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DIREKTORATET**

*Statlig program for forurensningsovervåking*

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## **Tilførselsprogrammet 2011**

**Passive air and water sampling at Andøya, Bjørnøya  
and Jan Mayen, 2010-2011.**

TA  
2937  
2012

*Tilførselsprogrammet utføres av:*



Statens strålevern  
Norwegian Radiation Protection Authority



# Norwegian Institute for Water Research

– an institute in the Environmental Research Alliance of Norway

# REPORT

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**Abstract**

As part of the monitoring programme established by the Norwegian Climate and Pollution Directorate (Klif) to assess fluxes of contaminants in the Barents Sea, Norwegian Sea and North Sea, passive sampling was undertaken at Andøya, Bjørnøya and Jan Mayen to measure levels of polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), organochlorines (OCs) and polybrominated diphenylethers (PBDEs) in air and water. Semipermeable membrane devices and silicone strips were deployed in water for a period of 10 months. PAH concentrations in water were mostly quantifiable, and found generally lower at Jan Mayen than those measured at Bjørnøya and Andøya. PCB concentrations were mostly below limits of detection (low picogram/litre). Limits of detection were adequate for pentachlorobenzene and hexachlorobenzene, while concentrations of hexachlorocyclohexane isomers and *p,p'*-DDE were closer to limits of detection. Two PBDE congeners, PBDE-47 and PBDE-99 were consistently detected. For certain compounds, it was possible to compare dissolved water concentrations with those measured in cod liver from Jan Mayen. The non-targeted screening with GC/TOF/MS identified a short list of chemicals present in air and water. Results from polyurethane foam samplers (PUFs) deployed in the air are broadly consistent with results from past findings and active air samplers, yet also revealed difficulties when applying this method at Arctic sites, which are mainly attributed to the relatively harsh climatic conditions. Contaminant levels in air were successfully measured at the three sites using PUF air samplers. Based on results presented here, some recommendations are also provided.

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1. Passiv prøvetaking	1. Passive sampling
2. Arktisk overvåking	2. Arctic monitoring
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## *Tilførselsprogrammet 2012:*

**Passive air and water sampling at Andøya, Bjørnøya and Jan Mayen**

**Data from 2010-2011**

## **Forord**

Klima- og forurensningsdirektoratet (Klif) har etablert et program for overvåking av tilførsler av miljøfarlige stoff til forvaltningsplanområdene Barentshavet, Norskehavet og Nordsjøen (Tilførselsprogrammet). Tilførslene fordeles mellom bidrag fra 8 kilder og til 12 regioner. I 2009 ble programmet utvidet til å omfatte overvåking som primært skal dekke behov i forvaltningsplanene, og utfylle og supplere eksisterende programmer på nasjonalt og internasjonalt nivå.

Dette prosjektet er utført av Norsk institutt for vannforskning (NIVA) i partnerskap med Havforskningsinstituttet (IMR), Nasjonalt institutt for ernærings- og sjømatforskning (NIFES), Norsk institutt for luftforskning (NILU), Statens strålevern (NRPA) og Bjerknes Centre for Climate Research (BCCR) ved Klif kontrakt nr. 5011020. Denne rapporten gjelder undersøkelser med hjelp av passive prøvetakere i 2010 utført av NIVA og NILU. Tre andre rapporter er produsert: undersøkelser miljøgifter og radionuklider i Nordsjøen i 2010 utføres av NIVA, IMR, NIFES, NILU og NRPA, undersøkelser av havforsuring som utføres av NIVA, IMR og BCCR og undersøkelser fra fast værstasjon på Andøya i 2010 utført av NILU.

Vi vil takke sjefsingeniør Gunnar Skotte fra Klif, for god oppfølging og støtte under gjennomføringen av prosjektet.

Takk rettes også til staben på de meteorologiske stasjonene på Bjørnøya og Jan Mayen, og personalet ved rakettavskytningsområdet på Andøya (ALOMAR), og til mannskapet fra Kystvakten for feltarbeid.

SPMD- og silicone-strip-prøvetakere, samt ekstraksjon og analyse av disse ble gjennomført av NIVA. PUF passive-prøvetakere, samt ekstraksjon og analyse av disse ble gjennomført av NILU. Guttorm Christiansen (Akvaplan-niva) sto for hoveddel av organisering og gjennomføring av feltarbeidet.

Arbeid med denne rapporten ble ledet av forsker Ian Allan (NIVA) med betydelig bidrag fra forsker Wenche Aas (NILU), Katherine Langford (NIVA), Guttorm Christiansen, Norman Green (NIVA), forsker Knut Breivik (NILU), forsker Kine Bæk (NIVA) har også arbeidet med rapporten.

Forsker Norman Green har vært leder for hele prosjektet.

Etter avtale med Klif har denne rapporten egen mal og er skrevet på engelsk



Norman W. Green  
Oslo, 17. juni 2012



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## Summary

The Norwegian Climate and Pollution Directorate (Klif) has established a monitoring programme to assess fluxes of contaminants in the Barents Sea, Norwegian Sea and North Sea. This includes the measurement of trace levels of organic contaminants in air, water, sediment and biota at Andøya on the Norwegian coast, Bjørnøya and Jan Mayen. For air and water monitoring, passive sampling was selected for its ability to provide low limits of detections and time-integrative information on levels in these compartments. The aim of this work was to establish a programme for the measurement of levels and temporal trends in polycyclic aromatic hydrocarbon (PAH), polychlorinated biphenyl (PCB), organochlorine (OC) and polybrominated diphenylether (PBDE) concentrations at the three selected sites.

For the monitoring of contaminants dissolved in water, two types of samplers made of different polymers were selected for this work. Semipermeable membrane devices (SPMDs) and silicone strips were deployed for periods of 10-12 months at each of the three sites. Passive sampling devices were deployed at Andøya, Bjørnøya and Jan Mayen. Samplers exposed at Andøya and Bjørnøya during the period 2010-2012 were repeatedly lost due to sea conditions at these sites. Therefore no data are available for these locations. Useful and novel data was obtained from Jan Mayen for samplers exposed for 273 days between 2010 and 2011. The relatively lengthy deployments for samplers exposed at Jan Mayen ensured improved limits of detection. For certain compounds, it was also possible to compare dissolved water concentrations with those measured in fish (cod) liver.

All target analyses indicated low contaminant concentrations at Jan Mayen. Highest concentrations ( $\sim 1 \text{ ng L}^{-1}$ ) were observed for lindane ( $\gamma$ -HCH) and its isomer,  $\alpha$ -HCH. Lowest concentrations were observed for PBDE congener 47 below  $1 \text{ pg L}^{-1}$ . PAH concentrations appeared generally low at Jan Mayen and lower than at Andøya or Bjørnøya. The heaviest PAHs remained undetected after 273 days of exposure. PCB concentrations in water were very low and close to or below limits of detection for Jan Mayen (similarly to Andøya and Bjørnøya). These limits of detection are in the low  $\text{pg L}^{-1}$ . Pentachlorobenzene and hexachlorobenzene concentrations were in a similar range to those measured at Andøya and Bjørnøya. Limits of detection for *p,p'*-DDE and HCH isomers are in a similar range as that of concentrations measured, i.e. a few  $\text{pg L}^{-1}$ . For HCH isomers, silicone strips appeared to absorb higher amounts than SPMDs and allowed to verify isomer ratios for the water phase. Ratios were consistent with data from Bjørnøya (2009-2010). PBDE-47 and PBDE-99 are consistently found above limits of detection. PBDE-47 was found at a concentration approximately an order of magnitude lower than at the two other sampling locations. PBDE-209 was detected very close to LODs in silicone strips. Concentrations in the low  $\text{pg L}^{-1}$  were estimated but are associated with significant uncertainty. Screening for hexabromocyclododecane (HBCDD) isomers did not result in the detection of this chemical in any of the samplers exposed at Jan Mayen.

In most cases, estimates of contaminant concentrations in water appear to be well below (by a factor of  $> 100$ ) environmental quality standards set by the European Union's Water Framework Directive (WFD) (See **Table s1**). Accounting for partitioning to suspended particles is not likely to result in substantially higher estimates of water concentrations for these chemicals. One exception was for HCH that was apparently close to EQS levels. For Jan Mayen, bioaccumulation factors ( $\log\text{BAF}$  values) based on concentrations measured in cod liver were in agreement with  $\log K_{ow}$  values for chemicals of interest (**Table s1**). Values were generally close to those reported for Andøya and Bjørnøya for 2009-2010.



**Table s1.** Annual-average environmental quality standards (AA-EQS), dissolved concentrations in water and cod liver-water bioaccumulation factors for selected Water Framework Directive (WFD) priority substances

Priority substances	logK <sub>ow</sub>	WFD		Jan Mayen
		AA-EQS (ng L <sup>-1</sup> )	C <sub>w</sub> (ng L <sup>-1</sup> )	logBAF <sup>a</sup>
Anthracene		100	0.03 (SPMD)	
Pentabromodiphenylether <sup>a</sup>		0.2	<0.0016 (Sil)	
Fluoranthene		100	0.37 (Sil)	
Hexachlorobenzene	5.50	10	0.076 (Sil)	5.81
Hexachlorocyclohexane	3.81/4.14	2	1.6 (Sil)	3.27/3.56
Pentachlorobenzene	5.18	7	0.017 (Sil)	5.30
Benzo[a]pyrene		50	<0.01 (SPMD)	
Benzo[b+k]fluoranthene*		30	0.062 (SPMD)	
Benzo[ghi]perylene & indeno[1,2,3-cd]pyrene**		2	<0.02 (SPMD)	
Sum of DDTs***	~6.3	25	0.006 (Sil)	6.96/7.89
p,p'-DDT		10	<0.006 (Sil)	
PCB-28	5.67		0.0038 (Sil)	6.14
PBDE-47	6.60			7.40

<sup>a</sup>logBAF= bioaccumulation factor chemicals found in cod liver (lipid normalised)  
<sup>b</sup>BDE-28, BDE-47, BDE-99, BDE-100, BDE-153, BDE-154  
\*Sum of benzo[b]fluoranthene and benzo[k]fluoranthene  
\*\*Sum of Benzo[ghi]perylene and indeno[1,2,3-cd]pyrene  
\*\*\*Sum of isomers with CAS numbers: 50-29-3, 789-02-6 and 72-54-8

The performance of silicone strips and SPMDs is generally similar. The larger volume of silicone strips improves limits of detection for chemicals that have reached equilibrium. Unless sampler conformation is radically changed, exposure time should be kept to 12 months for deployments in water. Alternatively sampler exposures could be undertaken using alternative cages to enable higher water turbulences near the sampler surface and hence higher sampling rates (and lower limits of detection). The exposure of time-integrative absorption-based samplers (such as SPMDs and silicone strips) in the air resulted in the detection of some contaminants (forthcoming results).

