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Environmental Contaminants in an Urban Fjord, 2018

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REPORT

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Summary

This programme, “Environmental Contaminants in an Urban Fjord” has covered sampling and analyses of sediment and organisms in a marine food web of the Inner Oslofjord, in addition to samples of blood and eggs from herring gull and eider duck. The programme also included inputs of pollutants via surface water (storm water), and effluent water and sludge from a sewage treatment plant. The bioaccumulation potential of the contaminants in the Oslo fjord food web was evaluated. The exposure to/accumulation of the contaminants was also assessed in birds. A vast number of chemical parameters have been quantified, in addition to some biological effect parameters in cod, and the report serves as valuable documentation of the concentrations of these chemicals in different compartments of the Inner Oslofjord marine ecosystem.

Four keywords	Fire emneord
1. Contaminants	1. Miljøgifter
2. Uban areas	2. Urbane områder
3. Food web	3. Næringskjede
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Environmental Contaminants in an Urban Fjord, 2018

Preface

The programme covers sampling and analyses of organisms in a marine food web of the Inner Oslofjord in 2018 in addition to samples of blood and eggs of herring gull. Furthermore, additional samples of blood and eggs of eider duck from the Inner Oslofjord were analysed for selected contaminants in 2018. The programme also includes inputs of pollutants via surface water (storm water), and sewage treatment plant discharges. This monitoring programme adds to results from other monitoring programmes such as "Contaminants in coastal waters" (MILKYS) and "the Norwegian river monitoring programme". These programmes are referred to, when relevant. 2018 represents the sixth year of the Urban Fjord programme. Some changes/improvements were made in the design from 2014 to 2015 and from 2016 to 2017.

The study was carried out by NIVA, with a majority of the chemical analyses performed by the Norwegian Institute for Air Research, NILU. Collection of herring gulls and eider duck was conducted by the University of Oslo (Morten Helberg, Centre for Ecological and Evolutionary Synthesis).

Besides the authors of this report, several persons are acknowledged for their contribution in sample collection, sample preparation, data treatment and analysis: Ingar Johansen, Gunhild Borgersen, Alfhild Kringstad, Camilla With Fagerli, Tânia Gomes, Marthe Torunn Solhaug Jenssen, Pawel Rostowski, Mikael Harju, Hilde Uggerud, Marit Vadset, Inger-Christin Steen, Carsten Lome, Dag Hjermann, Nina Cathrine Knudtzon and Helene Skjeie Thorstensen.

The report has been quality assured by Marianne Olsen.

Oslo, June 2019

Anders Ruus
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Table of contents

Summary

This programme, “Environmental Contaminants in an Urban Fjord” has covered sampling and analyses of sediment and organisms in a marine food web of the Inner Oslofjord in 2018, in addition to samples of blood and eggs from herring gull. Furthermore, optional samples of blood and eggs of eider duck from the Inner Oslofjord were analysed for selected contaminants in 2018. The programme also includes inputs of pollutants via surface water (storm water), and sewage treatment plant discharges.

The objective of the programme was to monitor the inputs of chemicals present in a densely populated area and to study how this contaminant input affects a fjord system. The present study represents one step towards the Norwegian Environment Agency’s general aim to:

- Estimate the degree of bioaccumulation of selected contaminants at several trophic levels in marine food chains.
- Connect pollutant exposure of marine organisms to toxic effects at different biological levels, including endocrine disruption and contaminant interactions ("cocktail effects").
- Identify sources and sinks (i.e. the fate) of environmental contaminants in fjord systems and design targeted actions.

Furthermore, there is an intention that data will be used in international chemical regulation, such as REACH and the Stockholm Convention. The programme was also meant to provide data from governmental monitoring in Norway to comply with the requirements of The Water Framework Directive (The Water Regulation/“Vannforskriften”). 2018 represents the sixth year of the Urban Fjord programme. Some changes/improvements have been made in the design from the start in 2013 to 2018.

The bioaccumulation potential of the contaminants in the Oslo fjord food web was evaluated. The exposure to/accumulation of the contaminants was also assessed in herring gull, as an indicator of an urban fjord inhabitant. In 2018, eider ducks from the Inner Oslofjord were also analysed for selected contaminants. A vast number of chemical parameters have been quantified, in addition to some biological effect parameters in cod, and the report serves as valuable documentation of the concentrations of these chemicals in different compartments of the Inner Oslofjord marine ecosystem.

Analyses of stable isotopes of carbon and nitrogen showed nearly identical results/trophic interactions as in 2015-2017. The isotopic signatures of the eider duck correspond much better with a member of the Inner Oslofjord Marine food web, compared to herring gull, because of their marine diet. The biomagnifying potential of contaminants was evaluated by calculation of Trophic Magnification Factors (TMFs) and several contaminants, and especially legacy contaminants with well-known biomagnifying properties, displayed a positive significant relationship between (log_{10}-) concentrations and trophic position. Arsenic (As), silver (Ag), PFOS and PFOSA were contaminants that displayed a positive significant relationship between (log_{10}-) concentrations and trophic position. For PFOS, this was the case also when eider duck was included in the food web.

The sediments of the inner Oslofjord is a potential source of environmental contaminants to sediment dwelling organisms and the contaminants may thus enter the food chain. Several of the target compounds of this study were detected in sediment. Inputs of several compounds to the fjord via storm water and effluent water from a sewage treatment plant (STP) is also shown.

Concentrations of some compounds exceeded environmental quality standards in sediment (PCB7, Zn, As, Ni, Hg and PFOS), storm water (Bisphenol A, MCCPs, Cu, Zn, As and PFOS) and STP effluent water (MCCPs and PFOS).

Dechlorane plus, a flame retardant in plastics and polymers, was detected in particulate phases, i.e. the particulate fraction in storm water, sewage sludge and sediment. Furthermore, it was found in polychaetes, cod and herring gull (blood and eggs). The sediment concentration appeared in the same range as concentrations found in sediments of the North American Great Lakes. Furthermore, the concentrations in cod appeared a factor ~2 higher than in brown trout from Lake Mjøsa, which were higher than found in trout from Lake Ontario, Canada. The concentrations in herring gull eggs appeared a factor of approximately 3-5 lower than those in eggs of herring gull from the Great Lakes, North America.

As previously reported, concentrations of specific compounds in eggs of herring gull from the Oslo area in 2018 showed interesting differences from concentrations in herring gull eggs from more remote marine colonies (Sklinna and Røst, 2012), suggesting urban influence on the Oslo gulls. In blood of gulls, concentrations of DBDPE were higher than concentrations of any PBDE congeners, as also observed in sediments, storm water and cod liver, likely reflecting that DBDPE is a substitute for BDE-209 in the market.

A significant negative relationship between AChE-activity and the length of cod was found, as previously observed, which may be a result of lower AChE:muscle protein-ratio in larger cod. Thus, no causal relationship between any compounds and AChE activity can be suggested in this study.

Sammendrag

Tittel: Environmental Contaminants in an Urban Fjord, 2018
År: 2019
Forfattere: Anders Ruus, Kine Bæk, Thomas Rundberget, Ian Allan, Bjørnar Beylich, Martin Schlabach (NILU), Nicholas Warner (NILU), Katrine Borgå, Morten Helberg (UiO)
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Dette programmet, "Miljøgifter i en Urban Fjord" har omfattet prøvetaking og analyse av sediment og organismer i en marin næringskjede i Indre Oslofjord i 2018, i tillegg til prøver av blod og egg fra gråmåke. Videre ble blod og egg fra ærfugl i Indre Oslofjord analysert for utvalgte stoffer, som opsjon i 2018. Programmet omfattet også undersøkelser av tilførsler av miljøgifter via overvann, samt via kloakkrenseanlegg.

Målet med programmet var å undersøke tilførsler av miljøgifter som er tilstede i et tett befolket område og studere hvordan disse påvirker et fjordsystem. Denne undersøkelsen er ett skritt mot Miljødirektoratets generelle mål om å:

- Anslå graden av bioakkumulering av utvalgte miljøgifter på flere trofiske nivåer i marine næringskjeder.
- Koble eksponeringen av miljøgifter på marine organismer til toksiske effekter på ulike biologiske nivåer, inkludert hormonforstyrrende effekter og interaksjonseffekter ("cocktaileffekter").
- Identifisere kilder og sluk for miljøgifter i fjordsystemer ("skjebnen" til miljøgifter i en fjord), og utforme målrettede tiltak.

Intensjonen er videre at data skal brukes i internasjonale miljøgiftreguleringer, som REACH og Stockholmkonvensjonen. Dessuten skal programmet frembringe data som vil være til hjelp i å gjennomføre kravene i Vanndirektivet ("Vannforskriften") i forbindelse med statlig basisovervåking. 2018 er det sjette året "Miljøgifter i en Urban Fjord" har vært gjennomført. Det er gjort noen forandringer/forbedringer i design/innhold av programmet fra starten i 2013, frem til 2018.

Bioakkumuleringspotensialet til de ulike miljøgiftene i Oslofjord-næringsnettet er undersøkt. Eksponering for/akkumulering av disse stoffene er også undersøkt i gråmåke, som representant for «urbane innbyggere». I 2018 er også utvalgte miljøgifter analysert i ærfugl fra indre Oslofjord. Konsentrasjoner av et stort antall kjemiske parametere er kvantifisert i denne undersøkelsen, i tillegg til enkelte biologisk effekt-parametere i torsk. Rapporten fungerer som verdifull dokumentasjon av konsentrasjonene av ulike kjemikalier i ulike deler («compartments») av det marine økosystemet i Indre Oslofjord.

Analyser av stabile isotoper av karbon og nitrogen viste nær identiske resultater/trofiske interaksjoner som i 2015-2017. Isotop-signaturen i ærfugl korresponderte vesentlig bedre med det marine næringsnettet, enn det signaturen i gråmåke gjorde, sannsynligvis på grunn av en mer marint basert diett. Biomagnifiseringspotensialet til stoffene i undersøkelsen ble evaluert ved beregning av trofiske magnifiseringsfaktorer (TMF) og flere stoffer, særlig eldre miljøgifter med kjente biomagnifiserende egenskaper, viste som ventet positive sammenhenger mellom (log_{10}-) konsentrasjoner og trofisk posisjon. Arsen (As), sølv (Ag), PFOS og PFOSA var stoffer som viste

positive sammenhenger mellom (log_{10}-) konsentrasjoner og trofisk posisjon. For PFOS var dette også tilfelle når ærfugl ble inkludert i næringsnettet.

Sedimentene i Indre Oslofjord er i utgangspunktet en potensiell kilde for miljøgifter i sedimentlevende bunndyr og således den marine næringskjeden. Flere av stoffene i denne undersøkelsen ble funnet i sediment. Tilførsel til fjorden via overvann og utslippsvann fra kloakkrenseanlegg ble også vist for flere av stoffene. Konsentrasjoner av enkelte stoffer overskred miljøkvalitetsstandarder i sediment (PCB7, Zn, As, Ni, Hg og PFOS), overvann (Bisphenol A, MCCPs, Cu, Zn, As og PFOS) og utslippsvann fra kloakkrenseanlegg (MCCPs og PFOS).

Dechlorane plus, et flammehemmende middel i plast og polymerer, ble detektert i partikkelfaser, spesifikt partikkelfraksjon i overvann, kloakkslam og sediment. Det ble også funnet i polychaeter, torsk og gråmåke (blod og egg). Sedimentkonsentrasjonene fremsto i samme størrelse som tidligere funnet i de store innsjøene i Nord-Amerika. Konsentrasjonene i torsk fremsto en faktor ~2 høyere enn i ørret fra Mjøsa, som igjen er høyere enn i ørret fra Lake Ontario (Canada). Konsentrasjonene i egg fra gråmåke fremsto en faktor omtrent 3-5 lavere enn i egg av gråmåke fra de store innsjøene i Nord-Amerika.

