland	Norway	Norway	Sweden	Sweden
Location	**Lake Ørn**	**Lake Silkeborg**	**Lake Sørvágsvatn**	**Myrene Vestmanna**	**River Vantaa**	**Pirkkalan Pyhäjärvi**	**Isortoq**	**Badesö Kobbefjord**	**Elliðavatn**	**Lake Mjøsa**	**Lake Mjøsa**	**Lake Vättern.**	**Lake Vänern.**
PFECHS	<0.02	<0.02	<0.02	<0.02	0.94	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.24	<0.02
ADONA	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
HFPO-DA	<0.02	<0.02	<0.02	<0.02	<0.1	<0.1	<0.02	<0.02	<0.02	<0.02	<0.02	0.02	<0.02
6:2 Cl-PFESA	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
8:2 Cl-PFESA	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02

Table A5-31: Sludge concentrations (ng/g d.w.) of PFCAs and PFSAs

Country	Denmark	Denmark	Faroe Islands	Faroe Islands	Finland	Finland	Norway	Norway	Sweden	Sweden	Sweden	Sweden
Location	**Viborg**	**Randers**	**Sersjantvíkin**	**Sersjantvíkin**	**Viinikanlahti**	**Viikinmäki**	**HIAS -Sept**	**HIAS - June**	**Umeå**	**Henriksdal**	**Ryaverken**	**Gässlösa**
PFPrA	<3.7	<3.7	<3.7	<3.7	<1.5	n.q.	n.q.	<3.7	<3.7	<3.7	<3.7	<3.7
PFBA	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
PFPeA	n.q.	<0.04	n.q.	n.q.	0.66	0.84	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
PFHxA	1.57	0.69	0.43	0.57	0.92	1.53	<0.04	0.76	0.50	0.73	0.60	1.11
PFHpA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.51	<0.2	0.43
L-PFOA	0.79	0.87	0.75	<0.5	<0.5	<0.5	1.18	1.29	<0.5	0.99	0.67	1.53
Br-PFOA	<0.24	<0.24	<0.24	<0.24	<0.24	<0.24	<0.24	<0.24	<0.24	<0.24	<0.24	<0.24
PFNA	0.61	1.92	<0.04	<0.04	<0.04	<0.04	0.67	0.56	<0.04	0.52	<0.04	0.85
PFDA	5.59	5.15	<0.04	<0.04	0.87	1.23	3.39	1.28	0.95	2.37	1.36	3.45
PFUnDA	2.18	2.15	<0.04	<0.04	0.56	1.07	0.96	<0.04	<0.04	3.29	2.84	2.89
PFDoDA	n.q.	n.q.	n.q.	n.q.	0.73	1.79	1.10	n.q.	n.q.	n.q.	<0.04	n.q.
PFTrDA	n.q.	n.q.	n.q.	n.q.	0.11	0.31	0.35	n.q.	n.q.	n.q.	<0.04	n.q.
PFTDA	n.q.	n.q.	<0.04	n.q.	<0.04	<0.04	<0.04	n.q.	<0.04	n.q.	<0.04	<0.04
PFHxDA	n.q.	n.q.	n.q.	n.q.	<0.04	<0.04	<0.04	n.q.	<0.04	n.q.	<0.04	<0.04
PFOcDA	n.q.	n.q.	n.q.	n.q.	<0.04	<0.04	<0.04	n.q.	<0.04	n.q.	<0.04	<0.04
PFEtS	n.q.	n.q.	n.q.	n.q.	<0.2	<0.2	<0.2	n.q.	n.q.	n.q.	n.q.	n.q.
PFPrS	n.q.	n.q.	n.q.	n.q.	<0.04	<0.04	<0.04	n.q.	n.q.	n.q.	n.q.	n.q.
PFBS	<0.04	<0.04	n.q.	n.q.	<0.04	<0.04	<0.04	n.q.	<0.04	<0.04	<0.04	n.q.
PFPeS	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.20
L-PFHxS	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
Br-PFHxS	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
PFHpS	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
L-PFOS	5.98	7.00	<0.04	n.q.	2.18	3.78	2.82	2.60	4.09	7.46	11.9	10.9
Br-PFOS	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
PFNS	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
PFDS	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
PFDoDS	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04