Passive samplers are able to provide information on contaminant levels in locations where it is generally difficult to obtain samples of biota. In addition, they appear very suited to the evaluation of long term trends in concentrations.

Non-targeted GC/TOF/MS screening identified a short list of additional chemicals present in silicone strips deployed in air and water at Jan Mayen. Personal care products such as galaxolide and tonalide were not found in extracts. Caffeine was not found and this indicates that, as expected, this marker of human impact is not prone to long-range transport. No phosphorus flame retardants were identified during this screening.

Polyurethane foam samplers (PUFs) were deployed in the air at the same three sites (Jan Mayen, Bjørnøya and Andøya). Each site had three measurement periods in 2011 with parallel sampling of two identical PUF samplers. The results obtained on the basis of passive air samplers are broadly consistent with results from past findings and active air samplers, yet also revealed difficulties when applying this method at Arctic sites, which are mainly attributed to the climatic conditions experienced (colder temperatures and elevated wind speeds). Thus, the results presented are only expected to represent the “true” air concentrations within a factor of ~2-3. This needs to be taken into consideration when interpreting the results and if these data are to be used to discuss potential equilibrium status and net flux directions between air and surface seawater. A general observation is that concentrations of PCBs, chlordanes and PAHs are comparable between the sites. HCB and pentachlorobenzene (PeCB) were highest at Jan Mayen and lowest at Andøya, while concentrations of α-HCH were higher at the two most Arctic sites (Jan Mayen and Bjørnøya).

## Sammendrag

Klima- og forurensningsdirektoratet (Klif) har etablert et program for overvåking av tilførsler av miljøfarlige stoffer til Barentshavet, Norskehavet og Nordsjøen (Tilførselsprogrammet). I programmet måles nivåer av organiske miljøgifter i luft, vann, sediment og biota på Andøya, Bjørnøya og Jan Mayen. I denne rapporten er kun resultatene fra passive prøvetakere i vann og luft presentert.

Passive prøvetakere ble utplassert i luft og vann for å kunne måle tidsintegreerte og særdeles lave konsentrasjoner i disse matriksene. Målsetningen med dette arbeidet var å etablere et overvåkningsprogram for målinger av nivåer og trender av polyaromatiske hydrokarboner (PAH), polyklorerte bifenyler (PCB), klororganiske forbindelser og polybromerte difenyletere (PBDE) på de tre utvalgte stasjonene.

For målinger av miljøgifter i den frie oppløste fasen ble det benyttet to typer passive prøvetakere, såkalte *SemiPermeable Membrane Devices* (SPMD) og silikonstrips. Prøvetakerne ble utplassert 10-12 måneder på de ulike stasjonene. Prøvetakerne på Andøya og Bjørnøya fra 2010-2012 forsvant i løpet av utplasseringstiden, antagelig pga dårlige værforhold, og resultater mangler for disse stasjonene. Fra Jan Mayen ble det innhentet data fra prøvetakere som var plassert ut i 273 døgn i tidsrommet 2010-2011. Etter den lange utplasseringstiden på Jan Mayen kunne man måle konsentrasjoner av miljøgifter som var betydelig høyere enn deteksjonsgrensen, og man kunne sammenligne funnene med konsentrasjoner målt i torskelerver.

Konsentrasjonene av miljøgifter i vann fra Jan Mayen var generelt lave. Lindan ( $\gamma$ -HCH) og isomeren  $\alpha$ -HCH, ble målt i høyeste konsentrasjon,  $\sim 1 \text{ ng L}^{-1}$  under utplasseringen. Kongeneren PBDE-47 ble målt i laveste konsentrasjon som var under  $1 \text{ pg L}^{-1}$ . Målingene i 2009-2010 viste at konsentrasjonen av PAH var generelt lavere på Jan Mayen enn på Andøya og Bjørnøya. Nivået av PCB var lavt og under deteksjonsgrensen ( $\text{pg L}^{-1}$ ), for de fleste kongenerene. Konsentrasjonen av pentaklorbenzen og heksaklorbenzen ble målt til samme nivå på de ulike stasjonene (data fra Andøya og Bjørnøya 2009-2010).

Konsentrasjoner av *p,p'*-DDE og HCH isomerene var nær deteksjonsgrensen ( $\text{pg L}^{-1}$ ).

Silikonstripsene absorberte høyere mengder av HCH- isomerene enn SPMDene. Forholdet mellom isomerene i vannfasen ble beregnet og resultatene stemte overens med funn fra målinger utført på Bjørnøya 2009-2010.

Nivåene av PBDE-47 and PBDE-99 var konsekvent over deteksjonsgrensen. På Jan Mayen var konsentrasjonen av PBDE-47 en størrelsesorden lavere i forhold til de andre prøvestasjonene (data fra Andøya og Bjørnøya 2009-2010). I silikonstripsene ble PBDE-209 påvist i nivåer nær deteksjonsgrensen ( $\text{pg L}^{-1}$ ). Heksabromosyklododekan (HBCCD) ble ikke påvist i noen av prøvetakerne som var utplassert på Jan Mayen.

I de fleste tilfeller var beregnede konsentrasjoner i vann langt under miljøkvalitetsstandarder (med en faktor  $> 100$ ) gitt i Vanndirektivet, såkalte EQS-verdier (Environmental Quality Standards, Tabell s1), iberegnet estimert fraksjon som eventuelt vil være bundet til partikulært materiale. Et unntak var heksaklorsyklododekan, hvor målte konsentrasjon var nær EQS-verdi. Bioakkumeringsfaktorer ( $\log\text{BAF}$ ), basert på målte konsentrasjoner i torskelerver-vannfase fra Jan Mayen var i overensstemmelse med  $\log K_{ow}$ -verdier for de ulike målte forbindelsene (Tabell s1). Verdiene var nær tidligere rapporterte verdier fra Andøya og Bjørnøya i 2009-2010.

**Tabell s1.** Årlige gjennomsnittlige miljøkvalitetsstandarder (AA-EQS) for miljøgifter i kystvann i henhold til Vanddirektivet. Konsentrasjoner målt i fri oppløst fase ( $C_w$ ), ved hjelp av SPMD eller silikonstrips (Sil), og bioakkumeringsfaktorer (BAF) for torskelerver-vannfase for utvalgte prioriterte stoffer i Vanddirektivet.

Prioritert stoffer i Vanddirektivet	log $K_{ow}$	Vanddirektivet		
		AA-EQS (ng L <sup>-1</sup> )	C <sub>w</sub> (ng L <sup>-1</sup> )	logBAF <sup>a</sup>
Antracen		100	0.03 (SPMD)	
Bromerte difenyletere <sup>b</sup>		0.2	<0.0016 (Sil)	
Fluoranten		100	0.37 (Sil)	
Heksaklorbenzen	5.50	10	0.076 (Sil)	5.81
Heksaklorsykloheksan	3.81/4.14	2	1.6 (Sil)	3.27/3.56
Pentaklorbenzen	5.18	7	0.017 (Sil)	5.30
Benzo[a]pyren		50	<0.01 (SPMD)	
Benzo[b+k]fluoranten*		30	0.062 (SPMD)	
Benzo[ghi]perylene & indeno[1,2,3-cd]pyren**		2	<0.02 (SPMD)	
Sum av DDT***	~6.3	25	0.006 (Sil)	6.96/7.89
p,p'-DDT		10	<0.006 (Sil)	
PCB-28	5.67		0.0038 (Sil)	6.14
PBDE-47	6.60			7.40

<sup>a</sup>logBAF= bioakkumuleringsfaktor i torskelerver (lipid normalisert) - vannfase

<sup>b</sup>BDE-28, BDE-47, BDE-99, BDE-100, BDE-153, BDE-154

\*Sum av benzo[b]fluoranten og benzo[k]fluoranten

\*\*Sum av Benzo[ghi]perylene og indeno[1,2,3-cd]pyren

\*\*\*Sum av isomere med CAS nummer: 50-29-3, 789-02-6 og 72-54-8

Ikke-målrettet GC/TOF/MS screening identifiserte noen forbindelser til stede i silikonstrips som var utplassert i luft og vann på Jan Mayen. Personlige pleieprodukter slik som galaxolid og tonalid ble ikke påvist. Koffein som er en markør for menneskelig påvirkning, ble som forventet, ikke påvist, noe som indikerer at denne forbindelsen ikke langtransporteres. Ingen fosfororganiske flammehemmere ble påvist i denne screeningen.

Silikonstripsene og SPMDene ga tilsvarende resultater, men silikonstripsene som har større volum, vil ved likevekt ha oppsamlet større masse av miljøgifter. Basert på disse dataene bør prøvetakerne utplasseres i 12 måneder. For å oppnå høyere turbulens rundt prøvetakerne og derved øke opptakraten, bør det vurderes å benytte andre typer holdere/bur for utplassering av prøvetakerne. Passive prøvetakere kan skaffe til veie informasjon om nivået av miljøgifter i områder hvor det er vanskelig å innhente prøver av biota, og de er spesielt egnede til å måle konsentrasjoner over lengre perioder.

Prøvetakere av polyuretanskum, såkalte PUF-plugger ble utplassert i luft på de samme tre stasjonene. Hver stasjon hadde tre måleperioder i løpet av 2011, med to parallelle prøvetakere ved hver utplassering. Resultater fra passive prøvetakere i luft er i samsvar med funn fra tidligere undersøkelser hvor aktive prøvetakere var plassert ut. Resultatene viste også at det er utfordringer ved å benytte passive prøvetakere i Arktiske strøk, pga lavere temperaturer og høye vindhastigheter. Presenterte resultater vil derfor ha en usikkerhetsfaktor på ~ 2-3. Dette må tas i betraktning når resultatene skal tolkes, og dataene eventuelt skal benyttes til å diskutere potensiell likevektstatus og netto transporter mellom luft og vann. Som en generell observasjon så viste resultatene at konsentrasjonen av PCB, klordaner og PAH var i samme størrelsesorden ved de ulike stasjonene. Heksaklorbenzen og pentaklorbenzen var høyest på Jan Mayen, og lavest på Andøya, mens konsentrasjonen av  $\alpha$ -HCH var høyest på de nordligste stasjonene (Jan Mayen og Bjørnøya).

# 1. Introduction

The Norwegian Climate and Pollution Agency (Klif) has established the *Tilførselsprogrammet* - a program for calculations of discharges, transport pathways and deposition of environmental hazardous substances in Norwegian marine areas (Green *et al.*, 2010). This includes the measurement of trace levels of organic contaminants in air, water, sediment and biota at Andøya on the Norwegian coast, Bjørnøya and Jan Mayen. While for many classes of contaminants the measurement of concentrations in sediment and biota is relatively straightforward, the measurement of trace levels in air and water require the use of sampling techniques that allow very low limits of detection. Passive sampling (Vrana *et al.*, 2005) was selected because of its potential to achieve these low limits of detection and for its ability to provide time-integrative information on levels in air and water.