Som rapportert tidligere viste konsentrasjonene av enkelte stoffer funnet i gråmåkeegg fra Oslofjordområdet i 2018 interessante forskjeller fra konsentrasjoner funnet i gråmåkeegg fra mer fjerntliggende marine kolonier (Sklinna og Røst, 2012), som kan tyde på urban påvirkning av måkene fra Oslofjorden. I blod fra gråmåke var konsentrasjonene av DBDPE høyere enn konsentrasjonene av de enkelte PBDE-kongenerne. Tilsvarende ble observert i sediment, overvann og torsk, noe som sannsynligvis gjenspeiler at DBDPE er en erstatning for BDE-209 i markedet.

En signifikant negativ sammenheng ble funnet mellom AChE-aktivitet og lengde av torsk, som tidligere rapportert. Dette kan være et resultat av lavere AChE:muskelprotein-ratio i større torsk. Det kan derfor ikke vises til noen kausal sammenheng mellom kontaminanter og AChE-aktivitet i torsk i denne undersøkelsen.

1 Introduction

"Environmental contaminants in an urban fjord" is a programme designed to monitor discharges of anthropogenic chemicals in a densely populated area and to study how this contaminant input affects a fjord system. The programme addresses inputs of pollutants from potential sources, measurements of contaminant concentrations in different marine species, assessment of bioaccumulation patterns within a food web and estimation of effect risks in organisms. The programme contributes to the Norwegian Environment Agency's ongoing monitoring activity in coastal areas and supplements two other monitoring programmes: "the Norwegian river monitoring programme " and "MILKYS - Environmental contaminants in coastal waters".

1.1 Objectives

The environmental monitoring activity in the present programme contributes to the Norwegian Environment Agency's general aim to:

- Estimate the bioaccumulation of selected contaminants at several trophic levels in marine food chains.
- Connect pollutant exposure of marine organisms to toxic effects at different levels of biological organisation, including endocrine disruption and contaminant interactions ("cocktail effects").
- Identify sources and sinks of environmental contaminants in fjord systems ("the fate of the contaminants in a fjord") and designing targeted actions.

The programme will also provide data that will aid to implement the requirements of The Water Framework Directive (The Water Regulation/"Vannforskriften") regarding governmental basic monitoring as well as used in international chemical regulation. The present report (2018) represents the sixth year of the Urban Fjord project.

2 Material and Methods

2.1 Sample Collection

Polychaetes, zooplankton (krill), prawns, blue mussel, herring and cod were collected as representatives of a food chain in the inner Oslo Fjord. In addition, sediment was collected. The samples were collected in an area within 4.7 km from Steilene (**Figure 1**), the autumn of 2018. Herring gull samples (blood and eggs) were also collected within the programme (spring 2018), as a representative of an urban fjord inhabitant. **Table 1** shows the sampling plan of the programme. The programme also included samples of storm water, and effluent water and sludge from a waste water treatment plant. Optional/additional samples of eider duck (blood and eggs) were also collected in the Inner Oslofjord in 2018.

2.1.1 Sediment

Sediment was collected at station Cm21 by means of a van Veen grab (0.15 m^2) from Research Vessel Trygve Braarud. Four grabs of the top layer (0-2 cm in grab samples with undisturbed surface) were prepared[1] for one sample.

2.1.2 Food web of the Inner Oslofjord

Polychaetes, zooplankton (krill), prawns, blue mussel, herring and cod were collected as representatives of a food chain in the inner Oslo Fjord.

Polychaetes were collected at station Cm21 (**Figure 1**) using a van Veen grab (0.15 m^2) from RV Trygve Braaarud. When possible (dependent on species and mechanical damage), the worms were held in a container of clean seawater for 6-8 hours prior to freezing and analysis. This was done in order to allow the worms to purge any residual sediment from the gut. Some gut content (sediment particles and/or organic matter) may still have been included in the polychaet samples, possibly having some influence on the chemical analysis, but the amount of gut content was minor relative to the polychaete tissue. Material for three pooled samples was collected. The samples consisted of the species listed in **Table 2**.

Krill (*Euphausiacea*) were collected as representatives of the zooplankton by Midtmeie, southwest of Steilene (**Figure 1**). A fry trawl was operated from RV Trygve Braarud for this purpose. Material for three pooled samples was collected.

Prawns (*Pandalus borealis*) were caught with benthic trawl from RV Trygve Braarud in the same area as zooplankton (krill), Midtmeie, southwest of Steilene (**Figure 1**). Material for three pooled samples (of 50 individuals each; size: 82-144 mm) was collected.

Mussels were collected at Steilene (**Figure 1**) by standard procedures (handpicked, using rake, or snorkelling; as in "Contaminants in coastal waters", MILKYS; Green et al. 2018). Three pooled samples (each of 15-16 shells; shell length 53 to 74 mm) was prepared. The method for collecting and preparing blue mussels was based on the National Standard for mussel collection (NS 9434:2017).

[1] According to the Norwegian Environment Agency guidelines for risk assessment of contaminated sediment (M-409/2015).

Herring (*Clupea harengus*) were caught with trawl from RV Trygve Braarud at Midtmeie, southwest of Steilene (**Figure 1**). Material (muscle tissue) for three pooled samples (of 5 individuals in each; length: 25-28 cm, weight: 129-190 g) was collected.

Cod (*Gadus morhua*) were caught with trawl from RV Trygve Braarud at Midtmeie, southwest of Steilene (**Figure 1**). Samples of muscle tissue, liver and bile were taken. Biometric data for the fish are given in Appendix.

2.1.3 Herring gull

Herring Gull (*Larus argentatus*) blood samples (from adult breeding individuals trapped at nest) and eggs (15 egg samples and 15 blood samples) were sampled at Søndre Skjælholmen (Nesodden municipality; 59.85317 N, 10.7281 E; **Figure 1**). Biometric data for the birds are given in Appendix. Adult birds were trapped by walk-in trap placed at the nest. Blood samples (~5 ml) were taken from a vein under the wing. Adult female and egg were sampled from the same nest.

2.1.4 Eider duck

As part of an option under the programme, samples of blood and eggs of Eider duck (*Somateria mollissima*) from the Inner Oslofjord were collected in spring 2018. The samples were from Husbergøya also in Nesodden municipality (**Figure 1**). Biometric data for the birds are given in Appendix. All females were incubating birds trapped at nest late in the incubation period.

2.1.5 Storm water

Storm water samples were collected at one occasion at two specific sampling points (Bryn Ring 3/E6, and Breivoll E6, downstream terminal; **Figure 1**). The samples were collected from manholes by filling bottles directly in the storm water. Subsequently, the storm water samples were separated into a filtered fraction (hereafter referred to as “dissolved fraction”) and a particulate fraction by filtering (polyethylene (PE) frit, 20 µm porosity prior to analysis of per-and polyfluorinated substances (at NIVA) and Whatman Glass Microfilters GF, pore size 1.2 µm, prior to analysis of other chemical parameters (at NILU)).

2.1.6 Sewage treatment plant

Sludge and treated effleunt water were collected from Bekkelaget Sewage Treatment Plant (STP; **Figure 1**) at two occasions (June 25th and June 26th). Samples of effluent water were collected by the use of the STPs fixed equipment for collection of 24h-samples (according to rules for accredited sampling). Aliquots were transferred to appropriate flasks for the different analytes.

Table 1. Overview of samples collected for the «Urban Fjord" programme, including optional sampling conducted in 2018.

Species/sample	Matrix	Locality	Frequency	No. for analysis
Sediment	Whole sediment	Cm21	Once per year	1
Polychaetes	Pooled samples, whole individuals	Cm21	Once per year	3 pooled samples
Zooplankton (krill)	Pooled samples, whole individuals	Midtmeie	Once per year	3 pooled samples
Prawns	Pooled samples, soft tissue tails	Midtmeie	Once per year	3 pooled samples
Blue mussel	Pooled samples, soft body	Steilene	Once per year	3 pooled samples
Herring	Muscle	Midtmeie	Once per year	3 pooled samples
Cod	Muscle, liver, bile	Midtmeie	Once per year	15 individuals
Herring gull (blood)	Blood	Søndre skjælholmen	Once per year	15 individuals
Herring gull (egg)	Egg	Søndre skjælholmen	Once per year	15 eggs
Eider duck (blood) *	Blood	Husbergøya	Optional	15 individuals
Eider duck (egg) *	Egg	Husbergøya	Optional	15 eggs
Inputs storm water	Water (dissolved) and particulate fraction	See **Figure 1**	Once per year	4 samples (2 samples of dissolved fraction plus 2 of particulate fraction)
Inputs from Sewage Treatment Plant	Effluent water and sludge	Bekkelaget	Twice per year	4 samples (2 samples of discharge water and 2 samples of sludge)

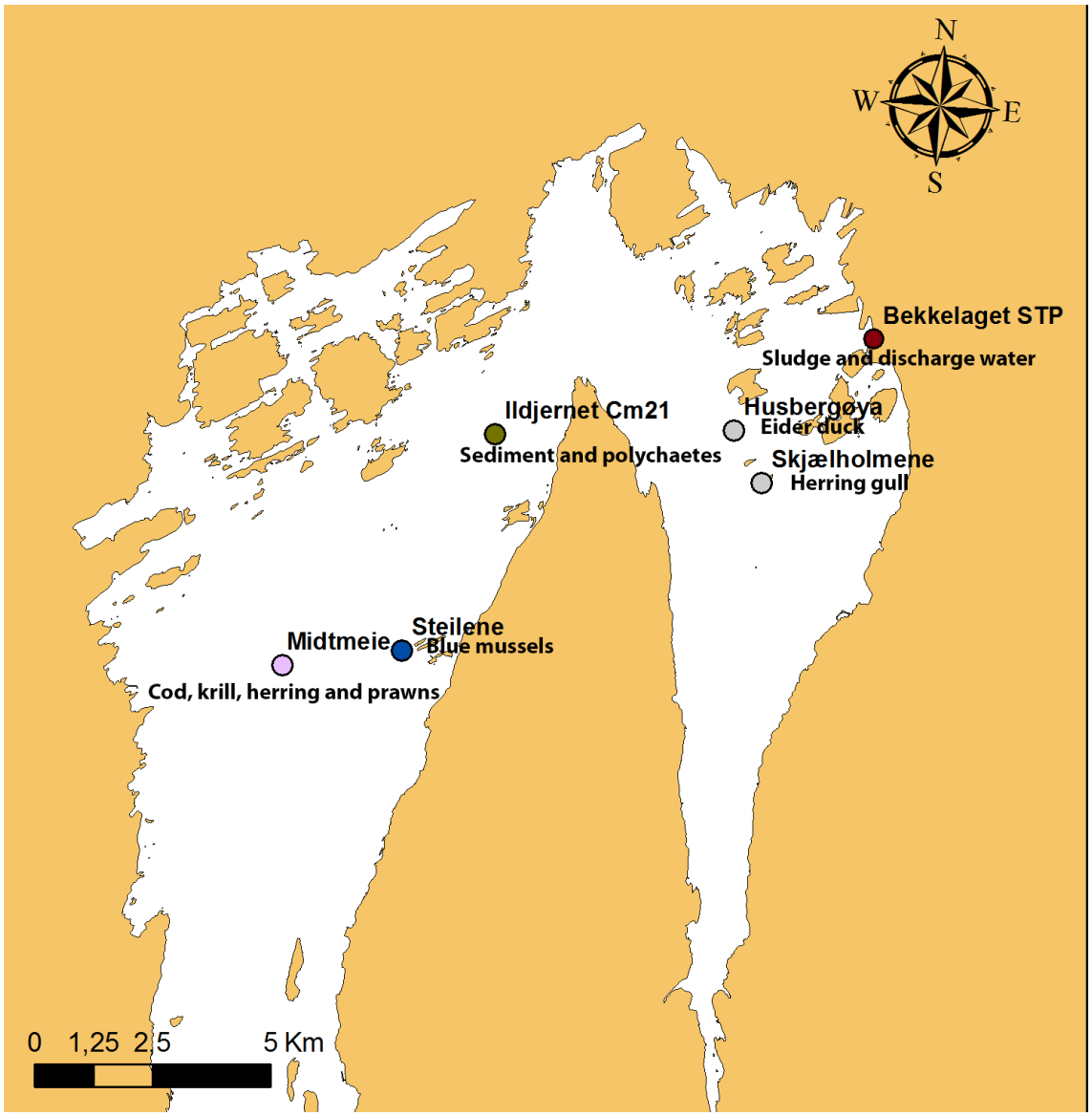
* Optional activity conducted in 2018

Table 2. Species constituting polychaete samples (grams of each species).