Table A5-32: Sludge concentrations (ng/g d.w.) of PFCA precursors

Country	Denmark	Denmark	Faroe Islands	Faroe Islands	Finland	Finland	Norway	Norway	Sweden	Sweden	Sweden	Sweden
Location	**Viborg**	**Randers**	**Sersjantvíkin**	**Sersjantvíkin**	**Viinikanlahti**	**Viikinmäki**	**HIAS -Sept**	**HIAS - June**	**Umeå**	**Henriksdal**	**Ryaverken**	**Gässlösa**
4:2 FTSA	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
6:2 FTSA	0.11	0.18	0.09	0.08	<0.04	0.07	0.06	0.10	0.08	0.18	0.11	0.14
8:2 FTSA	1.82	1.80	<0.04	<0.04	0.64	1.28	1.74	1.88	1.24	1.38	1.06	1.30
5:3 FTCA	11.5	16.3	<0.04	<0.04	9.34	21.5	8.67	2.73	2.36	6.86	6.03	83.8
6:2 FTUCA	<0.04	<0.04	<0.04	n.q.	<0.04	<0.04	<0.04	0.58	<0.04	<0.04	<0.04	1.27
7:3 FTCA	<0.04	3.72	<0.04	<0.04	1.06	5.33	3.33	<0.04	<0.04	0.57	<0.04	3.58
8:2 FTUCA	n.q.	<0.04	n.q.	n.q.	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
10:2 FTUCA	n.q.	<0.04	n.q.	n.q.	<0.04	<0.04	<0.04	n.q.	<0.04	<0.04	<0.04	<0.04
SAmPAP	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
diSAmPAP	0.15	0.21	<0.04	<0.04	0.15	0.31	<0.04	<0.04	0.40	0.37	0.23	0.12
6:2 monoPAP	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
8:2 monoPAP	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
10:2 monoPAP	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
4:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
4:2/6:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
2:2/8:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
6:2 diPAP	4.97	4.46	9.89	5.72	6.59	14.0	15.6	16.7	4.58	8.16	2.92	5.02
4:2/8:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
2:2/10:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
8:2 diPAP	7.25	4.89	6.58	7.37	4.56	5.19	5.22	6.67	3.53	3.92	4.15	3.01
6:2/10:2 diPAP	7.47	3.56	7.19	2.22	4.58	5.34	5.15	4.08	3.79	3.61	3.37	4.31
4:2/12:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
6:2/8:2 diPAP	6.17	6.89	9.23	7.32	2.58	3.18	4.81	11.64	3.31	4.73	2.62	5.15
4:2/10:2 diPAP	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
8:2/10:2 diPAP	5.26	1.63	<0.04	0.05	4.21	5.95	3.36	0.08	0.07	3.79	2.66	2.66
6:2/12:2 diPAP	4.47	2.52	1.90	0.59	2.51	2.17	1.69	2.25	1.38	0.52	3.03	1.45
10:2 diPAP	7.79	22.7	0.17	1.25	9.94	16.6	13.9	4.96	5.13	10.0	8.98	9.88

Country	Denmark	Denmark	Faroe Islands	Faroe Islands	Finland	Finland	Norway	Norway	Sweden	Sweden	Sweden	Sweden
Location	**Viborg**	**Randers**	**Sersjantvíkin**	**Sersjantvíkin**	**Viinikanlahti**	**Viikinmäki**	**HIAS -Sept**	**HIAS - June**	**Umeå**	**Henriksdal**	**Ryaverken**	**Gässlösa**
8:2/12:2 diPAP	17.9	26.2	<0.2	<0.2	7.45	11.2	3.99	<0.2	22.0	8.11	1.36	13.83
6:2/14:2 diPAP	12.6	<0.2	<0.2	<0.2	6.32	4.18	0.15	<0.2	2.58	<0.2	13.73	1.17
10:2/12:2 diPAP	<0.2	0.83	0.62	0.72	1.90	1.91	0.25	0.20	0.44	0.35	<0.2	<0.2
8:2/14:2 diPAP	<0.2	<0.2	<0.2	<0.2	1.35	6.14	<0.02	<0.2	<0.2	<0.2	<0.2	<0.2
12:2 diPAP	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
10:2/14:2 diPAP	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
8:2/16:2 diPAP	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2