The aim of this work was to establish a monitoring programme for the measurement of levels and temporal trends in polycyclic aromatic hydrocarbon (PAHs), polychlorinated biphenyl (PCBs), organochlorine (OCs) and polybrominated diphenylether (PBDEs) concentrations at the three selected sites. In addition, it is hoped that these data can also support concentrations measured in aquatic biota and in bottom sediment, and provide information on fluxes of contaminants between water and air masses.

## 2. Material and methods

### 2.1 Sampling sites for passive sampling

As part of the *Tilførselsprogrammet* project, three sites for the measurement of trace organic contaminant levels in water and air were selected. These included a site on the Northern coast of Norway (Andøya), a site near Bjørnøya (Bear Island) between continental Norway and the Spitzbergen, and a site further west at Jan Mayen. Coordinates can be found in *Table 1*, while a map with sampling locations is given in *Figure 1*.

*Table 1. Coordinates of sites for passive sampling at Andøya and Bjørnøya*

	Andøya	Bjørnøya	Jan Mayen
<b>Water</b>	N69° 15.442' E16° 10.371'	N74° 30.720' E18° 57.970'	N70° 54.300' W8° 37.400'
<b>Air</b>	N69° 09.510' E15° 59.740'	N74° 30.210' E18° 59.570'	N70° 58.700' W8° 29.500'



*Figure 1. Map showing sites selected for passive sampling (red dots)*

## 2.2 Exposure periods

Exposure periods for passive samplers deployed in water at Jan Mayen and successfully retrieved are provided in **Table 2**. Samplers were exposed for 273 days at Jan Mayen from the 29.06.2010 to the 29.03.2011. Samplers deployed at Andøya and at Bjørnøya for period from Mid2010 to Mid2011 then Mid2011 until 2012 were lost. No information is provided for sampling at Jan Mayen for the period from Mid2011 to 2012, since passive samplers were also lost at sea.

**Table 2.** Deployment and retrieval dates and periods of exposure for passive samplers deployed in water at Jan Mayen

	Jan Mayen Water
<b>Deployment</b>	29.06.2010
<b>Retrieval</b>	29.03.2011
<b>Exposure time (d)</b>	273

Two passive air samplers were deployed in parallel at each site. The sampling periods were supposed to be three months (90 days), but was sometimes exposed longer or shorter due to logistical reasons. Some samples were also lost, but 2011 had a better coverage than the previous year (Allan *et al.*, 2011). The two parallel samples were analysed and the average values are reported here. A list of the deployed and analysed samplers is given in **Table 3**.

**Table 3.** Deployment and retrieval dates and periods of exposure for passive samplers deployed in air at Andøya, Bjørnøya and Jan Mayen.

sample	Andøya			Bjørnøya			Jan Mayen		
	1	2	3	1	2	3	1	2	3
<b>Deployment</b>	14-Jan-11	12-Aug-11	17-Nov-11	23-Nov-10	2-Jan-11	3-Apr-11	26-Jun-10	6-Feb-11	29-Mar-11
<b>Retrieval</b>	12-Aug-11	17-Nov-11	27-Jan-12	2-Jan-11	3-Apr-11	27-Aug-11	6-Feb-11	29-Mar-11	26-Sep-11
<b>nr.days</b>	210	97	71	40	91	146	225	51	181

## 2.3 Passive samplers for air and water monitoring

Two types of passive sampling devices were used for measurements in water. These were polydimethylsiloxane (PDMS or silicone) and semipermeable membrane devices (SPMDs) made of polyethylene tubing filled with triolein lipids (Rusina *et al.*, 2010; Huckins *et al.*, 2006; Vrana *et al.*, 2005). One type of passive air samplers is used, with polyurethane foam (PUF). For details of the different samplers, see Allan *et al.* (2011) and references within.

## 2.4 Analysis for trace organic contaminants

### 2.4.1 Extraction and analyses at NIVA

Extraction procedures described in detail in Allan *et al.* (2011) were used here. Samples were

**PAH analysis:** Extracts were analysed used a HP-6890N gas chromatograph (GC) equipped with a HP 5973 Mass Selective Detector (MS) (Agilent Technologies, USA) operated in single ion monitoring mode (SIM) with electron impact ionisation.

**PCB/OC analysis:** Analyses for chlorinated compounds were originally (Allan *et al.*, 2011) undertaken by Agilent 6890N gas chromatograph (GC) equipped with a G2397A micro Electron Capture detector ( $\mu$ ECD) (Agilent Technologies, USA). Here, extracts were analysed by GC linked to

a mass spectrometer (see PAH method above). Comparability of data provided by the two types of detectors (ECD and MS) was assessed prior to this change of procedures.

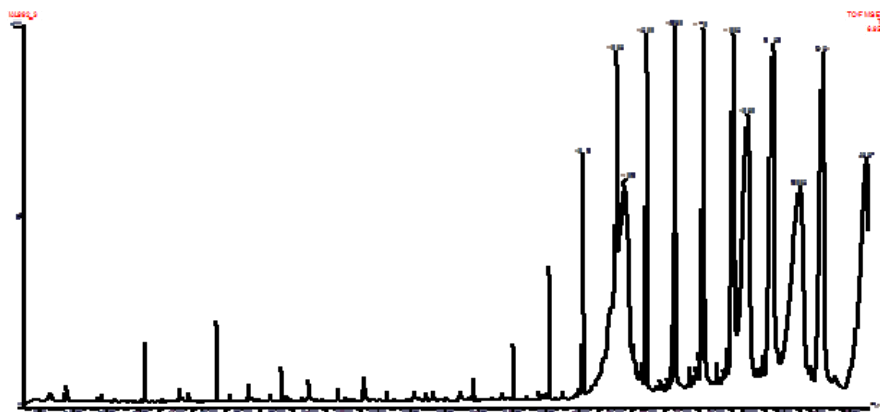
**PBDE (incl. HBCDD) analysis:** Extracts were analysed using a HP-6890 gas chromatograph (GC) equipped with a HP 5973 Mass Selective Detector (MS) (Agilent Technologies, USA) operated in single ion monitoring mode (SIM) with negative chemical ionisation (NCI) and methane as the reagent gas.

The sum of HBCDD isomers was assessed on the PBDE GC/MS chromatograms. A spike/recovery test with a silicone strip sampler was undertaken to test the extraction efficiency. Recoveries were > 100%.

**Non target screening with GC/TOF-MS:** Samples were screened by gas chromatography coupled to time-of-flight mass spectrometry (GC/ToF/MS) (GCT Premier, Waters, Sweden). Potential analytes were separated on a DB5-MS column (30 m x 250 µm x 25 µm id) (J&W Scientific) at a constant flow rate of 1 ml/min.

The GC/ToF/MS was operated with greater than 8000 resolution, with a source temperature of 180 °C and an injector temperature of 270 °C. The initial oven temperature was 60 °C with a 3 minute hold time, the temperature was then ramped at 5 °C/min to 180 °C and held for 10 minutes. The MS scan range was 50-800 m/z (an example of full scan chromatogram is given in *Figure 2*).

ChromaLynx software (Waters, Sweden) was used for the deconvolution of non-target analytes (*Figure 3*). Peaks tentatively identified using ChromaLynx were then confirmed using accurate mass determination (*Figure 4*). Retrospective targeted analysis was also performed to indicate the presence of specific human impact markers such as caffeine, benzophenone and musk xylenes. Caffeine, a stimulant found in tea, coffee, many medications and energy drinks is a good indicator receiving waters being impacted with treated and non-treated wastewater. Benzophenone is a UV filter used in sun screens but is also used extensively in other personal care products as are musk xylenes and are also frequently detected in Norwegian surface waters where there is human influence (Langford and Thomas, 2008; non published data).