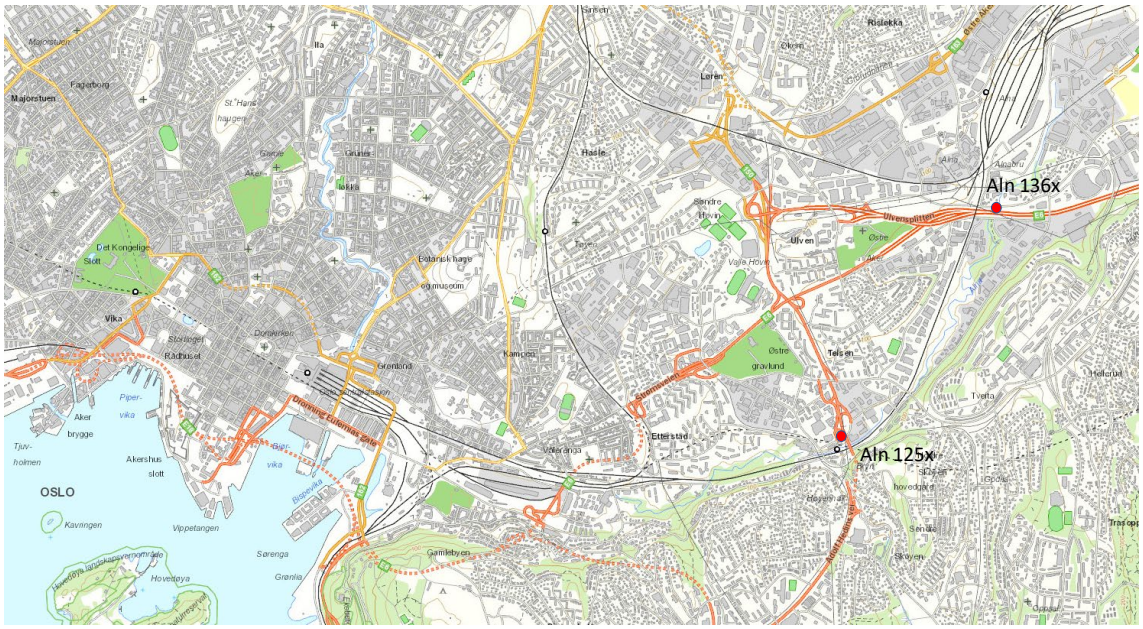
	Inner Oslofjord (Cm21)		
	Repl. 1	**Repl. 2**	**Repl. 3**
P.crassa	0	0	74
Lumbrineridae	157	0	0
Terbellidae	0	146	0
Aphrodita aculeata	0	0	63
*Misc. **	0	0	113
Total (grams)	**157**	**146**	**250**

* *Inter alia*: *Nephtys, Glycera, Goniadidae, Ophelina, Ophiodromus flexuosus, Skoloplos, Spiophanes kroyeri, Scalibregma inflatum.*

A.


N
W
E
S
Bekkelaget STP
Sludge and discharge water
Ildjernet Cm21
Sediment and polychaetes
Husbergøya
Eider duck
Skjælholmene
Herring gull
Steilene
Blue mussels
Midtmeie
Cod, krill, herring and prawns
0 1,25 2,5 5 Km
Sediment and polychaetes
Blue mussel
Krill, prawns, herring and cod
Herring gull and/or eider duck
Bekkelaget STP

B.



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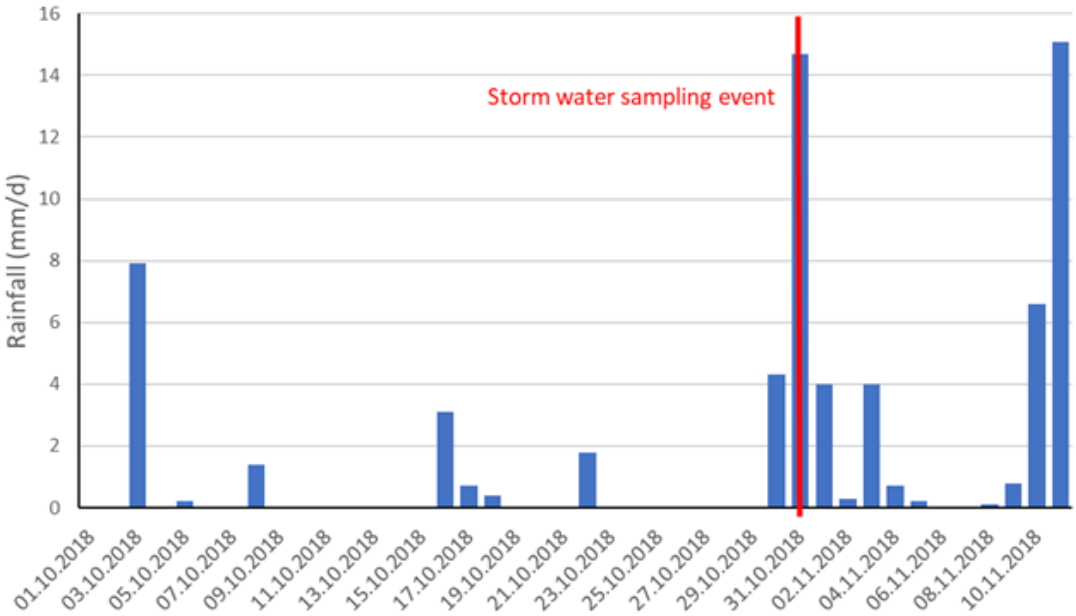


Figure 1. A.: (previous page) Map depicting stations for collection of sediment and polychaetes, blue mussel, and krill, prawns, herring and cod in the Inner Oslofjord, as well as collection of herring gull and eider duck eggs and blood (grey dots) in the inner Oslofjord. The map also shows the location of Bekkelaget STP. B.: Map depicting sites for collection of storm water/surface water samples. C.: Overview of time of sampling of storm water/surface water in relation to rainfall (mm/d).

2.2 Chemical analysis, support parameters and biological effect parameters

Table 3 to **Table 7** provide a detailed overview of the compounds/parameters analysed in the different samples (main programme and additional in 2018). The samples were analysed at NIVA and NILU. Stable isotopes of carbon and nitrogen were analysed at IFE.

Biological effect parameters (in cod) were also included in the programme (**Table 8**). These were analysed at NIVA.

Table 3. Overview: Analyses in different matrices from the different localities.

Species/matrix	Locality	Analytes
Sediment	Cm21 (Inner Oslofjord)	Metals, PCB, PFAS, bisphenols, brominated flame retardants, octylphenol, nonylphenol, chloroparafins, UV-chemicals, siloxanes.
Polychaetes	Cm21 (Inner Oslofjord)	Metals, PCB, PFAS, bisphenols, brominated flame retardants, octylphenol, nonylphenol, chloroparafins, UV-chemicals, siloxanes, stable isotopes of C and N.
Zooplankton (krill)	Midtmeie	Metals, PCB, PFAS, bisphenols, brominated flame retardants, octylphenol, nonylphenol, chloroparafins, UV-chemicals, siloxanes, stable isotopes of C and N.
Prawns	Midtmeie	Metals, PCB, PFAS, bisphenols, brominated flame retardants, octylphenol, nonylphenol, chloroparafins, UV-chemicals, siloxanes, stable isotopes of C and N.
Blue mussel	Steilene	Metals, PCB, PFAS, bisphenols, brominated flame retardants, octylphenol, nonylphenol, chloroparafins, UV-chemicals, siloxanes, stable isotopes of C and N.
Herring	Midtmeie	Metals, PCB, PFAS, bisphenols, brominated flame retardants, octylphenol, nonylphenol, chloroparafins, UV-chemicals, siloxanes, stable isotopes of C and N.
Cod [1]	Midtmeie	Metals, PCB, PFAS, bisphenols, brominated flame retardants, octylphenol, nonylphenol, chloroparafins, UV-chemicals, siloxanes, stable isotopes of C and N.
Herring gull (blood)	Søndre skjælholmen	Metals, PCB, PFAS, bisphenols, brominated flame retardants, octylphenol, nonylphenol, chloroparafins, UV-chemicals, siloxanes (incl. M3T(Ph)), antioxidant MB1, stable isotopes of C and N.
Herring gull (eggs)	Søndre skjælholmen	Metals, PCB, PFAS, bisphenols, brominated flame retardants, octylphenol, nonylphenol, chloroparafins, UV-chemicals, siloxanes (incl. M3T(Ph)), antioxidant MB1, stable isotopes of C and N.

Eider duck [2] (blood)	Husbergøya	PFAS, stable isotopes of C and N.
Eider duck [2] (egg)	Husbergøya	PFAS, stable isotopes of C and N.
Inputs storm water [3]	See **Figure 1**	Metals, PCB, PFAS, bisphenols, brominated flame retardants, octylphenol, nonylphenol, chloroparafins, UV-chemicals, siloxanes.
Sewage Treatment Plant [4]	Bekkelaget	Silver (Ag), PFAS, bisphenols, brominated flame retardants, octylphenol, nonylphenol, chloroparafins, UV-chemicals, PFR, siloxanes (incl. M3T(Ph)), antioxidant MB1.

[1] Liver. Mercury in fillet. Bisphenols, octylphenol and nonylphenol in bile.
[2] Additional sampling and analysis of eider duck samples from Husbergøya performed in 2018.
[3] Dissolved and particulate fractions.
[4] Sludge and discharge water.

Table 4. Overview: Additional analyses performed in 2018.

Species/matrix	Analytes
Sediment, polychaetes, zooplankton (krill), prawns, blue mussel, herring, cod, Herring gull (blood and egg), Stormwater (dissolved and particulate fractions)	Declorane plus
Sediment, polychaetes, zooplankton (krill), prawns, blue mussel, herring, cod, Stormwater (dissolved and particulate fractions)	Antioxidant MB1

Table 5. Analytes included in the programme (see the electronic Appendix for CAS-no.). Additional compounds are indicated.