Table A5-33: Sludge concentrations (ng/g d.w.) of PFSA precursors

Country	Denmark	Denmark	Faroe Islands	Faroe Islands	Finland	Finland	Norway	Norway	Sweden	Sweden	Sweden	Sweden
Location	**Viborg**	**Randers**	**Sersjantvíkin**	**Sersjantvíkin**	**Viinikanlahti**	**Viikinmäki**	**HIAS -Sept**	**HIAS - June**	**Umeå**	**Henriksdal**	**Ryaverken**	**Gässlösa**
FOSAA	4.11	7.12	<4	3.01	<4	<4	<4	<4	<4	3.28	<4	2.05
MeFOSAA	13.5	16.4	0.96	3.41	1.98	4.19	2.45	1.28	2.66	4.42	1.92	10.0
EtFOSAA	13.5	11.3	0.51	1.77	3.67	6.69	4.98	4.07	8.57	8.51	7.56	9.00

Table A5-34: Sludge concentrations (ng/g d.w.) of PFPiA/PFPA

Country	Denmark	Denmark	Faroe Islands	Faroe Islands	Finland	Finland	Norway	Norway	Sweden	Sweden	Sweden	Sweden
Location	**Viborg**	**Randers**	**Sersjantvíkin**	**Sersjantvíkin**	**Viinikanlahti**	**Viikinmäki**	**HIAS -Sept**	**HIAS - June**	**Umeå**	**Henriksdal**	**Ryaverken**	**Gässlösa**
PFHxPA	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
PFOPA	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
PFDPA	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
6:6 PFPiA	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4
6:8 PFPiA	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
8:8 PFPiA	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4

Table A5-35: Sludge concentrations (ng/g d.w.) of novel PFAS

Country	Denmark	Denmark	Faroe Islands	Faroe Islands	Finland	Finland	Norway	Norway	Sweden	Sweden	Sweden	Sweden
Location	**Viborg**	**Randers**	**Sersjantvíkin**	**Sersjantvíkin**	**Viinikanlahti**	**Viikinmäki**	**HIAS -Sept**	**HIAS - June**	**Umeå**	**Henriksdal**	**Ryaverken**	**Gässlösa**
PFECHS	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
ADONA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
HFPO-DA	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4
6:2 Cl-PFESA	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
8:2 Cl-PFESA	<0.04	<0.04	<0.04	n.q.	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04

Table A5-36: Effluent water (dissolved + particle phase) concentrations (ng/L) of PFCAs and PFSAs