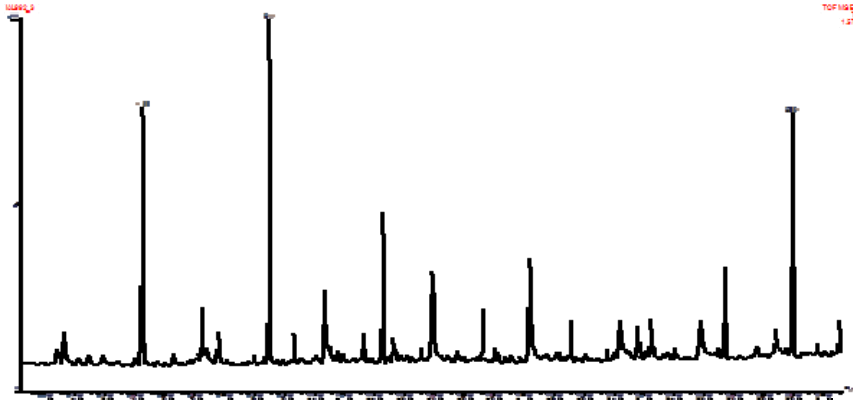


Figure 2. Full scan chromatogram of a Jan Mayen water sample

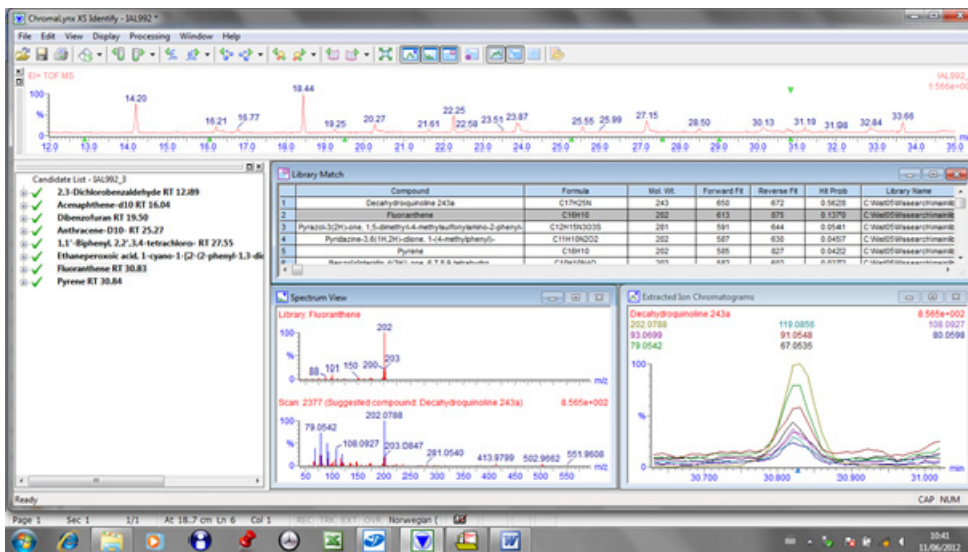


Figure 3. ChromaLynx deconvolution software to tentatively identify peaks

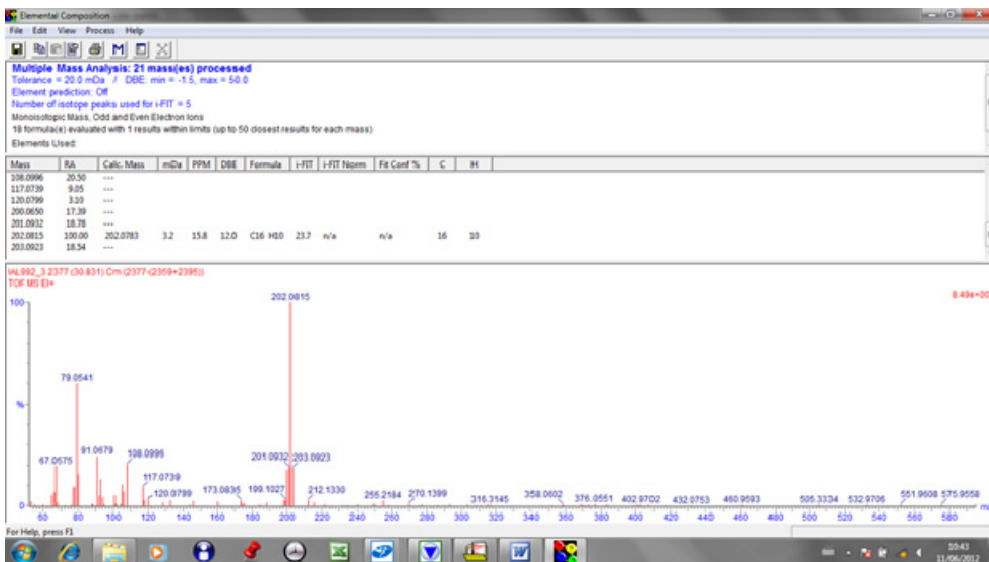


Figure 4. Accurate mass determination for confirmation of peak identity.



### 2.4.2 Extraction and analyses at NILU

The PUF discs were pre-cleaned by soxhlet extraction, dried and spiked with PRCs prior deployment, and returned to the laboratory for clean-up and analysis after exposure in the field. A mixture of internal standards was added to the PUFs before Soxhlet extraction and further clean-up. The cleanup procedure involves separation into two extracts, with acid treatment and silica fractionation for analysis of the halogenated compounds, and silica fractionation for the PAH extracts. The extracts were further concentrated by a gentle stream of nitrogen to ~50 µL and added recovery standards as detailed in Halse *et al* (2011). Identification and quantification of individual substances was carried out using a gas chromatograph coupled to a high resolution (PCBs, hexachlorocyclohexane HCH isomers, hexachlorobenzene HCB, DDTs) and low resolution (PAHs, chlordanes) mass spectrometer. For these substances, the expected uncertainty associated with the overall chemical analysis alone is expected to be in the range of 20-35%, but will vary for different compounds and substance groups. Further details on the analytical method used are provided in (Halse *et al.*, 2011).

## 3. Results and discussion

### 3.1 Contaminant concentrations in water

#### 3.1.1 Calculation of dissolved concentrations

Performance reference compounds (PRCs) are labelled-analogues of compounds of interest. These are reproducibly spiked into the samplers and dissipate from the samplers during exposure. Their dissipation, owing to isotropic exchange between sampler and water, can be used to estimate sampling rates. Significant PRC dissipation was observed for all samplers exposed in water at Jan Mayen and this allowed the estimation of sampling rates for PRC analogues. The most useable PRC for SPMDs was chrysene- $d_{12}$ . Sampling rates calculated from this PRC were 2.3 and 2.5 L d<sup>-1</sup> for replicate samplers (Huckins *et al.*, 2006). This range is similar to that found for deployments at Andøya (Allan *et al.*, 2011). Sampling rates were calculated from fluoranthene- $d_{10}$  and chrysene- $d_{12}$  PRC data for silicone strips (Rusina *et al.*, 2010). Sampling rates were in the range 2.2-2.6 L d<sup>-1</sup> and close to those obtained for SPMDs.

Overall, these sampling rates are relatively low but similar to those observed at Andøya and Bjørnøya in 2009-2010. This may be the result of the low temperatures experienced during these deployments. It can be assumed that under these conditions, sampling remained integrative for compounds with log  $K_{ow} > 6.0$ . From this data, deployment and sampler specific sampling rates were estimated for all compounds of interest. As mentioned previously, some uncertainty is linked to the selection of the model itself but also can be the result of uncertainty of some of the model parameters (e.g. sampler-water partition coefficients  $K_{sw}$  values used for some compounds such as PBDEs).

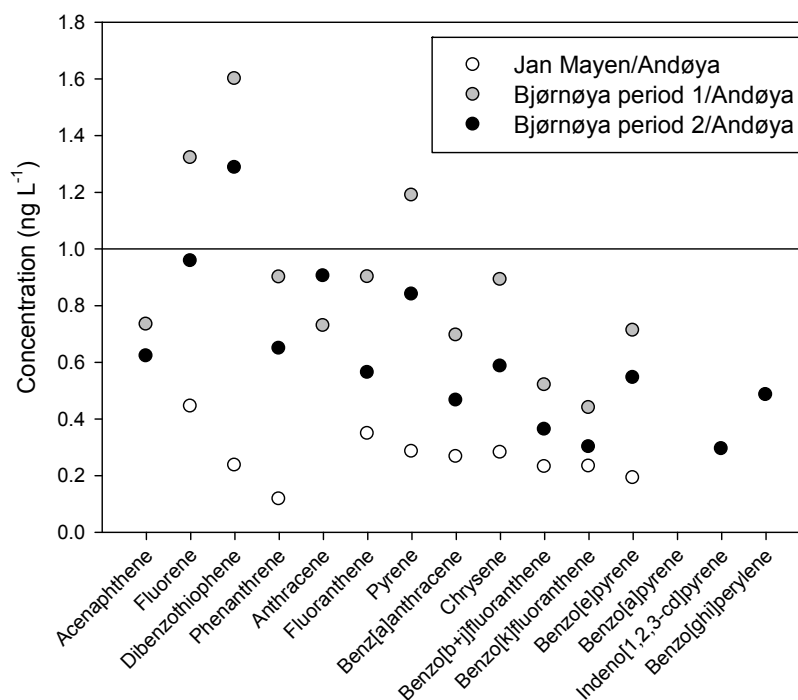
#### 3.1.2 Polycyclic aromatic hydrocarbons (PAHs)

Estimated dissolved concentrations of PAHs measured at Jan Mayen are presented in **Table 4**. Many PAHs were above limits of detection. No data for naphthalene is presented due to the level of these compounds in field and preparation controls (higher than in exposed samplers). Despite the long exposure time, the heavier PAHs (e.g. dibenzo[*a,h*]anthracene) remained below limits of detection (LODs close to 10 pg L<sup>-1</sup>) (see **Table 4**). Data for fluoranthene, pyrene, benz[*a*]anthracene, chrysene, benzo[*b,j*]fluoranthene, benzo[*k*]fluoranthene and benzo[*e*]pyrene from the two types of samplers are very consistent. Standard deviations based on duplicate samplers are in a very acceptable range (< 10 %), particularly when considering the long exposures. All dissolved PAH concentrations were below 1 ng L<sup>-1</sup>.

**Table 4.** Dissolved concentrations of PAHs in water measured with silicone strips and SPMDs at Jan Mayen (dissolved concentration in water (Cw) in ng L<sup>-1</sup>; standard deviation (SD) from replicate samplers). Concentrations above detection limit are shaded.

	Silicone strips		SPMDs	
	Cw (ng L <sup>-1</sup> )	SD	Cw (ng L <sup>-1</sup> )	SD
Acenaphthylene	<0.2		<0.07	
Acenaphthene	<0.08		<0.1	
Fluorene	0.61	0.02	0.09	0.01
Dibenzothiophene	0.036	0.001	<0.03	
Phenanthrene	0.27	0.004	0.061	0.008
Anthracene	<0.02		0.03	0.00
Fluoranthene	0.37	0.01	0.21	0.02
Pyrene	0.071	0.001	0.056	0.007
Benz[a]anthracene	0.015	0.000	0.011	0.000
Chrysene	0.047	0.001	0.043	0.001
Benzo[b+] <i>l</i> fluoranthene	0.046	0.000	0.049	0.001
Benzo[k] <i>l</i> fluoranthene	0.012	0.000	0.013	0.001
Benzo[e]pyrene	0.019	0.001	0.020	0.000
Benzo[a]pyrene	<0.009		<0.01	
Perylene	<0.009		<0.01	
Indeno[1,2,3- <i>cd</i> ]pyrene	<0.010		<0.01	
Dibenzo[ <i>ah</i> ]anthracene	<0.010		<0.01	
Benzo[ <i>ghi</i> ]perylene	<0.009		<0.01	

PAH concentrations measured with silicone strips at Jan Mayen were a factor of 2.5 to 10 below those measured at Andøya on the coast of Norway (Figure 5). These concentrations were also generally lower than those reported in 2011 for Bjørnøya.



**Figure 5.** Ratios of PAH concentrations measured with silicone strips at Jan Mayen and Bjørnøya over those from the coastal area of Andøya. Note: a ratio below 1 for example indicates lower concentrations at Jan Mayen and Bjørnøya.

### 3.1.3 Polychlorinated biphenyls (PCBs) and other organochlorines (OCs)

Dissolved concentrations of  $\alpha$ - and  $\gamma$ -HCH,  $p,p'$ -DDE,  $p,p'$ -DDD,  $p,p'$ -DDT, HCB, PCBs and pentachlorobenzene (PeCB) measured at Jan Mayen are presented in **Table 5**. PCB-28 was detected in silicone strips while PCB-153 was found in one SPMD. An estimate of PCB-28 concentration was 3.8  $\mu\text{g L}^{-1}$ .

PeCB, HCB,  $\alpha$ -HCH and  $p,p'$ -DDE were consistently found in both types of samplers. Levels of  $p,p'$ -DDD and  $\gamma$ -HCH above LOD were only observed in silicone strips. Estimates of HCB and  $p,p'$ -DDE concentrations in water given by the two samplers are consistent. Data for other compounds, particularly those with lower  $K_{ow}$  values (e.g.  $\alpha$ -HCH) likely to have reached equilibrium show more significant differences in estimates of concentrations in water. These could be due to uncertainties in sampler-water partition coefficients, or reflecting different sampling times for the two types of samplers. The detection of  $\gamma$ -HCH was possible with silicone strips most likely due to their larger volume that resulted in lower limits of detection for compounds that equilibrate relatively rapidly.