Parameter	Single compounds
Metals	Hg, Pb, Cd, Ni, Ag, Cu (plus Cr, Zn, Fe, As, Sb)
PCB	PCB-28, -52, -101, -118, -138, -153, -180 (plus -18, -31, -33, -37, -47, -66, -74, -99, -105, -114, -122, -123, -128, -141, -149, -156, -157, -167, -170, -183, -187, -189, -194, -206, -209)
PFAS	PFBS, PFHxS, PFOS, PFOSA, 6:2 FTS, 8:2 FTS, 4:2 FTS, PFDS, PFDoS, N-EtFOSE, N-MeFOSE, N-EtFOSA, N-MeFOSA, N-MeFOSAA, N-EtFOSAA) Perfluorinated carboxylic acids (6-15 C-atoms): PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnA, PFDoA, PFTrA, PFTeA, PFPeA (plus PFPS, PFHpS, PFNS and 10:2 FTS)
Brominated flameretardants	PBDEs *: BDE-47, -99, -100, -126, -153, -154, -183, -196, -202, -206, -207, and -209. Tetrabromobisphenol A (TBBPA), Decabromodiphenyl ethane (DBDPE), Bis(2-ethylhexyl) tetrabromophtalate (TBPH/BEH-TBP), Hexabromobenzene (HBB), pentabromotoluene (PBT) (plus tribromoanisole, TBA)
Bisphenols	Bisphenol A, bisphenol S, bisphenol F (plus bisphenol AF, AP, B, E, FL, M, Z) (Bisphenol F is also separated in 2,2'- and 4,4'-)
Octyl-/nonylphenol	Octyl-/nonylphenol (isomer-spesifc, i.e. we separate 4- and 4-tert)
UV-chemicals	Octocrylene, benzophenone-3, ethylhexylmethoxycinnamate
Chloroparaffins	SCCP (C10-C13) and MCCP (C14-C17)
Siloxanes	Octamethylcyclotetrasiloxane (D4), decamethylcyclopentasiloxane (D5), dodecamethylcyclohexasiloxane (D6) Tris(trimethylsiloxy) Phenylsilane (M3T(Ph))
Phosphorus flame retardants (PFR)	tri-iso-butylphosphate (TIBP), tributylphosphate (TBP), tri(2-chloroethyl)phosphate (TCEP), tri(1-chloro-2-propyl)phosphate (TCPP), tri(1,3-dichloro-2-propyl)phosphate (TDCP), tri(2-butoxyethhyl)phosphate (TBEP), triphenylphosphate (TPhP), 2-ethylhexyl-di-phenylphosphate (EHDPP), dibutylphenylphosphate (DBPhP), butyldiphenylphosphate (BdPhP), tris(2-ethylhexyl)phosphate (TEHP), tris-o-cresylphosphate (ToCrP), tricresylphosphate (TCrP)
Antioxidant MB1	4,4'-methylenebis[2,6- bis (1,1 dimethylethyl)-phenol]

* Plus BDE-17, -28, -49, -66, -71, -77, -85, -119, -138, -156, -184, -191, -197.

Table 6. Specifics regarding compunds analysed in 2017 as an option under the programme.

Parameter	Single compounds
M3T(Ph)	Tris(trimethylsiloxy) Phenylsilane (siloxane)
MB1	4,4'-methylenebis[2,6-bis (1,1-dimethylethyl)-phenol]
Declorane plus	Declorane plus, Dec-602, -603 og -604 (plus -601)

Table 7. Support parameters included in the programme.

Parameter	Specific single parameters	Comment
Stable isotopes	$\delta^{15}N$ and $\delta^{13}C$	In biological matrices
Lipid content (%) in biota		In biological matrices
Weight and length		Fish
Age		Cod
Grain size distribution	Fraction <63 µm	Sediment
TOC		Sediment

Table 8. Biological effect parameters (in cod).

Parameter	Indicator of
Acetylcholin esterase (AChE)	Inhibition by contaminants such as organophosphates
Other relevant physiological parameters: **Liversomatic index** **Gonadosomatic index**	

2.2.1 Background, target compounds

The metals are naturally occurring elements, but human activities have through history led to increasing amounts of several of them in the environment. In the aquatic environment, inorganic mercury (Hg) may be transformed to the organic form methylmercury, mainly by bacterial activity. In fish, the majority of the mercury is in the form of methylmercury, which is more bioaccumulative and toxic than inorganic mercury (Wolfe et al. 1998). Cadmium (Cd) has been used e.g. in various industrial processes, such as protecting steel against corrosion. Other applications have been e.g. batteries, pigments, ceramic glaze and surface treatments, but the element is also a contaminant in products, including some types of fertilizer. Cadmium can enter fish by passive diffusion across the gills or by entering the marine food chain at the plankton and microorganisms level and thereby being transferred to fish through the diet. Cadmium is highly toxic to humans and its bioaccumulative properties prevents the reduction of the accumulated body burden (Bosch et al. 2016). Lead (Pb) has a great number of industrial applications, both in its elemental form and in the form of alloys and compounds. The major use of lead has been the manufacture of lead accumulators. Furhermore, tetralkyl lead, R_4Pb, mostly tetraethyl lead is an organic lead species used as anti-knocking agents in leaded gasoline. This application has declined dramatically due to restrictions imposed through environmental legislation. Lead infers with the biosynthesis of porphyrins and heme, eventually leading to anaemia.

Polychlorinated biphenyls (PCBs) are a group of industrial chemicals (209 theoretical congeners), that are also formed as byproduct in different industrial processes and combustion processes. The PCBs have unique physical and chemical properties, such as high thermal and chemical stability and high electrical resistance, hence their application in many industrial applications, such as hydraulic fluids, cooling liquids in transformers and dielectric liquids in capacitors. They have also been applied in plasticizers, lubricants, inks and paints. In Norway, the production and use of PCBs was restricted since the 1970s and later banned by law. Immunosuppressive effects, endocrine disrupting effects and impairment of reproduction are some toxic effects expressed by PCBs (Safe, 1994).

PFAS compounds have been applied in both industrial processes and consumer products since the 1950s. They may for instance give products water and dirt repellent properties, and they have been used to impregnate textiles and in food packaging. Some of the PFAS compounds have properties that prevent fire and evaporation of volatile compounds, and have therefore been used in firefighting, such as PFOS. Firefighting foam was previously the largest source of PFOS emissions in Norway, before PFOS containing foams were banned in 2007.

The brominated flame retardants have been applied in products to prevent fire. In Norway, brominated flame retardants can mainly be found in electrical/electronic products. Brominated flame retardants can also be found in cars, plastic insulation materials (polystyrene), and in textiles, such as furniture and workwear.

There are many different bisphenols available, and bisphenol A is the most known substance. It is used e.g. as raw material for plastics and paints and may be found in imported plastic products. There is less knowledge regarding other bisphenols, such as bisphenol AF, bisphenol B, bisphenol BP, bisphenol F, bisphenol M and bisphenol S. These substances can be used as a replacement for bisphenol A. Bisphenol S is a substitute for bisphenol A in heat-sensitive paper. Furthermore, bisphenol F and bisphenol B may possibly replace bisphenol A in products made of epoxy resin and polycarbonate, such as epoxy paint and plastic cutlery.

Alkylphenols have been/are used in f.i. textiles, plastic products, paints and lubricants. Nonyl- and octylphenol ethoxylates have been widely used in products such as detergents and cosmetics. Emissions of nonyl- and octylphenols have been substantially reduced the last couple of decades. The decrease is mainly due to reduced application in detergents following regulations.

Short-chained chlorinated paraffins (SCCPs) are banned in Norway, but the compounds may still be found in several imported plastic products. Medium-chained chlorinated paraffins (MCCPs) may also be found in imported products. These substances are primarily applied as softeners and flame retardants and can be found in rubber and PVC used for the production of e.g. cables and floor coverings.

Octocrylene, benzophenone-3 and ethylhexylmethoxycinnamate are used is in sunscreens and other cosmetics to absorb UV rays from the sun, protecting the skin from damage.

Siloxanes have properties that affect the consistency of products such as shampoo and creams to facilitate their use. Siloxanes can otherwise be found in e.g. car wax, paint, insulation materials and cement. Cosmetic products such as soap, skin care products, deodorants and makeup are likely the largest source of siloxane emissions in Norway.

The phosphorus flame retardants have been applied in products to prevent fire. They are widely used in plastics as flame retardants and plasticizers. They are also used as antifoams and as additives in lubricants, hydraulic oils, floor polishers and adhesives.

4,4'-methylenebis[2,6-bis(1,1-dimethylethyl)-phenol (MB1) is used as an industrial anti-oxidant and additive to plastics.

Dechlorane plus is used as a flame retardant in plastics and polymers, such as nylon, polyurethane, polypropylene, neoprene and silicone rubber. As such, it can be found in electronic wires and cables, cars, plastic roofing materials and hard plastic couplings. It may also function as a softener. Dechlorane plus is marketed as an alternative to deca-BDE (BDE-209).

2.2.2 Analysis of metals

Metal analyses were performed by NILU.

Sample Preparation
Sediment-/sludge- and biota-samples were added supra pure acid and digested at high pressure and temperature in a microwave- based digestion unit (UltraClave). A minimum of two blanks were included with each digestion. Furthermore, reference material (traceable to NIST) was digested with the samples.

Water samples were preserved in original bottles with 1% (v/v) nitric acid.

Instrumental Analysis
Concentrations of nickel (Ni), cadmium (Cd), mercury (Hg), lead (Pb), silver (Ag) and copper (Cu) were determined using inductively coupled plasma mass spectrometer (ICP-MS). All samples, standards and blanks were added internal standard prior to analysis. In addition, Chromium (Cr), zinc (Zn), iron (Fe), arsenic (As) and antimony (Sb) were determined.

Limits of Detection
Detection limits (LoD) and Quantification limits (LoQ) were calculated from 3 times and 10 times the standard deviation of blanks, respectively.

Quality assurance and accreditation
NILU's laboratories are accredited by Norwegian Accreditation for ISO/IEC 17025. Silver (Ag) is not included in NILUs accredited method for determination of metals. However, analysis of Ag follows all principles in the accredited method.

2.2.3 Analysis of PCBs, brominated flame retardants and S/MCCP

Polychlorinated biphenyls (PCBs), brominated flame retardants (TBBPA analysed with phenolic compounds; see Chapter 2.2.5), and short- and medium chained chloroparaffins (S/MCCP) were analysed by NILU.

Extraction
Prior to extraction, the samples were added a mixture of isotope labelled PCBs for quantification purposes.

The water-, sludge-/sediment- and biota-samples were extracted with organic solvents and concentrated under nitrogen flow, followed by a clean-up procedure using concentrated sulphuric acid and a silica column to remove lipids and other interferences prior to analysis.

Analysis
The compounds were quantified on GC-HRMS (Waters Autospec) and/or BG-QToF (Agilent 7200B).

Limits of Detection
The limits of detection (LoD) and quantification (LoQ) were calculated for each sample, using the accepted standard method, i.e. the average of blanks plus 3 and 10 times the standard deviation for blanks, for LoD and LoQ, respectively.

Quality assurance and accreditation
NILU's laboratories are accredited by Norwegian Accreditation for ISO/IEC 17025. NILU is accredited for the analysis of PCBs. For the other compounds, the same quality assurance procedures (as for the accredited compounds) were applied.

2.2.4 Analysis of PFAS

Per- and polyfluorinated substances (PFAS) were analysed by NIVA

Extraction
Prior to extraction, the samples were added a mixture of isotope labelled PFAS, for quantification purposes. Sediment-/sludge-, water- and biota-samples were extracted with organic solvents and use of buffers for pH control. The extracts were cleaned using solid phase extraction (SPE) and active coal if needed (the latter for lipid rich biota samples). Water samples were concentrated and cleaned up using an SPE column. All samples were concentrated under nitrogen flow.

Analysis
PFAS compounds were analysed using LC-qTOF-MS.

Limits of Detection
The limits of detection (LoD) and quantification (LoQ) were calculated for each sample, using the accepted standard method; 3 times the signal/noise ratio (z/n) and 9 times z/n, respectively.

Quality assurance and accreditation
NIVA's laboratory is accredited by Norwegian Accreditation for ISO/IEC 17025. NIVA is not accredited for these particular compounds, but to the extent possible, documentation, preparation, analysis and calculations are performed in accordance with accredited methods.