Country	Den-mark	Denmark	Faroe Islands	Faroe Islands	Finland	Finland	Green-land	Green-land	Iceland	Iceland	Norway	Norway	Sweden	Sweden
Location	Viborg	Randers	Sersjantví kin	Landss-júkrahúsið	Viikin-mäki	Viinikan-lahti	Qerner-tunnguit	Nuukullak	Hafnar-fjordur	Kletta-gardar	HIAS June	HIAS Sept	Henriks-dal	Gässlösa
PFPrA	1.79	2.02	<1.40	2.95	2.33	2.26	7.32	47.20	34.20	17.60	3.40	3.93	7.03	5.91
PFBA	8.86	9.36	3.20	3.03	3.71	5.45	2.56	7.51	1.75	1.09	8.32	5.42	3.82	11.97
PFPeA	3.57	2.87	0.84	2.47	5.21	5.56	1.08	5.36	0.58	2.18	2.45	2.45	6.61	14.26
PFHxA	8.35	7.84	8.39	4.23	6.46	9.78	3.84	8.95	2.43	3.14	7.46	7.95	8.83	26.64
PFHpA	2.18	2.32	0.70	0.59	1.66	2.18	0.72	1.57	0.27	0.50	1.48	1.64	3.41	15.60
L-PFOA	5.32	6.15	2.22	1.08	3.54	5.08	1.46	4.05	0.50	0.93	4.98	5.27	5.80	33.08
Br-PFOA	0.53	0.79	0.12	0.10	0.30	0.50	0.18	0.76	0.07	0.11	0.31	0.32	0.50	2.43
PFNA	0.66	1.32	0.35	0.45	1.41	1.05	0.50	8.39	0.33	0.17	1.91	1.04	1.09	2.74
PFDA	0.83	0.96	0.54	0.36	1.05	0.96	0.46	3.93	0.34	<0.21	0.73	1.40	1.04	1.09
PFUnDA	<0.13	0.22	<0.13	0.39	0.23	0.17	0.27	3.08	0.70	0.18	0.16	0.16	0.21	0.22
PFDoDA	<0.05	<0.05	0.11	<0.05	<0.05	<0.05	<0.05	0.38	0.09	<0.05	<0.05	<0.05	<0.05	<0.05
PFTrDA	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.05	1.64	0.14	<0.02	<0.02	<0.02	<0.02	<0.02
PFTDA	<0.18	n.q.	<0.18	n.q.	n.q.	<0.18	<0.18	0.21	<0.18	<0.18	<0.18	<0.18	<0.18	<0.18
PFHxDA	<1.34	<1.34	<1.34	n.q.	n.q.	<1.34	n.q.	n.q.	n.q.	n.q.	<1.34	<1.34	<1.34	<1.34
PFOcDA	<0.08	<0.08	0.15	n.q.	n.q.	<0.08	n.q.	n.q.	n.q.	n.q.	<0.08	<0.08	<0.08	<0.08
PFEtS	<0.54	<0.54	0.73	<0.54	<0.54	0.60	<0.54	<0.54	<0.54	0.64	<0.54	<0.54	0.73	1.29
PFPrS	<0.14	0.27	0.69	1.84	<0.14	0.16	0.21	0.88	6.01	0.76	<0.14	<0.14	<0.14	0.57
PFBS	9.25	9.24	1.75	0.92	5.75	7.42	4.61	3.58	0.81	3.04	5.08	5.81	13.11	11.30
PFPeS	0.11	0.17	0.03	<0.03	0.51	0.25	<0.03	0.07	<0.03	0.43	0.08	0.10	0.41	1.16
L-PFHxS	0.56	0.65	0.26	1.65	1.19	0.69	0.24	1.25	0.23	2.27	0.33	0.40	2.37	4.31
Br-PFHxS	<0.2	<0.2	<0.2	n.q.	<0.2	<0.2	<0.2	n.q.	<0.2	<0.2	<0.2	<0.2	0.47	0.63
PFHpS	0.26	<0.02	0.12	<0.02	0.23	0.58	0.22	0.21	0.34	0.36	<0.02	<0.02	0.21	0.09
L-PFOS	4.19	5.78	2.47	2.82	5.37	14.67	4.85	19.61	5.67	9.80	1.33	1.52	4.78	5.53
Br-PFOS	1.14	1.54	0.69	0.48	2.24	7.82	5.09	5.25	2.66	4.99	0.76	0.85	3.11	5.06
PFNS	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.73
PFDS	<0.01	<0.01	<0.01	nq	<0.01	<0.01	<0.01	0.02	0.17	0.29	<0.01	<0.01	<0.01	0.07
PFDoDS	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.20	0.78	0.37	<0.01	<0.01	<0.01	0.05

Table A5-37: Effluent water (dissolved + particle phase) concentrations (ng/L) of PFCA precursors