**Table 5.** Dissolved concentrations of PCBs and organochlorines (OCs) in water measured with silicone strips and SPMDs at Jan Mayen (concentration in  $\text{ng L}^{-1}$ ; standard deviation (SD) from replicate samplers). Concentrations above detection limit are shaded.

	Silicone strips		SPMDs	
	Cw ( $\text{ng L}^{-1}$ )	SD	Cw ( $\text{ng L}^{-1}$ )	SD
<b>PCB-28</b>	0.0038	0.0003	<0.002	
<b>PCB-52</b>	<0.002		<0.002	
<b>PCB-101</b>	<0.002		<0.002	
<b>PCB-118</b>	<0.002		<0.003	
<b>PCB-105</b>	<0.002		<0.002	
<b>PCB-153</b>	<0.002		0.0034	**
<b>PCB-138</b>	<0.002		<0.003	
<b>PCB-156</b>	<0.002		<0.004	
<b>PCB-180</b>	<0.002		<0.004	
<b>PCB-209</b>	<0.003		<0.007	
<b>PeCB</b>	0.017	0.001	0.0071	0.0002
<b><math>\alpha</math>-HCH</b>	1.1	0.1	0.14	0.04
<b>HCB</b>	0.076	0.005	0.059	0.001
<b><math>\gamma</math>-HCH</b>	0.50	0.06	<0.2	
<b><math>p,p'</math>-DDE</b>	0.0018	0.0000	0.0025	0.0004
<b><math>p,p'</math>-DDD</b>	0.0042	*	<0.004	
<b><math>p,p'</math>-DDT</b>	<0.006		<0.004	

\*Detected and quantified in only one sampler

\*\*Detected and quantified in only one sampler (possible sampler contamination)

Isomers of HCH were detected in some but not all samplers from all three stations (including data from Allan et al. (2011)). The table below presents the concentrations measured at Jan Mayen in the present study and compares these values to data found in the literature. Concentrations and ratios (~ 2.2) of concentrations of  $\alpha$ -HCH and  $\gamma$ -HCH measured at Jan Mayen are very similar to those measured in 2009-2010 at Bjørnøya (**Table 6**). Passive sampling data are scarce or non-existent, and most data is based on high volume water sampling. Based on our limited dataset,  $\alpha/\gamma$ -HCH ratio appears close or below 1 at Andøya and generally shows slightly higher concentrations for Bjørnøya and Jan Mayen. There is some uncertainty regarding the sampler-water interaction ( $\log K_{sw}$ ) values for silicone strips used here and data should be treated with care. Values of  $K_{sw}$  were obtained from other researchers (F. Smedes; personal comm.). The difference in isomer concentrations observed at Bjørnøya and Jan Mayen supports the current notion that there is distillation of the  $\gamma$ -isomer during air transport above the Atlantic Ocean (the ocean acts as a sink). This process increases the relative level of the  $\alpha$ -isomer in the air in the Arctic and results in increases in concentrations of  $\alpha$ -HCH in Arctic

water. Photo-isomerisation processes resulting in the conversion of the  $\gamma$ -HCH into  $\alpha$ -HCH may also be responsible for the relative concentrations of the two isomers.

**Table 6.** Water concentrations of  $\alpha$ - and  $\gamma$ -HCH observed in this study (silicone strip data) and found in the literature and resulting isomer ratios.

Site/Coordinates	Concentration (pg L <sup>-1</sup> )			
	$\alpha$ -HCH	$\gamma$ -HCH	$\alpha$ / $\gamma$ -HCH ratio	
Jan Mayen	1100	500	2.2	This study
Andøya	467	366	1.3	Allan <i>et al.</i> , 2011
Bjørnøya	1054/828	454/393	2.3/2.1	Allan <i>et al.</i> , 2011
N75 E14	59	72	0.8	Lakaschus <i>et al.</i> (2002)
N59.8 E42	194	504	0.4	Lakaschus <i>et al.</i> (2002)
Near Greenland	0.9	0.2	4.5	Summarised in Walker <i>et al.</i> (1999)
E. Arctic Ocean	0.91	0.27	1.5-5	

Very few passive sampling measurements of *p,p'*-DDE and HCB for Arctic waters exist. Booij *et al.* (2007) measured HCB with SPMDs during a cruise in the English Channel/Atlantic. Concentrations measured on the Norwegian coast are in agreement with the levels they observed (**Table 7**). Data summarised by Barber *et al.* (2005) indicated seawater concentrations for HCB generally in the range 5-27 pg L<sup>-1</sup>. Concentrations measured at Jan Mayen are slightly higher than that (**Table 7**).

DDT's degradation product *p,p'*-DDE was also measured as part of the study of Booij *et al.* (2007) and was found at concentrations in the low pg L<sup>-1</sup> level, close to those measured at Andøya, Bjørnøya and Jan Mayen.

**Table 7.** Water concentrations of *p,p'*-DDE and HCB observed in this study (silicone strip/SPMD) and found in the literature

Site/Coordinates	Concentration (pg L <sup>-1</sup> )		
	<i>p,p'</i> -DDE	HCB	
Jan Mayen	1.8/2.5	76/59	This study
Andøya	4.2	29/45	Allan <i>et al.</i> , 2011
Bjørnøya	2.3	48-117	Allan <i>et al.</i> , 2011
English Channel/Atlantic ocean	1.4	9	Booij <i>et al.</i> (2007)
Seawater (active sampling)		5-27	Barber <i>et al.</i> (2005)

### 3.1.4 Polybrominated diphenylethers (PBDEs)

Dissolved concentrations of PBDEs measured with silicone strips at Jan Mayen are given in **Table 8**. No data for SPMDs is reported since levels in the control samplers for BDE-47, BDE-99 and BDE-209 were high. These were approximately 20 % (BDE-99), 50 % (BDE-47) and 100 % (BDE-209) of amounts found in samplers exposed in Jan Mayen. Masses of BDE-99 accumulated in SPMDs (control data subtracted) are of a similar level as those found in silicone strips (data not shown). Contamination of SPMDs with PBDEs during production is possible and may be relatively variable.

Two PBDEs, the tetrabromodiphenylether PBDE-47 and the pentabromodiphenylether PBDE-99, were consistently detected in silicone. Concentrations of PBDE-47 and PBDE-99 measured with silicone strips were 0.27 and 0.58 pg L<sup>-1</sup>, respectively. The reproducibility of the measurement of BDE-47 and BDE-99 with silicone is generally poorer than those for PAHs and PCBs/OCs, but SDs remain under 30 %. BDE-209 was also found very close to limits of detection in silicone strips, allowing tentative estimation of dissolved concentrations.

Concentrations of BDE-99 and BDE209 at all three stations are generally similar, levels of BDE-47 appear lower (by one order of magnitude) at Jan Mayen than at the other two locations (Allan *et al.*, 2011).

**Table 8.** Dissolved concentrations of PBDEs in water measured with silicone strips and SPMDs at Andøya (concentration in  $\text{pg L}^{-1}$ ; standard deviation (SD) from replicate samplers). Concentrations above detection limit are shaded.

	Silicone strips	
	Cw ( $\text{ng L}^{-1}$ )	SD
PBDE-28	<0.0002	
PBDE-47	0.00027	0.00005
PBDE-49	<0.0002	
PBDE-66	<0.0002	
PBDE-71	<0.0002	
PBDE-77	<0.0002	
PBDE-85	<0.0002	
PBDE-99	0.00058	0.00014
PBDE-100	<0.0001	
PBDE-138	<0.0005	
PBDE-153	<0.0002	
PBDE-154	<0.0002	
PBDE-183	<0.0005	
PBDE-196	<0.0006	
PBDE-205	<0.0006	
PBDE-209	0.0025	0.0005

### 3.1.5 Hexabromocyclododecane (HBCDD)

Extracts from silicone strips and SPMDs were screened for HBCDD. No HBCDD (sum of all isomers) was found in any of the samples. The limit of detection for this was  $0.5 \text{ ng sampler}^{-1}$ . Knowledge and understanding of sampling rates for this chemical does not allow us to calculate limits of detection in terms of concentrations in water. However these are likely to be of the same order of magnitude as those found for PBDEs.

### 3.1.6 Comparison of data obtained with Environmental Quality Standards (EQS) set by the European Union's Water Framework Directive

Under Water Framework Directive legislation (2000/60/EC), the European Union has established target Environmental Quality Standards (AA-EQS) for a set of priority substances (2008/105/EC) for inland and coastal waters. Assuming these concentrations (in the whole water) can also be applied for areas around Jan Mayen and Bjørnøya, they provide a basis as reference values for establishing good water quality status. Priority substances that were analysed for in passive sampler extracts from Jan Mayen are given in **Table 9**, together with respective AA-EQS values and dissolved concentrations estimated with the passive sampling devices. One has to bear in mind that passive sampling-derived concentrations are for freely dissolved contaminants while AA-EQS values refer to "whole water" samples. On average, passive sampling-derived concentrations for Jan Mayen are > 1000 times lower than AA-EQS values for anthracene, benzo[*a*]pyrene and *p,p'*-DDT. Those for fluoranthene, hexachlorobenzene, pentachlorobenzene, benzo[*b+k*]fluoranthene are between 100 and 1000 times lower than AA-EQS values. On average, the sum of concentrations of benzo[*ghi*]perylene and indeno[*1,2,3-cd*]pyrene are approximately a factor of 100 lower than EQS values. The sum of five PBDE congener concentrations (including LODs) was a factor of 100 below EQS. Hexachlorocyclohexane (HCH) was apparently close to EQS levels.

**Table 9.** EU WFD's annual average environmental quality standards (AA-EQS) for a range of priority substances that were analysed for in samplers deployed at Jan Mayen and concentrations in water measured at this site.