Samples were analysed in groups with at least one additive standard sample and a blank control. To ensure repeatability, a random sample from each matrix was selected for duplicate analysis.

2.2.5 Analysis of alkylphenols and bisphenols

Alkylphenols and bisphenols (octylphenol, nonylphenol, bisphenol A, S, F, AF, AP, B, E, FL, M og Z, as well as TBBPA) were analysed by NILU.

Extraction
Prior to extraction, the samples were added a mixture of isotope labelled phenols for quantification purposes.

The sediment- and biota-samples were extracted with organic solvents and concentrated under nitrogen flow. Then they were further cleaned with an SPE column to remove interferences prior to analysis. In addition, prior to the extraction and clean-up procedure for biota, liver and bile samples were subjected to an enzyme digestion procedure in order to convert possible Phase II metabolites of phenolic compounds into their respective free forms. Water samples were concentrated and purified on a SPE column. After elution from the SPE column, the water sample extracts were further concentrated under nitrogen and subjected to instrumental analysis.

Analysis
All samples were analysed by LC-QToF (Agilent 65/50), or LC-ToF (Waters Premier).

Limits of Detection
The limits of detection (LoD) and quantification (LoQ) were calculated for each sample, using the accepted standard method, i.e. the average of blanks plus 3 and 10 times the standard deviation for blanks, for LoD and LoQ, respectively.

Quality assurance and accreditation
NILU's laboratories are accredited by Norwegian Accreditation for ISO/IEC 17025. NILU is not accredited for the analysis of alkylphenols and bisphenols, but as far as possible, the documentation, sample preparation, analysis and calculation procedures were conducted according to the accredited methods.

2.2.6 Analysis of UV-chemicals

UV-chemicals (octocrylene, benzophenone and ethylhexylmethoxycinnamate) were analysed by NIVA. The methods are modified from earlier validated and published methods developed at NIVA (Langford et al. 2008; 2009; 2011; 2015; Thomas et al. 2014).

Extraction of UV-chemicals
Homogenized biota samples were added isotope labelled internal standards for quantification purposes. Then they were extracted twice with a combination of solvents. Extracts were concentrated under nitrogen flow and cleaned up using gel permeation chromatography (GPC) and/or SPE, dependent on complexity of matrix.

Analysis of UV-chemicals
UV-chemicals were analysed using GC-MSD (Agilent) or APGC-Vion (Waters).

Limits of Detection
The limits of detection (LoD) and quantification (LoQ) were calculated for each sample, using the accepted standard method; three times the signal/noise ratio (z/n) and 9 times z/n, respectively.

Quality assurance and accreditation
NIVA's laboratory is accredited by Norwegian Accreditation for ISO/IEC 17025. NIVA is not accredited for these particular compounds, but to the extent possible, documentation, preparation, analysis and calculations are performed in accordance with accredited methods.

2.2.7 Analysis of siloxanes

Siloxanes, i.e. octamethylcyclotetrasiloxane (D4), decamethylcyclopentasiloxane (D5), dodecamethylcyclohexasiloxane (D6) and M3T(Ph) were analysed by NILU. Already established methods based on liquid/liquid extraction (Warner et al. 2010, Warner et al. 2012) were used to extract and quantify siloxanes, in addition to headspace extraction techniques to analyse siloxanes in water and sediments.

Extraction
Sediment and biota tissues were extracted using solid-liquid extraction with a biphasic solvent system of acetonitrile and hexane. Extraction of water samples was performed using headspace extraction

Analysis
Collected extracts from sediment-/sludge- and biota tissues were analysed using Concurrent solvent recondensation large volume injection gas chromatography mass spectrometry (CSR-LVI-GCMS; Companioni-Damas et al. 2012). For water analysis, 2 ml of extracted headspace was directly injected onto a GCMS (Sparham et al. 2008).

Limits of Detection
The limits of detection (LoD) and quantification (LoQ) were calculated for each sample using the accepted standard method, i.e. the average of blanks plus 3 and 10 times the standard deviation for blanks, for LoD and LoQ, respectively.

Quality assurance and accreditation

NILU has extensive experience with analysis of siloxanes. The greatest risk in the analysis is background contamination, as these chemicals (D4, D5 and D6) are applied in e.g. skin care products. Using a state-of-the-art cleanroom and clean bench technologies, NILU is capable of performing trace analysis of these compounds in matrices from pristine environments, including the Arctic (Krogseth et al. 2013; Warner et al. 2013).

NILU's laboratories are accredited by Norwegian Accreditation for ISO/IEC 17025. NILU is not accredited for the analysis of siloxanes. However, to the extent possible, documentation, preparation, analysis and calculations were performed in accordance with accredited methods. NILU has previously participated in a laboratory intercalibration of siloxanes (McGoldrick et al. 2011) and has also worked closely with the industry in Artic monitoring programmes to develop methods to enhance result accuracy and limit reporting of false positives (Warner et al. 2013).

Samples were extracted and analysed in batches with a minimum of 3 procedural blanks to assess background contamination and calculate LOD and LOQ per extraction batch. As the sample matrix can contribute to the overall background response, procedural blanks were run both before and after samples to ensure results were above detection limits and not an artefact of background variation.

Field blanks were used to assess any potential contamination that occurred during sample collection and preparation. Each field blank consisted of approximately 3 grams of XAD-2 sorbent in filter bags of polypropylene/cellulose. XAD-2 sorbent was cleaned using a 1:1 mixture of hexane:dichloromethane and dried overnight in a clean cabinet equipped with a HEPA- and charcoal filter to prevent contamination from indoor air. Filter bags were cleaned by ultrasonic treatment in hexane for 30 min. Subsequently, hexane was removed and substituted with clean dichloromethane and the field blanks were sonicated once more for 30 min. After ultrasonic treatment, filter bags were placed in a clean cabinet to dry under similar conditions as the XAD-2 sorbent. Once dry, XAD-2 sorbent was transferred to filter bags and sealed in polypropylene containers to be sent for sampling purposes. Several field-blanks were stored at NILU’s laboratories (hereafter called reference blanks) and analysed to determine reference concentrations before sampling. The field blanks for sampling purposes were exposed and handled in the field during sampling and during preparation of samples. The results from the analysis of the field blanks are presented in **Table 9**.

Table 9. Results of the analysis of siloxanes in (field and reference) blanks, consisting of XAD resin in filter bags of polypropylene/cellulose

Description of sampling/purpose	D4 (ng/g)	D5 (ng/g)	D6 (ng/g)	M3T(Ph) (ng/g)
Field blank Herring gull blood	2.02	9.60	0.67	
Field blank reference Herring gull blood	0.76	4.59	0.57	
Field blank Misc. Biota	6.07	5.70	1.84	
Field blank reference Misc. Biota	0.77	5.26	0.77	
Field blank Herring gull egg	0.83	3.50	0.67	
Field blank reference Herring gull egg	0.50	3.36	0.50	
Field blank Cod liver	1.19	2.09	0.75	
Field blank reference Cod liver	0.85	4.35	0.73	
Field blank STP sludge	0.96	3.19	0.48	0.16
Field blank reference STP sludge	0.67	5.56	0.51	0.17

2.2.8 Analysis of PFR

Phosphorus flame retardants (PFRs) were analysed by NILU.

Extraction
Prior to extraction, the samples were added a mixture of isotope labelled PFR standards, for quantification purposes.

The water-, sediment-/sludge- and biota-samples were extracted with organic solvents and concentrated under nitrogen flow, followed by a clean-up procedure using a silica column to remove lipids and other interferences prior to analysis.

Analysis
PFR compounds were quantified on a Thermo TSQ Vantage UPLC/MS-MS.

Limits of detection
The limits of detection (LoD) and quantification (LoQ) were calculated for each sample, using the accepted standard method, i.e. the average of blanks plus 3 and 10 times the standard deviation for blanks, for LoD and LoQ, respectively.

Quality assurance and accreditation
NILU's laboratories are accredited by Norwegian Accreditation for ISO/IEC 17025. NILU is not accredited for the analysis of PFRs, but the same quality assurance procedures (as for the accredited compounds) were applied for the analyses of these compounds.

2.2.9 Analysis of antioxidant MB1

Antioxidant MB1 was analysed by NILU, with the same extraction methods as described for PCBs, brominated flame retardants and S/MCCP.

Extraction
The water-, sludge-/sediment- and biota-samples were extracted with organic solvents and concentrated under nitrogen flow, followed by a clean-up procedure using concentrated sulphuric acid and a silica column to remove lipids and other interferences prior to analysis.

Analysis
Antioxidant MB1 was analysed using GC-MS.

Limits of Detection
The limits of detection (LoD) and quantification (LoQ) were calculated for each sample, using the accepted standard method, i.e. the average of blanks plus 3 and 10 times the standard deviation for blanks, for LoD and LoQ, respectively.

Quality assurance and accreditation
NILU's laboratories are accredited by Norwegian Accreditation for ISO/IEC 17025. NILU is not accredited for the analysis of antioxidant MB1, but as far as possible, the documentation, sample preparation, analysis and calculation procedures were conducted according to the accredited methods.

2.2.10 Analysis of M3T(Ph)

M3T(Ph) was analysed by NILU. This compound was extracted and analysed with the siloxanes (D4, D5 and D6), as described above (Chapter 2.2.7).

Extraction
Already established methods based on liquid/liquid extraction (Warner et al. 2010, Warner et al. 2012) was used to extract M3T(Ph) with the siloxanes (see above; Chapter 2.2.7).

Analysis
Samples were analysed using Concurrent solvent recondensation large volume injection gas chromatography mass spectrometry (CSR-LVI-GCMS; Companioni-Damas et al. 2012).

Limits of Detection
The limit of detection (LoD) and quantification (LoQ) were calculated for each sample using the accepted standard method, i.e. the average of blanks plus 3 and 10 times the standard deviation for blanks, for LoD and LoQ, respectively.

Quality assurance and accreditation
NILU's laboratories are accredited by Norwegian Accreditation for ISO/IEC 17025. NILU is not accredited for the analysis of M3T(Ph). However, to the extent possible, documentation, preparation, analysis and calculations were performed in accordance with accredited methods.

2.2.11 Analysis of Dechlorane plus and related compounds

Dechlorane plus was analysed by NILU, with the same extraction methods as described for PCBs, brominated flame retardants and S/MCCP.

Extraction
The water-, sludge-/sediment- and biota-samples were extracted with organic solvents and concentrated under nitrogen flow, followed by a clean-up procedure using concentrated sulphuric acid and a silica column to remove lipids and other interferences prior to analysis.

Analysis
Dechlorane plus was quantified on GC-HRMS (Waters Autospec) and/or BG-QToF (Agilent 7200B).

Limits of Detection
The limits of detection (LoD) and quantification (LoQ) were calculated for each sample, using the accepted standard method, i.e. the average of blanks plus 3 and 10 times the standard deviation for blanks, for LoD and LoQ, respectively.

Quality assurance and accreditation
NILU's laboratories are accredited by Norwegian Accreditation for ISO/IEC 17025. NILU is not accredited for the analysis of dechlorane plus, but as far as possible, the documentation, sample preparation, analysis and calculation procedures were conducted according to the accredited methods.

2.2.12 Support parameters

Stable isotopes of nitrogen and carbon were analysed by IFE. Analysis of nitrogen and carbon isotopes was done by combustion in an element analyser, reduction of NOx in Cu-oven, separation of N_2 and CO_2 on a GC-column and determination of $\delta^{13}C$ and $\delta^{15}N$ at IRMS (Isotope Ratio Mass Spectrometer).