Country	Denmark	Denmark	Faroe Islands	Faroe Islands	Finland	Finland	Greenland	Greenland	Iceland	Iceland	Norway	Norway	Sweden	Sweden
Location	Viborg	Randers	Sersjantvík in	Landss-júkrahúsið	Viikinmäki	Viinikan-lahti	Qerner-tunnguit	Nuukullak	Hafnar-fjordur	Kletta-gardar	HIAS June	HIAS Sept	Henriksdal	Gässlösa
4:2 FTSA	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
6:2 FTSA	0.59	0.81	0.79	0.40	1.46	0.83	<0.28	1.69	<0.28	0.86	2.06	1.32	1.41	18.46
8:2 FTSA	0.21	0.08	0.09	0.16	1.61	0.20	0.22	0.12	0.06	0.18	0.23	0.10	0.48	0.92
5:3 FTCA	0.85	0.50	0.53	0.66	0.60	0.61	0.43	<0.06	0.50	0.38	4.83	4.33	0.64	4.35
6:2 FTUCA	<0.10	<0.10	<0.10	0.51	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.25	<0.10	0.59
7:3 FTCA	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.02	<0.10	<0.10	<0.10	<0.10	<0.10
8:2 FTUCA	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.09	<0.05	<0.05	<0.05	<0.05	0.14	0.07	0.09
10:2 FTUCA	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
SAmPAP	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
diSAmPAP	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
6:2 monoPAP	n.q.	n.q.	<0.11	<0.11	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
8:2 monoPAP	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
10:2 monoPAP	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
4:2 diPAP	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
4:2/6:2 diPAP	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
2:2/8:2 diPAP	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
6:2 diPAP	0.10	<0.02	<0.2	8.86	<0.02	<0.02	2.10	0.88	1.47	1.37	<0.02	<0.02	<0.02	<0.02
4:2/8:2 diPAP	<0.02	<0.02	<0.2	<0.2	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
2:2/10:2 diPAP	<0.02	<0.02	<0.2	<0.2	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
8:2 diPAP	<0.02	0.07	0.53	3.51	<0.02	0.14	1.21	0.50	0.59	0.55	<0.02	<0.02	<0.02	<0.02
6:2/10:2 diPAP	<0.02	<0.02	0.15	1.15	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
4:2/12:2 diPAP	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
6:2/8:2 diPAP	<0.02	0.08	<0.3	6.14	<0.02	0.36	2.05	0.37	0.79	0.48	0.08	<0.02	<0.02	0.07
4:2/10:2 diPAP	<0.02	<0.02	<0.3	<0.3	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
8:2/10:2 diPAP	<0.02	<0.02	<0.02	0.51	<0.02	<0.02	0.10	<0.02	0.09	0.07	<0.02	<0.02	<0.02	<0.02
6:2/12:2 diPAP	<0.02	<0.02	<0.02	0.43	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02

Country	Denmark	Denmark	Faroe Islands	Faroe Islands	Finland	Finland	Greenland	Greenland	Iceland	Iceland	Norway	Norway	Sweden	Sweden
Location	**Viborg**	**Randers**	**Sersjantvík in**	**Landss-júkrahúsið**	**Viikinmäki**	**Viinikan-lahti**	**Qerner-tunnguit**	**Nuukullak**	**Hafnar-fjordur**	**Kletta-gardar**	**HIAS June**	**HIAS Sept**	**Henriksdal**	**Gässlösa**
10:2 diPAP	<0.1	<0.1	1.95	6.58	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
8:2/12:2 diPAP	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
6:2/14:2 diPAP	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
10:2/12:2 diPAP	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
8:2/14:2 diPAP	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
12:2 diPAP	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
10:2/14:2 diPAP	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
8:2/16:2 diPAP	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

Table A5-38: Effluent water (dissolved + particle phase) concentrations (ng/L) of PFSA precursors

Country	Denmark	Denmark	Faroe Islands	Faroe Islands	Finland	Finland	Green-land	Green-land	Iceland	Iceland	Norway	Norway	Sweden	Sweden
Location	**Viborg**	**Randers**	**Sersjantvíkin**	**Landss-júkrahúsið**	**Viikin-mäki**	**Viinikan-lahti**	**Qerner-tunnguit**	**Nuukullak**	**Hafnar-fjordur**	**Kletta-gardar**	**HIAS June**	**HIAS Sept**	**Henriks-dal**	**Gässlösa**
FOSAA	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
MeFOSAA	0.23	0.23	0.21	<0.02	0.33	0.21	<0.02	<0.02	<0.02	<0.02	0.28	0.48	0.16	0.82
EtFOSAA	0.28	0.30	0.54	0.58	0.61	0.47	0.37	0.23	4.54	0.57	0.27	0.41	0.41	0.63