Priority substances	AA-EQS (ng L <sup>-1</sup> )	Jan Mayen (ng L <sup>-1</sup> )
Anthracene	100	0.03 (SPMD)
Pentabromodiphenylether <sup>a</sup>	0.2	<0.0016 (Sil)
Fluoranthene	100	0.37 (Sil)
Hexachlorobenzene	10	0.076 (Sil)
Hexachlorocyclohexane	2	1.6 (Sil)
Pentachlorobenzene	7	0.017 (Sil)
Benzo[a]pyrene	50	<0.01 (SPMD)
Benzo[b+k]fluoranthene*	30	0.062 (SPMD)
Benzo[ghi]perylene & indeno[1,2,3-cd]pyrene**	2	<0.02 (SPMD)
Sum of DDTs***	25	0.006 (Sil)
p,p'-DDT	10	<0.006 (Sil)

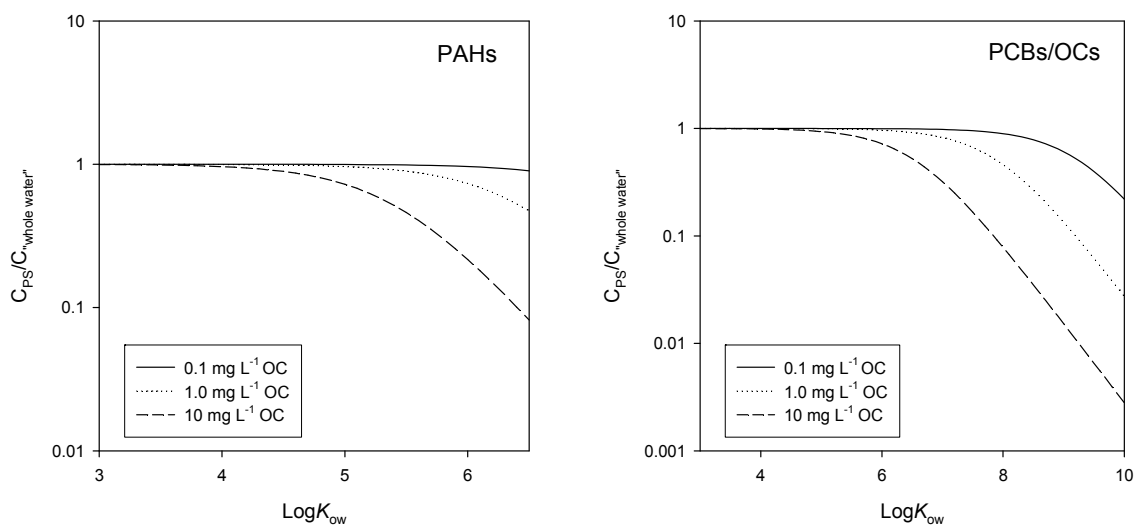
<sup>a</sup>BDE-28, BDE-47, BDE-99, BDE-100, BDE-153, BDE-154

\*Sum of benzo[b]fluoranthene and benzo[k]fluoranthene

\*\*Sum of Benzo[ghi]perylene and indeno[1,2,3-cd]pyrene

\*\*\*Sum of isomers with CAS numbers: 50-29-3, 789-02-6 and 72-54-8

Passive sampling-derived concentrations are for freely dissolved contaminants while AA-EQS values refer to “whole water” samples. This renders their direct comparison difficult. Depending on the amount and type of organic carbon in water, a proportion (more or less significant) of contaminants will be sorbed to particulate and dissolved organic matter. Based on published organic carbon-water partition coefficients,  $K_{oc}$  (Scharwzenbach *et al.*, 2003), it is possible to estimate the fraction of the “whole water” concentration that is being measured with a passive sampler. **Figure 6** presents modelled passive sampler-derived concentrations relative to “whole water” concentrations as a function of compound's hydrophobicity and the level of organic carbon (with no differentiation between particulate and dissolved organic carbon) in water. For example for PAHs with  $\log K_{ow}$  of 6.5 and a OC content of the water of 1 mg L<sup>-1</sup>, the passive sampler-derived concentration is approximately 50 % of the “whole water” concentration. This indicates that for most substances in the table above (**Table 9**), with a total organic carbon content of the water of 1 mg L<sup>-1</sup>, “whole water” concentrations are likely to be below EQS. This modelling is likely to be very uncertain for compounds such as pentabromodiphenylether with  $\log K_{ow}$  values between 6 and 10 and for which a larger proportion is likely to be associated with organic carbon in water (see **Figure 6**).



**Figure 6.** Modelled contaminant concentrations measured with passive sampling devices relative to “whole water” concentrations accounting for contaminant partitioning to organic carbon (OC) at three levels (0.1, 1.0 and 10 mg L<sup>-1</sup>).

### 3.1.7 Comparison of data obtained with concentrations in biota

As part of the overall project (Green *et al.*; 2010) contaminant concentrations were also measured in cod liver (*Gadus morhua*) at sampling sites at Jan Mayen. Bioaccumulation factors (BAFs) for compounds (some PCBs, OCs and PBDEs) measured in cod liver from Jan Mayen are presented in **Table 10**. Values obtained tend to be in good agreement with  $\log K_{ow}$  of the respective compounds and with  $\log$  BAF measured at Andøya and Bjørnøya. Differences of 0.8 and > 1 log unit can be seen between  $\log$  BAF measured at Jan Mayen and those from Andøya and Bjørnøya for *p,p'*-DDE and BDE-47, respectively.  $\log$  BAF values for BDE-99 and BDE-209 are significantly lower than what would be expected from their respective  $\log K_{ow}$  values.

**Table 10.** Bioaccumulation factor (normalised to lipid content of the liver),  $\log$  BAF (L kg<sup>-1</sup> lipid) for PCBs/OCs and PBDEs.  $\log K_{ow}$  values are given for information.

	$\log K_{ow}$	Log BAF (L kg <sup>-1</sup> lipid)*		Jan Mayen
		Andøya**	Bjørnøya**	
PCB-28	5.67	5.78		6.14
PeCB	5.18	5.21		5.30
$\alpha$ -HCH	3.81	3.60	3.59	3.56
HCB	5.50	5.48	5.65	5.81
$\gamma$ -HCH	4.14		3.85	3.27
<i>p,p'</i> -DDE	6.29	7.07		7.89
<i>p,p'</i> -DDD	6.33			6.96
PBDE-28	5.98	5.16		
PBDE-47	6.60	6.19	6.07	7.40
PBDE-99	7.22			5.37***
PBDE-209	10.3			5.59***

\*Data given only when both cod liver and water concentrations were > LODs

\*\*Data from Allan *et al.* (2011)

\*\*\*Data with large uncertainty



### 3.1.8 Non-target screening of silicone strip extracts by GC/TOF-MS

No caffeine or benzophenone was detected in any sample and no personal care products, such as Galaxolide or Tonalide musk compounds, were detected in either the laboratory or field control samples. No common phosphorus flame retardants were detected in these samplers. The deuterated PAH internal standards were detected in all samples confirming successful analysis of all samples.

**Table 11.** Compound identified in two water samples and one air sample from Jan Mayen.

Jan Mayen Water 1	Jan Mayen Water 2	Jan Mayen Air 1
Dichlorobenzaldehyde		Dichlorobenzaldehyde
Dibenzofuran*		Dibenzofuran*
	3,5-Dichlorobenzoyl chloride*	
3,5-Dichlorobenzoyl chloride*		
3-Phenyl-4-hydroxyacetophenone*	3-Phenyl-4-hydroxyacetophenone*	
Chlorinated compound		
Phthalate compound		Phthalate compound
Fluoranthene/Pyrene	Fluoranthene/Pyrene	
		Cyclic octaatomic sulphur

\*Denotes tentative determination and identification

The fact that no personal care products were detected in the control samples demonstrates good sample handling procedures in the field and in the laboratory which is a very important consideration when doing non-targeted screening of samples.

This small data set also supports the theory that long range transport is not an import process when considering the human impact marker caffeine which enables its use as an indicator of direct human impact to receiving waters.

Dichlorobenzaldehyde (*Table 11*) was identified in one water sample and in the air sample. It has historically been used in pesticide formulations and is an intermediate in pharmaceutical and dye processes.

Dibenzofuran was tentatively identified in the same 2 samples as dichlorobenzaldehyde. It has been used in insecticides manufacture and many other industrial processes. These 2 samples, 1 air and 1 water, both also contained a phthalate related compound and a chlorinated compound. It was not possible to identify the compounds but the mass spectrum showed the correct fingerprints to represent a chlorinated compound and a phthalate.

Biphenyl (CAS. 92-52-4) has been used in numerous industrial processes such as the textile industry and PCB manufacture. Limited data is available on current use patterns; however this biphenyl was detected in the air sample.

Octaatomic sulphur (octasulfur) was detected in the air sample.

### 3.2 Contaminant concentrations in air

The individual periods have been averaged over the whole sampling period to give an estimate of the annual average. Further, only a selection of the compounds measured are reported in this chapter,

however all the individual data points are found in Appendix A1. The average was weighted with number of days for each sampling period. Data for PBDEs are not included due to high uncertainty in the data and the fact that most of most compounds are under the detection limit ( $0.01 \text{ pg m}^{-3}$ ). In the following chapters also the measurements from 2010 (Allan *et al.*, 2011) are included for comparison.

### 3.2.1 Polycyclic aromatic hydrocarbons (PAHs)

The average concentration of the 8 different PAHs as shown in *Table 12* was quite similar ( $1\text{-}2 \text{ ng m}^{-3}$ ) for all the sites and between periods. The difference is too small to be called significant. The level is comparable to what was reported in the passive sampler study conducted in 2006 (Halse *et al.*, 2011).

The more abundant PAHs include phenanthrene and fluorene, and the contribution from heavier PAHs with higher affinity for particulate matter is much lower.

**Table 12.** Concentrations of selected PAH ( $\text{ng m}^{-3}$ ) in air measured with passive samplers

From To	Andøya		Bjørnøya		Jan Mayen	
	29-Nov-09 16-Aug-10	14-Jan-11 27-Jan-12	29-Dec-09 28-Aug-10	23-Nov-10 27-Aug-11	5-Jan-10 29-Jul-10	26-Jun-10 26-Sep-11
Fluorene	0.67	0.53	0.59	0.46	0.69	0.56
Phenanthrene	0.71	0.64	0.46	0.72	0.26	0.92
Anthracene	0.010	0.001	0.005	0.001	0.002	0.002
Fluoranthene	0.22	0.06	0.17	0.05	0.12	0.07
Benz(a)anthracene	0.01	0.003	0.003	0.004	0.001	0.01
Chrysene	0.02	0.05	0.016	0.07	0.012	0.09
Benzo(a)pyrene	0.005	0.001	0.001	0.001	0.003	0.001
Pyrene	0.08	0.05	0.06	0.06	0.03	0.08
<b>Sum 8 PAH</b>	<b>1.7</b>	<b>1.3</b>	<b>1.3</b>	<b>1.4</b>	<b>1.1</b>	<b>1.7</b>

### 3.2.2 Polychlorinated biphenyls (PCBs) and other organochlorines (OCs)

The concentrations of PCBs are shown in *Table 13*, and the level in 2010 was somewhat higher at Andøya compared with the two other sites, and with results from 2011. The difference is relatively larger for the heavier PCBs. This is a general pattern due to the more limited long-range atmospheric transport potential of heavier PCBs with distance from sources (Wania and Daly, 2002), but these differences are not significant in 2011, indicating the relatively large annual variability due to variations in meteorology and the number/magnitude of episodes between years.