Trophic level was calculated as follows (assuming a 3.8 increase per full trophic level; Hobson and Welch, 1992; and that blue mussel inhabit trophic level 2, filtrating algal particles on trophic level 1):

$$TL_{consumer} = 2 + (\delta^{15}N_{consumer} - \delta^{15}N_{blue\ mussel})/3.8$$

Captive-rearing studies on piscivorous birds indicate that the $\delta^{15}N$ isotopic fractionation factor between bird diet and tissue is less than that derived for other trophic steps, most likely linked to the fact that birds produce uric acid (Mizutani et al. 1991). According to Mizutani et al (1991) an isotopic fractionation factor of +2.4 ‰ is appropriate. Thus, the following equation was used to calculate the trophic level of herring gulls and eider ducks:

$$TL_{herring\ gull} = 3 + (\delta^{15}N_{herring\ gull} - (\delta^{15}N_{blue\ mussel} + 2.4))/3.8$$

Lipid content in biological samples was determined gravimetrically during extraction for chemical analyses.

Weight and length of fish were determined before dissection.

The age of the cod was read from otoliths. The age was read by counting the number of opaque zones (summer zones) and hyaline zones (winter zones).

Grain size distribution (fraction of particles <63 µm) in sediment was determined according to procedures described by Krumbein and Petttijohn (1938).

Total organic carbon content (TOC) in sediment was determined by catalytic combustion in an element analyser.

2.2.13 Biological effect parameters (cod)

Acetylcholinesterase (AChE)
Inhibition of Acetylcholinesterase (AChE) was measured in the microsomal fraction of muscle samples of cod, using methods described by Bocquené and Galgani (1998).

In addition to AChE, the following physiological parameters were measured/calculated: liversomatic index (LSI) and gonadosomatic index (GSI). These are measured of liver weight and gonad weight, respectively, relative to body mass:

Liversomatic and gonadosomatic indices

$$\text{Liversomatic index (LSI)} = \frac{[\text{liver weight (g)} \times 100]}{\text{body mass (g)}}$$

$$\text{Gonadosomatic index (GSI)} = \frac{[\text{gonad weight (g)} \times 100]}{\text{body mass (g)}}$$

2.3 Data treatment

Statistical analyses (linear regressions; general linear models) were performed with the use of Statistica software (Ver 13.1; Statsoft/Dell). A significance level of $\alpha = 0.05$ was chosen. When appropriate, data were $\log_{10}$-transformed.

When results are below LoD (especially when this occurs in many samples), the value of the information is reduced, and there are challenges regarding presentations and statistical evaluation. For the purpose of calculating mean concentrations, we have assigned these samples/parameters a value of zero. In regression models, we have omitted samples with non-detects from processing ("case-wise deletion").

It has earlier been pointed out (Ruus et al. 2015; The Norwegian Environment Agency M-375) that there was a need for a more balanced design, in terms of the number of individual samples from each species in the food web (when possible biomagnification of compounds in the Inner Oslofjord food web was evaluated). Therefore, pooled samples of cod (3 samples constituted of 5 individuals each) are constructed mathematically (mean of the 5 individuals) to obtain 3 samples of each species in the food web (in the same manner as in the 2015- to 2017-programmes; Ruus et al. 2016; Ruus et al. 2017; Ruus et al. 2019; The Norwegian Environment Agency M-601, M-812 and M-1131). The individuals were assigned to the different "pooled" samples according to their length (the five

smallest fish in one “pooled” sample, the five largest fish in one “pooled” sample, and the remaining five fish in one “pooled” sample). The same was applied for eider duck, when included in the food web: the “pooled” samples were compoused according to egg mass.

When exploring correlations between contaminant concentrations and trophic position, concentrations of the following contaminants were expressed on a wet weight basis: Metals, PFASs and phenolic compounds. The concentrations of the following contaminants were expressed on a lipid weight basis: PCBs and other organochlorine compounds, chlorinated paraffins, brominated flame retardants, siloxanes (including M3T(Ph)), UV-filters, antioxidant MB1 and declorane plus.

When exploring correlations between contaminant concentrations and biochemical response parameters (such AChE activity), concentrations were expressed on a wet weight basis.

Trophic Magnification Factors (TMFs) were calculated from statistically significant relationships:
Log_{10}[Contaminant] = a + b(Trophic position)
as TMF = 10^b.

3 Results and Discussion

The results of the chemical analyses (and lipid content of biological samples) are given in the electronic Appendix, where also analyses falling below LoD are indicated together with the values of the LoDs.

3.1 Stable isotopes

The results of the individual stable isotope-analysis of C and N are given in Appendix (Tables A4-A9).

Stable isotopes of carbon and nitrogen are useful indicators of food origin and trophic levels. $\delta^{13}C$ gives an indication of carbon source in the diet or a food web. For instance, it is in principle possible to detect differences in the importance of autochthonous (native marine) and allochthonous (watershed/origin on land) carbon sources in the food web, since the $\delta^{13}C$ signature of the land-based energy sources is lower (greater negative number). Also $\delta^{15}N$ (although to a lesser extent than $\delta^{13}C$) may be lower in allochthonous as compared to autochthonous organic matter (Helland et al. 2002), but more important, it increases in organisms with higher trophic level because of a greater retention of the heavier isotope (^{15}N). The relative increase of ^{15}N over ^{14}N is 3-5‰ per trophic level (Layman et al. 2012; Post 2002), and provides a continuous descriptor of trophic position. It is also the basis for Trophic Magnification Factors (TMFs) that give the factor of increase in concentrations of contaminants, and have been amended to Annex XIII of the European Community Regulation on chemicals and their safe use (REACH) for possible use in weight of evidence assessments of the bioaccumulative potential of chemicals as contaminants of concern.

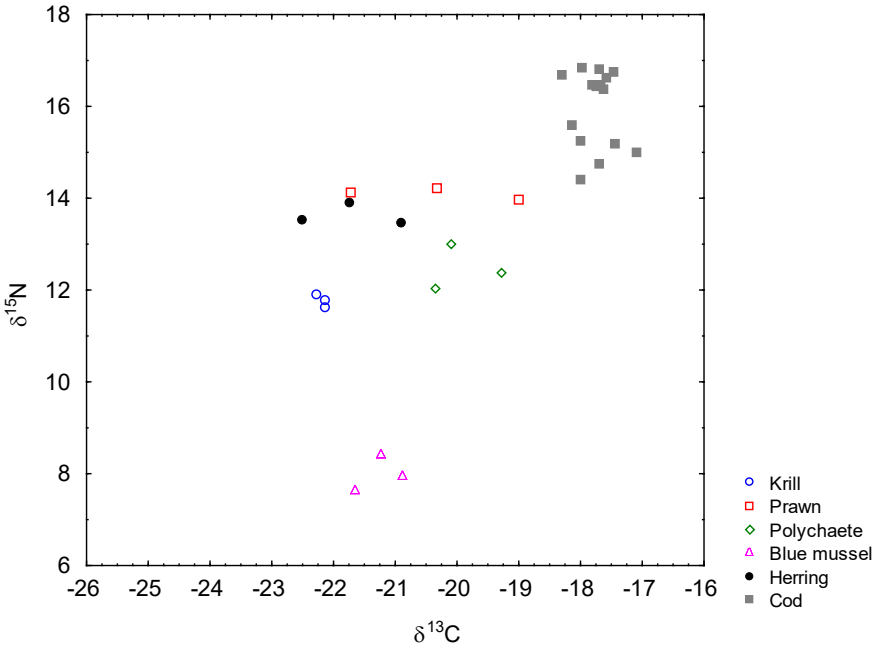
In the present report, the stable isotope data have been reviewed partly to indicate possible different energy sources for the organisms/individuals in question. Secondly, trophic level is calculated from $\delta^{15}N$ for the organisms to assess possible biomagnification of the compounds/contaminants in question in the Inner Oslofjord food web.

It has previously been noted (Ruus et al. 2014; Ruus et al. 2015; Ruus et al. 2016; Ruus et al. 2017; Ruus et al. 2019; The Norwegian Environment Agency M-205, M-375, M-601, M-812 and M-1131) that herring gull sampled in the Inner Oslofjord display low $\delta^{15}N$ and low $\delta^{13}C$, relative to the marine species sampled in the programme. This indicates that important food items for the gull are not related to the marine food web sampled. Herring gull is therefore treated separately (not as part of the food web) in the present study (as in the "Urban fjord" programme in 2015 to 2017; Ruus et al. 2016; Ruus et al. 2017; Ruus et al. 2019; The Norwegian Environment Agency M-601, M-812 and M-1131).

As in 2017, inclusion of additional eider duck samples (inner Oslofjord) were collected (**Figure 2** B.). However, the aquatic food web sampled was identical to that in 2015-2017. The results of the stable isotope analysis (**Figure 2** A) suggest that the species sampled in 2015-2018 well represent members of the marine food web of the Inner Oslofjord, as the differences in $\delta^{15}N$ seem to reflect expected trophic relationships; blue mussel (filters particulate organic matter from the water) < zooplankton (herbivore) < polychaetes (different modes of living, largely detritivorous) < herring (pelagic fish feeding on zooplankton) ≈ prawns (some scavenging behaviour) < cod (mesopelagic fish, predator on fish and benthic organisms). The food web spans over 2 to 3 (~2.1) trophic levels with blue mussel defined at trophic level 2 (see Chapter 2.2.12), zooplankton (krill) at trophic level 3.0, polychaetes at

trophic level 3.2, prawns and herring at trophic level 3.6 and 3.5, respectively, and cod at trophic level 4.1 in average (assuming an increase in $\delta^{15}N$ of 3.8‰ per integer trophic level). As such the isotopic signatures of the species in the food web were nearly identical to those observed in 2015-2017 (Ruus et al. 2016; Ruus et al. 2017; Ruus et al. 2019; The Norwegian Environment Agency M-601, M-812 and M-1131).

A.



B.