Table A5-39: Effluent water (dissolved + particle phase) concentrations (ng/L) of PFPiA/PFPA

Country	Denmark	Denmark	Faroe Islands	Faroe Islands	Finland	Finland	Green-land	Green-land	Iceland	Iceland	Norway	Norway	Sweden	Sweden
Location	**Viborg**	**Randers**	**Sersjantvíkin**	**Landss-júkrahúsið**	**Viikin-mäki**	**Viinikan-lahti**	**Qerner-tunnguit**	**Nuukullak**	**Hafnar-fjordur**	**Kletta-gardar**	**HIAS June**	**HIAS Sept**	**Henriks-dal**	**Gässlösa**
PFHxPA	<2	<2	<2	<2	<2	<2	n.q.	n.q.	<2	n.q.	<2	<2	<2	<2
PFOPA	<2	<2	<2	<2	<2	<2	n.q.	n.q.	<2	n.q.	<2	<2	<2	<2
PFDPA	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
6:6 PFPiA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
6:8 PFPiA	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
8:8 PFPiA	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2

Table A5-40: Effluent water (dissolved + particle phase) concentrations (ng/L) of novel PFAS

Country	Denmark	Denmark	Faroe Islands	Faroe Islands	Finland	Finland	Green-land	Green-land	Iceland	Iceland	Norway	Norway	Sweden	Sweden
Location	**Viborg**	**Randers**	**Sersjant víkin**	**Landss-júkrahúsið**	**Viikin-mäki**	**Viinikan-lahti**	**Qerner-tunnguit**	**Nuukullak**	**Hafnar-fjordur**	**Kletta-gardar**	**HIAS June**	**HIAS Sept**	**Henriks-dal**	**Gässlösa**
PFECHS	<0.02	0.21	<0.02	<0.02	0.18	0.13	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.15	0.37
ADONA	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
HFPO-DA	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
6:2 Cl-PFESA	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
8:2 Cl-PFESA	<0.13	<0.13	<0.13	<0.13	<0.13	<0.13	<0.13	<0.13	<0.13	<0.13	<0.13	<0.13	<0.13	<0.13

Appendix 6. Instrumental parameters for LC-MS/MS

Table A6-1: List of analytes, MRM transitions, cone voltage, and collision energy used for quantification and qualification of PFAS