The concentration of HCB on the other hand is highest at Jan Mayen and lowest at Andøya, similar is seen for pentachlorobenzene (PeCB), though the level is lower in the latter period at all sites. These are also among the most volatile substances investigated and which may have reached equilibrium during the sampling periods. Colder air temperatures which are typically also correlated with wind speeds and expected at the northernmost sites will favour enhanced partitioning and uptake from the gas phase to the PUF, leading to enhanced relative amounts sequestered by the northernmost samplers, and could thus help explain the elevated air concentrations at the northernmost sites. This also incidentally illustrates some of the limitations of the PAS method when used at cold and windy sites in the Arctic. The levels of HCB is also significantly higher than seen in the average concentration of HCB in the passive campaign in Europe in 2006 ( $49 \pm 18 \text{ pg m}^{-3}$ ) and for the active sampler. But the regional distribution with a tendency to higher HCB to the most northern sites is also seen for the

active samplers, where the HCB concentrations presented at Birkenes, Andøya and Zeppelin (Svalbard) the levels in 2011 was 24, 46 and 81  $\text{pg m}^{-3}$  respectively by (Aas et al., 2012)

For chlordanes the level between sites are very comparable; furthermore, the levels of the individual chlordanes as well as the sum of the selected four compounds, are similar or a bit higher to the average European level in air experienced in the passive campaign in summer 2006, i.e.  $3.5 \pm 2.7 \text{ pg/m}^3$  (Halse et al., 2011), though higher than what is seen in the active samplers which is about  $1 \text{ pg/m}^3$  in Norway (Aas et al., 2012).

The  $\alpha$ -HCH concentration is higher at the two most Arctic sites compared two Andøya. This may reflect that the ocean can act as a source of  $\alpha$ -HCH and/or enhanced uptake because of cold temperatures and enhanced wind speeds, though the uncertainty in the method is too high to conclude on this. For the regular monitoring with active sampler the levels of  $\alpha$ -HCH at Birkenes, Andøya and Zeppelin are around  $6\text{-}9 \text{ pg/m}^3$ , with highest level at Birkenes, but lower at Andøya compared to Zeppelin (Aas et al., 2012). As expected because of a more limited long range transport potential due to enhanced potential for wash-out by rain, the level of  $\gamma$ -HCH is lower than  $\alpha$ -HCH in these arctic sites and comparable to each other.

For DDTs the highest level is seen at Andøya for 2011, while at Bjørnøya in 2010. For all sites the *p,p'*-DDE is the most important isomer. The level is however higher than what is seen in the active sampler at Zeppelin and Andøya,  $0.4\text{-}0.6 \text{ pg m}^{-3}$  in 2011 (Aas et al., 2012).

**Table 13.** Concentrations of selected PCBs and OCs ( $\text{pg m}^{-3}$ ) in air measured with passive samplers.

From To	Andøya		Bjørnøya		Jan Mayen	
	29-Nov-09 16-Aug-10	14-Jan-11 27-Jan-12	29-Dec-09 28-Aug-10	23-Nov-10 27-Aug-11	5-Jan-10 29-Jul-10	26-Jun-10 26-Sep-11
PCB-28	3.5	1.5	2.1	1.3	1.7	1.5
PCB-52	2.5	1.9	2.3	1.5	2.0	1.9
PCB-101	2.5	1.3	1.4	0.9	1.1	1.0
PCB-118	0.6	0.4	0.5	0.4	0.3	0.3
PCB-138	1.6	0.5	0.5	0.4	0.4	0.3
PCB-I53	2.3	0.8	0.8	0.5	0.5	0.5
PCB180	0.8	0.1	0.2	0.1	0.1	0.1
Sum 7 PCB	13.9	6.5	7.8	5.1	6.2	5.7
HCB	66	56	107	71	129	112
PeCB	9	7	12	9	16	14
trans-Chlordane	0.6	1.0	1.0	0.7	1.0	1.0
cis-Chlordane	1.4	2.5	2.4	1.8	2.2	2.8
trans-Nonachlor	1.2	2.2	2.0	1.7	1.9	2.2
cis-Nonachlor	0.1	0.3	0.2	0.2	0.1	0.3
sum 4 chlordaner	3.3	6.1	5.6	4.4	5.2	6.2
$\alpha$ -HCH	11.7	11.6	21.3	13.4	18.5	23.2
$\gamma$ -HCH	2.9	3.8	3.1	2.3	2.6	3.6
p,p'-DDE	1.8	3.1	4.3	1.5	2.2	1.8
p,p'-DDD	0.06	0.09	0.07	0.07	0.23	0.07
o,p'-DDT	0.49	0.66	0.92	0.45	0.66	0.72
p,p'-DDT	0.31	0.48	0.55	0.19	0.27	0.25
Sum 4 DDTs	2.7	4.3	5.9	2.2	3.4	2.9

## 4. Conclusions

### 4.1 Passive sampling in water

Passive sampling devices (semipermeable membrane devices and silicone strips) were deployed at three sites, namely Andøya, Bjørnøya and Jan Mayen. Samplers exposed at Andøya and Bjørnøya during the period 2010-2012 were repeatedly lost due to sea conditions at these sites. Therefore no data are available for these locations. Useful and novel data was obtained from Jan Mayen for samplers exposed for close to 300 days between 2010 and 2011. The relatively lengthy deployments for samplers exposed at Jan Mayen ensured improved limits of detection. For certain compounds, it was possible to compare dissolved water concentrations with those measured in fish (cod) liver.

#### Detailed conclusions of this work are:

- A high number of samplers were lost due to sea conditions. Improvements in sampler deployment (e.g. using acoustic release equipment) are needed. Only data from one exposure at Jan Mayen are available.
- The quality of field control (and preparation control) silicone samplers was adequate, though procedures aiming to minimise possibilities for contamination of samplers during exposure and retrieval manipulations should be optimised.
- Dissipation of performance reference compounds allowed the quantification of contaminant exchange kinetics between water and the samplers. In turn, sampling rates could be calculated for the period of deployment. Sampling rates for silicone strips and SPMDs at Jan Mayen were similar to those observed for Andøya and Bjørnøya (2009-2010 data).
- All target analyses indicated low contaminant concentrations. Highest concentrations (about 1 ng L<sup>-1</sup>) were observed for lindane and its alpha isomer.
- PAH concentrations appeared generally lower at Jan Mayen than at Andøya or Bjørnøya.
- PCB concentrations in water are very low and close to or below limits of detection for Jan Mayen (similarly to Andøya and Bjørnøya). These limits of detection are in the low pg L<sup>-1</sup>.
- Limits of detection for PeCB and HCB are adequate.
- Limits of detection for *p,p'*-DDE and HCH isomers are in a similar range as that of concentrations measured. Silicone strips appear to absorb higher amount of HCH isomers than SPMDs and allowed to verify isomer ratios for the water phase.
- PBDE-47 and PBDE-99 are consistently found above limits of detection. PBDE-47 was found at a concentration approximately an order of magnitude lower than at the two other sampling locations. PBDE-209 was detected very close to LODs in silicone strips. Concentrations in the low pg L<sup>-1</sup> were estimated but are associated with significant uncertainty.
- Screening for HBCDD isomers did not result in the detection of this chemical in any of the silicone strips exposed at Jan Mayen.
- The performance of silicone strips and SPMDs is similar. It is possible however that discrepancies in the data obtained with the two types of samplers is the result their efficiency at low temperature. The larger volume of silicone strips improves limits of detection for chemicals that have reached equilibrium.
- Unless sampler conformation is radically changed, exposure time should be kept to 12 months for deployments in water. Alternatively sampler exposures could be undertaken using alternative cages to enable higher water turbulences near the sampler surface and hence higher sampling rates (and lower limits of detection).
- The exposure of time-integrative absorption-based samplers (such as SPMDs and silicone strips) in the air resulted in the detection of some contaminants (forthcoming results).
- In most cases, estimates of contaminant concentrations in water appear to be well below environmental quality standards set by the European Union's Water Framework Directive

(WFD). Accounting for partitioning to suspended particles is not likely to result in substantially higher water concentrations for these chemicals. One exception was for hexachlorocyclohexane that was close to EQS values.

- Passive samplers are able to provide information on contaminant levels in locations where it is generally difficult to obtain samples of biota. In addition, they appear very suited to the evaluation of long term trends in concentrations.

## **4.2 Air monitoring**

The results obtained on the basis of passive air samplers are broadly consistent with results from past findings and active air samplers, yet also revealed difficulties when applying this method at Arctic sites, which are mainly attributed to the climatic conditions experienced (colder temperatures and elevated wind speeds). Thus, the results presented are only expected to represent the “true” air concentrations within a factor of ~2-3. This needs to be taken into consideration when interpreting the results and if these data are to be used to discuss potential equilibrium status and net flux directions between air and surface seawater.

### **Main conclusions:**

- Levels of POPs in air have successfully been measured at three sites (Jan Mayen, Bjørnøya and Andøya) using passive air samplers (PUFs).
- Air concentrations have been back-calculated using depuration compounds, providing estimates of in situ uptake rates.
- The windy conditions often experienced at these Arctic sites lead to uncertainties in back-calculated air concentrations.
- The uncertainty in the PAS method (i.e. a factor 2-3) combined with the limited number of stations (3) makes it difficult to infer something about spatial patterns in air on the basis of the existing dataset, but some general observations are:
  - Concentrations of PCBs, chlordanes and PAHs are comparable between the sites
  - HCB and pentachlorobenzene (PeCB) are highest at Jan Mayen and lowest at Andøya
  - The concentration of  $\alpha$ -HCH is higher at the two most Arctic sites compared with Andøya.