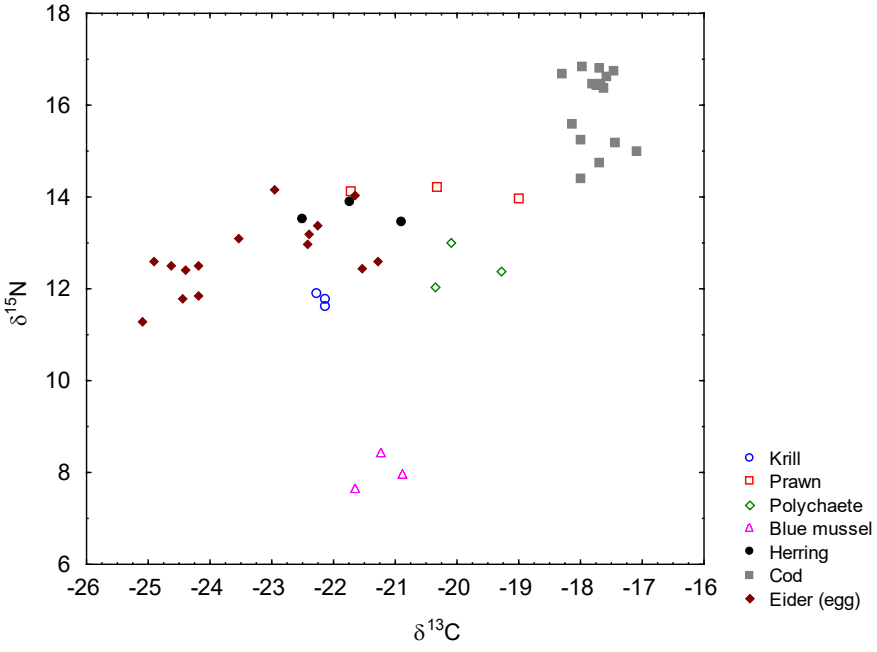


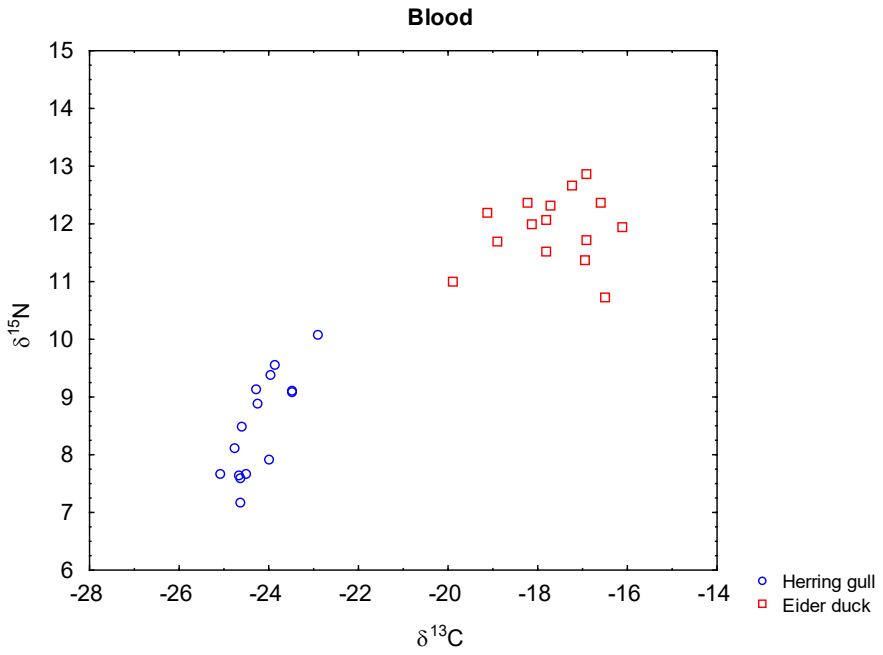
Figure 2. $\delta^{13}C$ plotted against $\delta^{15}N$ in organisms from the inner Oslofjord marine food web (A.), also with eider duck (blood) included (B.).

The isotopic signatures of the herring gulls showed the same patterns as in 2015-2017 (Ruus et al. 2016; Ruus et al. 2017; Ruus et al. 2019; The Norwegian Environment Agency M-601, M-812 and M-1131). When herring gull matrices (blood and eggs) are evaluated (**Figure 3**), it can be seen that the matrices show fairly similar δ^{15}N. Herring gull would therefore be placed on approximately the same average trophic level regardless of matrix. The δ^{13}C ratio is, however, higher in blood than in eggs likely related to different lipid content. It should be noted that samples were not treated to remove carbonates or lipid before stable isotope analysis. The C:N ratio was measured (Appendix, Tables A4 and A5) and a C:N ratio of >3.5 implies the presence of lipids, which may somewhat confound δ^{13}C interpretation, since lipids are ^{13}C -depleted relative to proteins (Sweeting et al. 2006). Eggs showed a higher C:N ratio than blood (Appendix, Tables A4 and A5). **Figure 3** also displays the isotopic signatures of eider duck (blood and egg), and the same applies: the matrices show fairly similar δ^{15}N, while the δ^{13}C ratio appear somewhat higher in blood than in eggs, likely related to different lipid content.

Analysis of samples (blood and egg) from eider duck from the Inner Oslofjord was an addition to the programme in 2018, as well as in 2017. As can be seen from **Figure 3**, δ^{15}N and δ^{13}C appear higher in the eider duck, than in the herring gull from the Inner Oslofjord (statistical significant differences for both δ^{15}N and δ^{13}C in both blood and eggs; p=0,000005; Mann-Whitney U). As such, the isotopic signatures of the eider duck correspond much better with a member of the Inner Oslofjord Marine food web (**Figure 2** B.).

Regarding the birds (herring gulls and eider duck), adult female and egg were sampled from the same nest (i.e. mother and future offspring). This is reflected in the isotopic signatures, as significant relationships were found between egg and blood for δ^{15}N in both species (δ^{13}C herring gull: R^2=0.08; p=0.30; δ^{13}C eider duck: R^2=0.21; p=0.08; δ^{15}N herring gull: R^2=0.49; p=0.0035; δ^{15}N eider duck: R^2=0.46; p=0.0054; **Figure 4**).

A.



B.

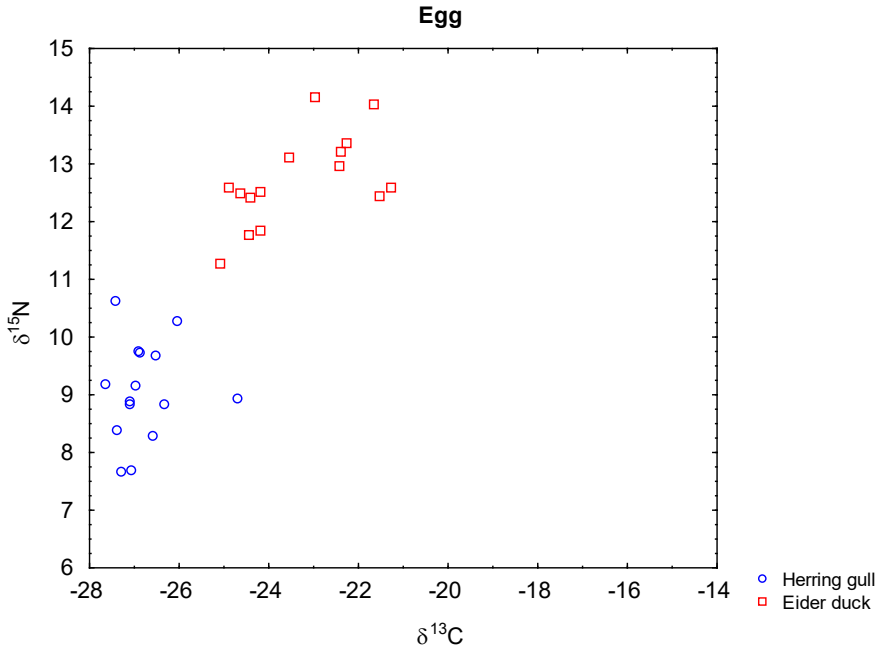


Figure 3. $\delta^{15}N$ plotted against $\delta^{13}C$ in blood (A.) and eggs (B.) of herring gull and eider duck from the Inner Oslofjord.

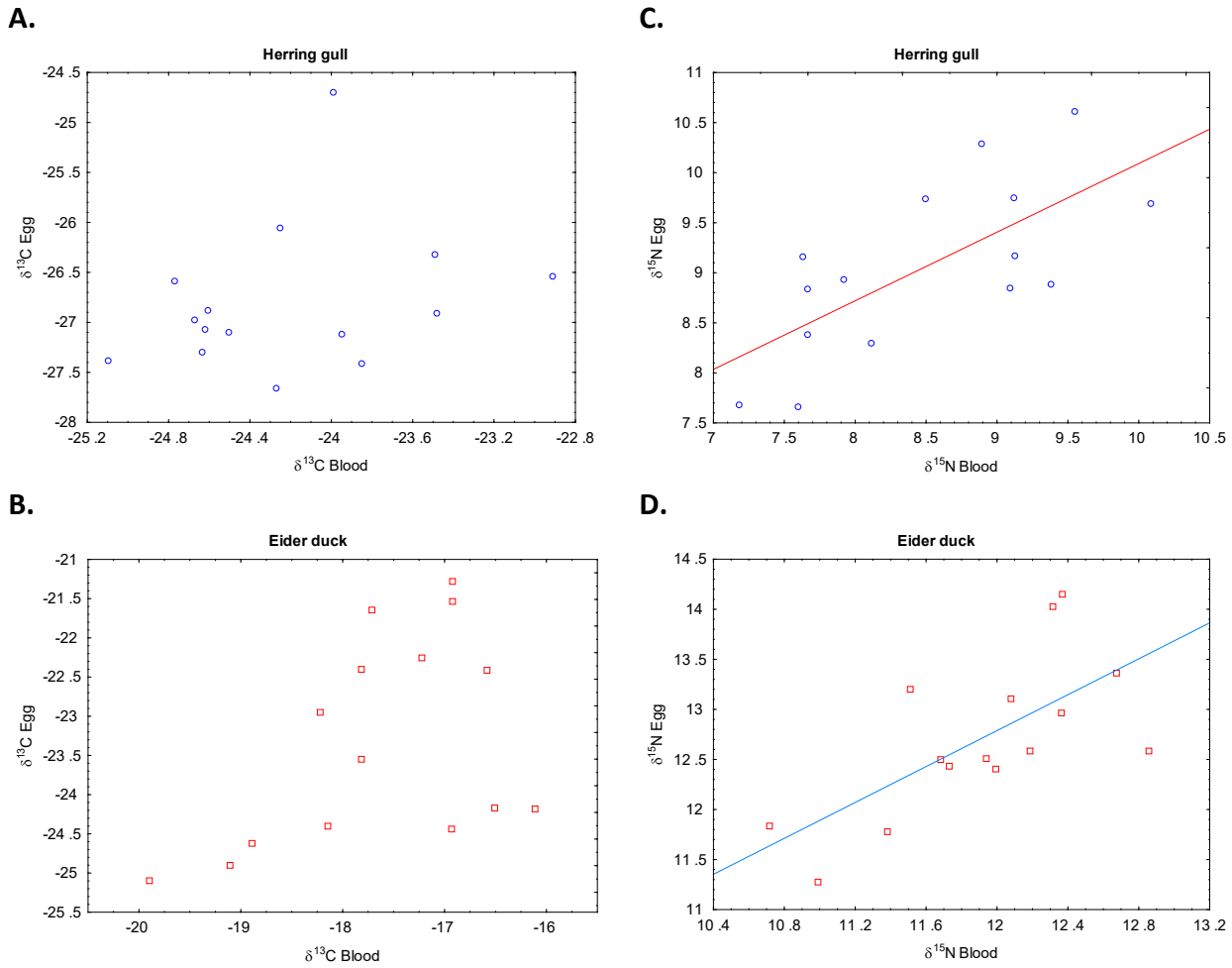


Figure 4. Isotopic ratios of carbon ($\delta^{13}C$; A. and B.) and nitrogen ($\delta^{15}N$, C. and D.) in herring gull (A. and C.) and eider duck (B. and D.) eggs plotted against isotopic ratios inn blood sampled at the same nest. Note: different scales on axes.

3.2 Environmental contaminants

A total of 168 single compounds were analysed in this study (not all compounds were analysed in all samples; see electronic Appendix). **Figure 5** gives the detection frequency (in %) of the various compounds in the different samples.