Analyte	Precursor/ product ions quantification (m/z)	Cone (V)	Coll (eV)	Precursor/ product ions qualification (m/z)	Cone (V)	Coll (eV)	Internal standard
TFA	112.9/68.96	26	10				^{13}C-PFBA
PFPrA	162.97/118.9	20	10				^{13}C-PFBA
PFBA	212.97/169	20	11				^{13}C-PFBA
PFPeA	262.97/219	20	8				^{13}C-PFPeA
PFHxA	312.97/269	20	9	312.97/118.95	20	26	^{13}C-PFHxA
PFHpA	362.97/319	20	10	362.97/168.97	20	16	^{13}C-PFHpA
PFOA	412.97/369	20	10	412.97/168.97	20	18	^{13}C-PFOA
PFNA	462.99/419	20	12	462.99/219	20	18	^{13}C-PFNA
PFDA	512.97/469	20	11	512.97/219	20	18	^{13}C-PFDA
PFUnDA	562.97/519	20	12	562.97/268.99	20	18	^{13}C-PFUnDA
PFDoDA	612.97/569	34	14	612.97/168.96	40	22	^{13}C-PFDoDA
PFTrDA	662.9/619	20	14	662.9/168.96	20	26	^{13}C-PFDoDA
PFTDA	712.9/669	20	14	712.9/168.97	20	28	^{13}C-PFTDA
PFHxDA	812.9/769	30	15	812.9/168.96	42	32	^{13}C-PFHxDA
PFOcDA	912.9/869	36	15	912.9/168.96	36	36	^{13}C-PFHxDA
PFEtS	198.8/79.8	65	20				^{13}C-PFBS
PFPrS	248.9/80.0	70	25				^{13}C-PFBS
PFBS	298.9/98.9	20	26	298.9/79.96	20	26	^{13}C-PFBS
PFPeS	348.90/98.96	20	26	348.90/79.96	20	30	^{13}C-PFHxS
PFHxS	398.9/98.9	20	30	398.9/79.96	20	34	^{18}O-PFHxS
PFHpS	448.97/98.90	20	30	448.97/79.96	20	35	^{13}C-PFOS
PFOS	498.97/98.96	20	38	498.97/79.96, 498.97/169.03	20	44, 34	^{13}C-PFOS
PFNS	548.90/98.96	20	38	548.90/79.96	20	44	^{13}C-PFOS
PFDS	598.97/98.9	20	42	598.97/79.96	20	58	^{13}C-PFOS
PFDoDS	698.90/98.90	20	40	698.90/79.96	20	45	^{13}C-PFOS
5:3 FTCA	340.9/236.97	10	16	340.9216.93	10	22	^{13}C-6:2 FTUCA
6:2 FTUCA	356.9/292.91	10	18	356.9/242.95	10	36	^{13}C-6:2 FTUCA
7:3 FTCA	440.9/336.89	12	14	440.9/316.93	12	20	^{13}C-8:2 FTUCA
8:2 FTUCA	456.9/392.84	10	18	456.9/392.84	10	38	^{13}C-8:2 FTUCA
10:2 FTUCA	556.84/492.82	8	16	556.84/242.94	8	38	^{13}C-10:2 FTUCA
FOSAA				555.8/418.85			^{2}H -Et-FOSAA
MeFOSAA				569.78/482.76			^{2}H -Et-FOSAA
EtFOSAA				583.84/482.8			^{2}H -Et-FOSAA
4:2 FTSA	327/307	20	20	327/81	20	28	^{13}C-6:2 FTSA
6:2 FTSA	427/407	20	20	427/81	20	28	^{13}C-6:2 FTSA
8:2 FTSA	527/507	20	20	527/80	20	28	^{13}C-8:2 FTSA
6:2 Cl-PFESA	530.9/351	58	24	530.9/83.0	58	24	^{13}C-PFOS
8:2 Cl-PFESA	630.9/451	58	24	630.9/83.0	58	24	^{13}C-PFOS
PFECHS	460.84/380.9	2	24	460.84/98.88	2	26	^{13}C-PFOA
4:2/6:2 diPAP	688.9/97	64	28	688.9/342.91, 688.9/442.91	64	18	^{13}C-6:2 diPAP
2:2/8:2 diPAP	688.9/97	64	28	688.9/242.91, 688.9/542.91	64	18	^{13}C-6:2 diPAP