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## **Appendix A. Concentration of POPs in air from passive samplers**



Table A.1 Concentration of all PCBs in air in the individual samples at Andøya, Bjørnøya and Jan Mayen and the averages for the periods, pg m<sup>-3</sup>.

start time endtime nr of days Unit	IUPAC-no.	Bjørnøya			Jan Mayen			Andøya			Average	
		period 1	period 2	period 3	period 1	period 2	period 3	period 1	period 2	period 3		
		pg/m <sup>3</sup>	pg/m <sup>3</sup>	pg/m <sup>3</sup>	pg/m <sup>3</sup>	pg/m <sup>3</sup>	pg/m <sup>3</sup>	pg/m <sup>3</sup>	pg/m <sup>3</sup>	pg/m <sup>3</sup>	pg/m <sup>3</sup>	pg/m <sup>3</sup>
23-Nov-10		17	11	5	16	29	7	14	3	8	16	7
2-Jan-11		100	88	52	135	128	78	112	34	65	110	56
3-Apr-11		2.8	3.2	1.1	4.5	3.5	1.5	3.2	0.5	3.4	5.8	2.3
27-Aug-11	18	1.6	2.0	0.7	2.1	1.8	0.7	1.5	0.6	2.2	3.2	1.4
	28	1.5	2.0	0.7	2.0	1.8	0.7	1.5	0.6	2.1	3.0	1.5
	31	1.0	1.2	0.4	1.2	1.1	0.4	0.9	0.4	1.3	2.0	0.9
	33	0.2	0.2	0.1	0.2	0.2	0.0	0.1	0.1	0.2	0.3	0.2
	37	0.5	0.8	0.3	0.7	0.7	0.3	0.5	0.3	1.0	1.2	0.6
	47	1.6	2.3	1.0	2.4	2.3	1.2	1.9	1.2	2.6	3.2	1.9
	52	0.5	0.6	0.3	0.5	0.5	0.2	0.4	0.4	0.8	0.9	0.6
	66	0.3	0.4	0.2	0.4	0.4	0.2	0.3	0.3	0.5	0.5	0.4
	74	0.4	0.6	0.3	0.6	0.5	0.3	0.4	0.3	0.7	0.8	0.5
	99	0.9	1.3	0.7	1.3	1.1	0.7	1.0	0.9	1.8	1.8	1.3
	101	0.09	0.19	0.08	0.13	0.10	0.06	0.10	0.10	0.15	0.17	0.13
	105	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01
	114	0.29	0.55	0.25	0.41	0.35	0.20	0.32	0.32	0.54	0.60	0.43
	118	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	122	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	123	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	128	0.04	0.12	0.04	0.05	0.03	0.01	0.03	0.01	0.01	0.01	0.02
	138	0.3	0.6	0.3	0.4	0.3	0.2	0.3	0.4	0.7	0.6	0.5
	141	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1
	149	0.5	0.8	0.4	0.8	0.6	0.5	0.6	0.6	1.3	1.0	0.9
	153	0.4	0.8	0.4	0.6	0.5	0.4	0.5	0.6	1.1	0.9	0.8
	156	0.02	0.07	0.02	0.02	0.01	0.01	0.02	0.02	0.03	0.01	0.02
	157	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	167	0.01	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01
	170	0.02	0.07	0.03	0.04	0.02	0.02	0.01	0.03	0.07	0.04	0.04
	180	0.07	0.20	0.12	0.12	0.09	0.09	0.11	0.11	0.23	0.13	0.15
	183	0.03	0.06	0.03	0.06	0.03	0.03	0.04	0.04	0.09	0.06	0.06
	187	0.09	0.18	0.10	0.15	0.13	0.10	0.13	0.14	0.29	0.19	0.19
	189	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	194	0.01	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	206	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Sum 7 PCBs		5	8	3	7	7	3	6	4	9	10	7
Sum PCBs		22	29	17	31	29	18	26	11	32	42	22

Table A 2 Concentration of the all the PAHs in air in the individual samples at Andøya, Bjørnøya and Jan Mayen and the averages for the periods, ng m<sup>-3</sup>.

start time endtime nr of days Unit	Bjørnøya				Jan Mayen				Andøya			
	period 1	period 2	period 3	Average	period 1	period 2	period 3	Average	period 1	period 2	period 3	Average
23-Nov-10 2-Jan-11 40	2-Jan-11 3-Apr-11 91	2-Jan-11 3-Apr-11 91	3-Apr-11 27-Aug-11 146	23-Nov-10 27-Aug-11 277	26-Jun-10 6-Feb-11 225	6-Feb-11 29-Mar-11 51	29-Mar-11 26-Sep-11 181	26-Jun-10 26-Sep-11 457	14-Jan-11 12-Aug-11 210	12-Aug-11 17-Nov-11 97	17-Nov-11 27-Jan-12 71	14-Jan-11 27-Jan-12 378
	ng/m <sup>3</sup>	ng/m <sup>3</sup>	ng/m <sup>3</sup>	ng/m <sup>3</sup>	ng/m <sup>3</sup>	ng/m <sup>3</sup>	ng/m <sup>3</sup>	ng/m <sup>3</sup>	ng/m <sup>3</sup>	ng/m <sup>3</sup>	ng/m <sup>3</sup>	ng/m <sup>3</sup>
Fluorene	0.33	0.34	0.56	0.46	0.53	0.46	0.63	0.56	0.46	0.67	0.56	0.53
Phenanthrene	0.52	0.61	0.84	0.72	0.85	0.88	1.01	0.92	0.48	0.87	0.83	0.64
Anthracene	0.004	0.001	0.001	0.001	0.001	0.001	0.003	0.002	0.001	0.001	0.001	0.001
Fluoranthene	0.05	0.04	0.06	0.05	0.06	0.08	0.07	0.07	0.03	0.06	0.15	0.06
Benzo(a)anthracene	0.003	0.004	0.005	0.004	0.005	0.006	0.006	0.006	0.002	0.004	0.006	0.003
Chrysene	0.05	0.06	0.08	0.07	0.08	0.10	0.10	0.09	0.03	0.07	0.09	0.05
Benzo(a)pyrene	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.0005	0.001	0.002	0.001
Pyrene	0.04	0.05	0.07	0.06	0.07	0.08	0.09	0.08	0.03	0.06	0.08	0.05
<b>Sum 8 PAHs</b>	1.0	1.1	1.6	1.4	1.6	1.6	1.9	1.7	1.0	1.7	1.7	1.3
Naphthalene	11.6	2.9	0.0	2.6	4.4	3.2	4.9	4.5	4.3	5.6	3.8	4.5
Benzo(b, f, k) fluoranthenes	0.011	0.014	0.017	0.015	0.018	0.022	0.022	0.020	0.006	0.016	0.020	0.011
Benzo(ghi)perylene	0.002	0.002	0.003	0.002	0.003	0.004	0.003	0.003	0.001	0.003	0.003	0.002
Acenaphthylene	0.006	0.001	0.001	0.002	0.001	0.001	0.001	0.001	0.017	0.001	0.012	0.012
Acenaphthene	0.15	0.15	0.14	0.14	0.25	0.12	0.29	0.25	0.24	0.34	0.17	0.25
Indeno(1,2,3-cd)pyrene	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.000	0.002	0.001	0.001
Dibenzo(ac,ah)anthracene	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
<b>Sum 16 EPA PAHs</b>	12.7	4.2	1.8	4.1	6.3	5.0	7.2	6.5	5.6	7.7	5.8	6.2
2-Methylnaphthalene	2.3	1.2	1.0	1.2	1.8	1.3	2.0	1.8	1.7	2.3	1.3	1.8
1-Methylnaphthalene	1.7	0.6	0.5	0.7	0.9	0.7	1.0	1.0	0.9	1.2	0.7	0.9
Biphenyl	1.0	0.2	0.2	0.3	0.4	0.3	0.5	0.4	0.4	0.6	0.7	0.5
3-Methylphenanthrene	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.1	0.2	0.1	0.1
2-Methylphenanthrene	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.2	0.2	0.1
2-Methylantracene	0.003	0.003	0.006	0.005	0.005	0.003	0.006	0.005	0.005	0.007	0.004	0.005
9-Methylphenanthrene	0.03	0.03	0.04	0.04	0.04	0.04	0.05	0.05	0.02	0.04	0.04	0.03
1-Methylphenanthrene	0.03	0.04	0.05	0.04	0.05	0.05	0.06	0.05	0.03	0.05	0.05	0.04
Retene	0.011	0.007	0.008	0.008	0.011	0.015	0.012	0.012	0.013	0.013	0.009	0.012

Table A 3 Concentration of all the pesticides in air in the individual samples at Andøya, Bjørnøya and Jan Mayen and the averages for the periods, pg m<sup>-3</sup>.

start time	Bjørnøya				Jan Mayen				Andøya			
	period 1	period 2	period 3	Average	period 1	period 2	period 3	Average	period 1	period 2	period 3	Average
endtime	23-Nov-10	2-Jan-11	3-Apr-11	23-Nov-10	26-Jun-10	6-Feb-11	29-Mar-11	26-Jun-10	14-Jan-11	12-Aug-11	17-Nov-11	14-Jan-11
nr of days	40	91	146	277	225	51	181	457	210	97	71	378
Unit	pg/m3	pg/m3	pg/m3	pg/m3	pg/m3	pg/m3	pg/m3	pg/m3	pg/m3	pg/m3	pg/m3	pg/m3
trans-Chlordane	0.6	1.2	0.4	0.7	1.1	1.3	0.7	1.0	0.7	1.2	1.6	1.0
cis-Chlordane	1.8	2.2	1.6	1.8	3.2	2.5	2.4	2.8	2.1	3.4	2.7	2.5
trans-Nonachlor	1.5	2.1	1.4	1.7	2.4	2.2	1.9	2.2	1.7	3.0	2.7	2.2
cis-Nonachlor	0.1	0.2	0.2	0.2	0.3	0.2	0.3	0.3	0.2	0.4	0.2	0.3
sum 4 chlordaner	4.0	5.6	3.7	4.4	7.0	6.2	5.3	6.2	4.7	8.1	7.2	6.1
α-HCH	17.3	14.4	11.7	13.4	27.2	15.6	20.3	23.2	8.1	15.9	16.2	11.6
γ-HCH	2.7	2.6	1.9	2.3	4.1	2.8	3.1	3.6	2.1	7.3	4.0	3.8
o,p'-DDE	0.2	0.4	0.1	0.2	0.4	0.4	0.1	0.3	0.2	0.3	0.5	0.3
p,p'-DDE	2.0	2.6	0.6	1.5	2.6	2.4	0.7	1.8	1.4	4.9	5.5	3.1
o,p'-DDD	0.05	0.10	0.04	0.06	0.10	0.09	0.07	0.09	0.07	0.13	0.12	0.09
p,p'-DDD	0.04	0.08	0.07	0.07	0.09	0.06	0.04	0.07	0.08	0.13	0.07	0.09
o,p'-DDT	0.6	0.7	0.3	0.4	1.0	0.8	0.4	0.7	0.4	0.9	1.0	0.7
p,p'-DDT	0.3	0.3	0.1	0.2	0.4	0.3	0.1	0.2	0.3	0.8	0.6	0.5
sum 6 DDT	3.3	4.1	1.2	2.5	4.5	4.1	1.4	3.2	2.4	7.3	7.8	4.7



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## Om Statlig program for forurensningsovervåking

Statlig program for forurensningsovervåking omfatter overvåking av forurensningsforholdene i luft og nedbør, skog, vassdrag, fjorder og havområder. Overvåkingsprogrammet dekker langsiktige undersøkelser av:

- overgjødsling
- forsuring (sur nedbør)
- ozon (ved bakken og i stratosfæren)
- klimagasser
- miljøgifter

Overvåkingsprogrammet skal gi informasjon om tilstanden og utviklingen av forurensningssituasjonen, og påvise eventuell uheldig utvikling på et tidlig tidspunkt. Programmet skal dekke myndighetenes informasjonsbehov om forurensningsforholdene, registrere virkningen av iverksatte tiltak for å redusere forurensningen, og danne grunnlag for vurdering av nye tiltak. Klima- og forurensningsdirektoratet er ansvarlig for gjennomføringen av overvåkingsprogrammet.