Analyte	Precursor/ product ions quantification (m/z)	Cone (V)	Coll (eV)	Precursor/ product ions qualification (m/z)	Cone (V)	Coll (eV)	Internal standard
6:2 diPAP	788.9/97	64	28	788.9/442.91	64	18	^{13}C-6:2 diPAP
4:2/8:2 diPAP	788.9/97	64	28	788.9/342.91, 788.9/542.91	64	18	^{13}C-6:2 diPAP
2:2/10:2 diPAP	788.9/97	64	28	788.9/242.91, 788.9/642.91	64	18	^{13}C-6:2 diPAP
6:2/8:2 diPAP	888.78/96.94	66	34	888.78/442.81, 888.78/542.81	66	26	^{13}C-6:2 diPAP
4:2/10:2 diPAP	888.78/96.94	66	34	888.78/342.81, 888.78/642.81	66	26	^{13}C-6:2 diPAP
8:2 diPAP	988.78/96.94	68	34	988.78/542.81	68	26	^{13}C-8:2 diPAP
6:2/10:2 diPAP	988.78/96.94	68	34	988.78/442.81, 988.78/642.81	68	26	^{13}C-8:2 diPAP
4:2/12:2 diPAP	988.78/96.94	68	34	988.78/342.81, 988.78/742.81	68	26	^{13}C-8:2 diPAP
8:2/10:2 diPAP	1088.78/96.94	68	34	1088.78/542.81, 1088.78/642.81	68	26	^{13}C-8:2 diPAP
10:2 diPAP	1188.78/96.94	68	34	1188.78/642.81	68	26	^{13}C-8:2 diPAP
8:2/12:2 diPAP	1188.78/96.94	68	34	1188.78/742.81, 1188.78/542.81	68	26	^{13}C-8:2 diPAP
6:2/14:2 diPAP	1188.78/96.94	68	34	1188.78/842.81, 1188.78/442.81	68	26	^{13}C-8:2 diPAP
PFHxPA	398.97/79	62	26				^{13}C-PFOA
PFOPA	499/79	62	30				^{13}C-PFOA
PFDPA	599.03/79	62	30				^{13}C-PFNA
PFDoPA	699/79	62	30				^{13}C-PFOA
PFTePA	799/79	62	30				^{13}C-PFOA
PFHxDPA	899/79	62	30				^{13}C-PFOA
C6/C6 PFPiA	701/401	62	28				^{13}C-PFDoDA
C6/C8 PFPiA	801/401	24	28	801/501	24	28	^{13}C-PFTDA
C8/C8 PFPiA	901/501	24	28				^{13}C-PFTDA
C6/C10 PFPiA	1001/401	24	28	1001/601	24	28	^{13}C-PFDoDA
C8/C10 PFPiA	1101/501	24	28	1101/601	24	28	^{13}C-PFDoDA
C6/C12 PFPiA	1101/401	24	28	1101/701	24	28	^{13}C-PFDoDA
C10/C10 PFPiA	1201/601	24	28				^{13}C-PFDoDA
C8/C12 PFPiA	1201/601	24	28	1201/701	24	28	^{13}C-PFDoDA
C6/C14 PFPiA	1201/401	24	28	1201/801	24	28	^{13}C-PFDoDA
C10/C12 PFPiA	1301/601	24	28	1301/701	24	28	^{13}C-PFDoDA
C8/C14 PFPiA	1301/501	24	28	1301/801	24	28	^{13}C-PFDoDA
C12/C12 PFPiA	1401/701	24	28				^{13}C-PFDoDA
C10/C14 PFPiA	1401/601	24	28	1001/801	24	28	^{13}C-PFDoDA
C14/C14 PFPiA	1501/701	24	28				^{13}C-PFDoDA
HFPO-DA (GenX)	284.92/168.72	20	7	328.95/284.86	20	17	^{13}C-HFPO-DA
ADONA	376.97/250.8	30	37	376.97/84.69	15	29	^{18}O-PFHxS

Appendix 7: Water content of sludge samples

Table A7-1: Water content of sludge samples

Country	Location	Water content (%)
Denmark	Viborg	73.9
Denmark	Randers	96.3
Faroe Islands	Sersjantvíkin	83.3
Faroe Islands	Sersjantvíkin	81.3
Finland	Tampere	70.0
Finland	Viikki	70.0
Norway	Hias	64.0
Norway	Hias. stange	66.8
Sweden	Umeå	70.5
Sweden	Henriksdal	73.7
Sweden	Ryaverken	74.8
Sweden	Gässlösa	78.9

Nordic Council of Ministers
Nordens Hus
Ved Stranden 18
DK-1061 Copenhagen K
www.norden.org

PFASs in the Nordic environment

This report describes a screening study of in all ninety-nine conventional and emerging per- and polyfluoroalkyl substances (PFASs) in the Nordic environment. In addition, extractable organic fluorine (EOF) was analysed. The latter can provide the amount, but not identity, of organofluorine in the samples, which in turn can be used to assess the mass balance between known and unknown PFASs. The study was initiated by the Nordic Screening Group and funded by these and the Nordic Council of Ministers through the Chemicals Group.

A total of 102 samples were analyzed in this study, including bird eggs, fish, marine mammals, terrestrial mammals, surface water, WWTP effluents and sludge, and air. Samples were collected by institutes from the participating countries and self-governing areas; Denmark, Faroe Islands, Finland, Greenland, Iceland, Norway, and Sweden.

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