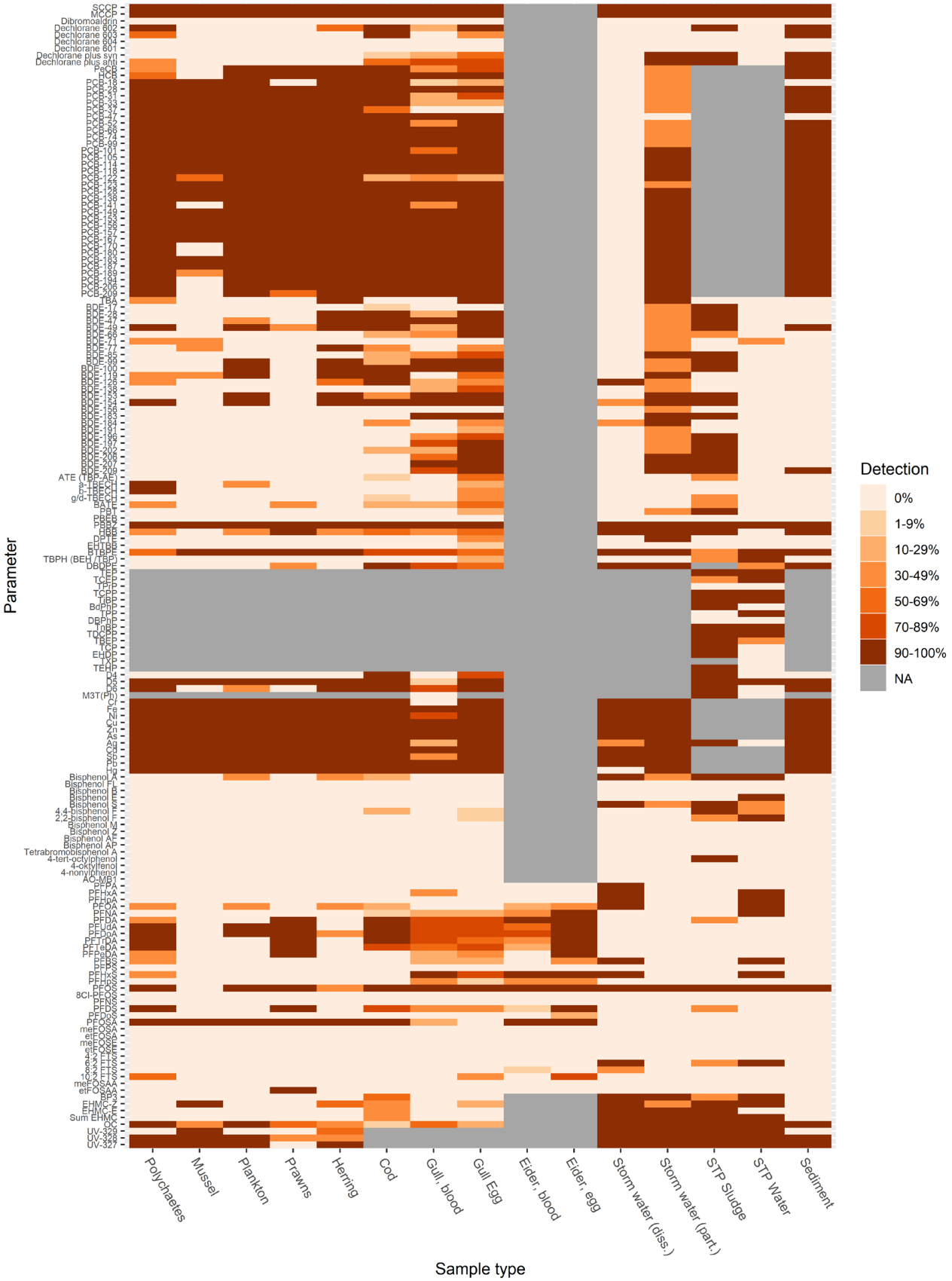
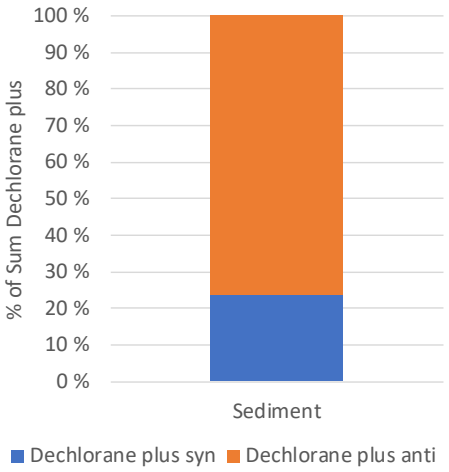


Figure 5. Detection frequency (%) of all the analysed compunds in the different environmental samples in this study.

3.2.1 Sediment

The sediments of the inner Oslofjord is a potential source of environmental contaminants to sediment dwelling organisms and the contaminants may thus enter the food chain. Several of the target compounds of this study were detected in the sediment sample. Inputs to the fjord via storm water and effluent water from a sewage treatment plant (see Chapters 3.2.6 and 3.2.7) for several of the compounds are also shown.

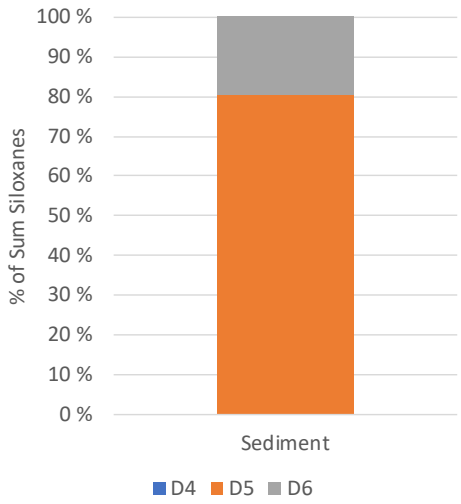
Dechlorane plus was found in the sediment sample (sum of *syn*- and *anti*-isomers 1.675 ng/g dry wt.; **Figure 6**). In addition, dechlorane 602 and 603 were detected in concentrations of 0.053 ng/g dry wt and 0.138 ng/g dry wt, respectively. (see electronic Appendix). The sediment concentration is in the same range as concentrations found in sediments of the North American Great Lakes, and 1-2 orders of magnitude lower than in sediments of Lake Ontario, close to a dechlorane plus manufacturing plant in the city of Niagara Falls (Sverko et al. 2011). The dechlorane plus facility at Niagara Falls is the only production facility in North America (Gauthier and Letcher, 2009). There is no production of dechlorane plus in Norway, and the registered use in the EU is in the order of 100 - 1000 tons per year (https://miljostatus.miljodirektoratet.no/tema/miljogifter/prioriterte-miljogifter/dekloraner/). It is likely that imported plastic products are important contributors to the concentrations of dechlorane plus in the Norwegian environment, which appear noteworthy as concentrations are not very different from those observed in North America.



	Dechlorane plus syn	Dechlorane plus anti
ng/g (dry wt.)	0.401	1.27

Figure 6. Relative contribution (%) of dechlorane plus syn- and anti-isomers to the sum of dechlorane plus in sediment from the Inner Oslofjord (station Cm21). Concentrations (ng/g dry wt.) are given in the associated table.

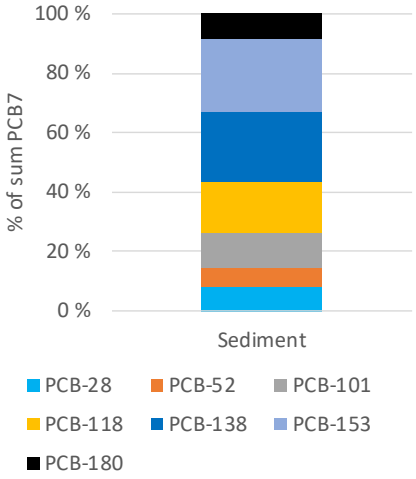
Of the siloxanes, D5 constituted the highest percentage of the sum in sediment, followed by D6 (**Figure 7**).



	D4	D5	D6
ng/g (dry wt.)	n.d.	57.88	14.19

Figure 7. Relative contribution (%) of Siloxanes to the sum of Siloxanes in sediment from the Inner Oslofjord (station Cm21). Concentrations (ng/g dry wt.) are given in the associated table.

The concentration of PCB7 in the sediment appeared a factor 4-5 lower than in 2017 (Ruus et al. 2019; The Norwegian Environment Agency M-1131). The relative contribution (%) of PCB-congeners to the sum of PCB7 is presented in **Figure 8**. PCB-118 -138 and -153 constituted the highest percentages.



	PCB-28	PCB-52	PCB-101	PCB-118	PCB-138	PCB-153	PCB-180
ng/g (dry wt.)	1.51	1.29	2.17	3.23	4.37	4.61	1.60

Figure 8. Relative contribution (%) of PCB-congeners to the sum of PCB7 in sediment from the Inner Oslofjord (station Cm21). Concentrations (ng/g dry wt.) are given in the associated table.

Of the polybrominated diphenyl ethers (PBDEs), only BDE-49 and -209 were detected in sediment, in concentrations of 0.05 ng/g dry wt and 2.51 ng/g dry wt, respectively. Of the other brominated compounds, DBDPE was found in a concentration of 42.8 ng/g dry wt.

Of the PFAS compounds, only PFOS was detected in sediment in a concentration of 0.35 ng/g dry wt.

For several compounds, environmental quality standards (EQS) for sediment are given through Norwegian law (The Water Regulation/"Vannforskriften"), according to the requirements of the Water Framework Directive. Furthermore, quality standards are given for even more compounds (Direktoratsgruppen vanndirektivet 2018). For the target compounds of this study of which quality standards exist, the sediment concentrations and EQSs are compared in **Table 10**. D5, PCB7, Zn, As, Ni, Hg and PFOS exceeded the quality standards. Regarding inputs to the fjord (apart from the storm water and STP effluent; Chapter 3.2.6), according to Kaste et al. (2018; The Norwegian Environment Agency M-1168), River Alna also brought some contaminants to the fjord (see Chapter 3.2.6).

Table 10. Concentrations of contaminants (mg/kg dry wt) of which Norwegian quality standards (Direktoratsgruppen vanndirektivet 2018) exist in sediment from the inner Oslofjord. Red numbers indicate concentrations exceeding the quality standard (annual average, AA-EQS).

River basin specific compounds	EQS (mg/kg dry wt.)	Sediment conc. (mg/kg dry wt.)
Bisphenol A	0.0011	<0.030 ***
Decamethylcyclopentasiloxane (D5)	0.044	0.058
Medium chained chloroparafins (MCCPs)	4.6	0.98
Copper (Cu)	84	69
PCB7	0.0041	0.0188
PFOA	0.071	<0.0005
Zinc (Zn)	139	248
TBBPA	0.108	<0.090
Arsenic (As)	18	35
Chromium (Cr)	660	108
EU priority substances		
Cadmium (Cd)	2.5	0.2
Lead (Pb)	150	109
Nickel (Ni)	42	52
Mercury (Hg)	0.52	1.10
Brominated diphenyl ethers *	0.062	<0.002
Hexachlorobenzene	0.017	0.0004
C10-13 chloroalkanes **	0.8	0.64
Pentachlorobenzene	0.4	0.0004
Nonylphenol (4-)	0.016	<0.085 ***
Oktylphenol (4-*tert*-)	0.0003	<0.04 ***
PFOS	0.00023	0.00035

* Sum of BDE-28, -47, -99, -100, -153 and -154.
** Short chained chloroparaffins (SCCPs)
*** Too high limit of detection to evaluate

3.2.2 Inner Oslofjord Food Web

Several legacy contaminants with well-known biomagnifying properties displayed a positive significant relationship between (log_{10}-)concentrations and trophic position (deduced from the $\delta^{15}N$ isotopic ratio) in the studied Inner Oslofjord marine food web. Of the 32 analysed PCB congeners, 28 showed significant biomagnification, including the seven congeners constituting PCB7 (PCB-153 and 180 shown in **Figure 9**; TMFs of PCB-28, -52, -101, -118 and -138 were 1.79, 2.05, 3.12, 4.38 and 4.64,

respectively). These findings correspond well with the findings from previous years of the "Urban fjord" programme (Ruus et al. 2016; Ruus et al. 2017; Ruus et al. 2019; The Norwegian Environment Agency M-601, M-812 and M-1131), as well as with previous observations from marine systems (Hallanger et al. 2011; Fisk et al. 2001). Thus, PCBs display expected behaviour in the Inner Oslofjord food web, suggesting again that the studied food web is appropriate for assessing biomagnifying behaviour of contaminants (where PCBs may serve as "benchmark").

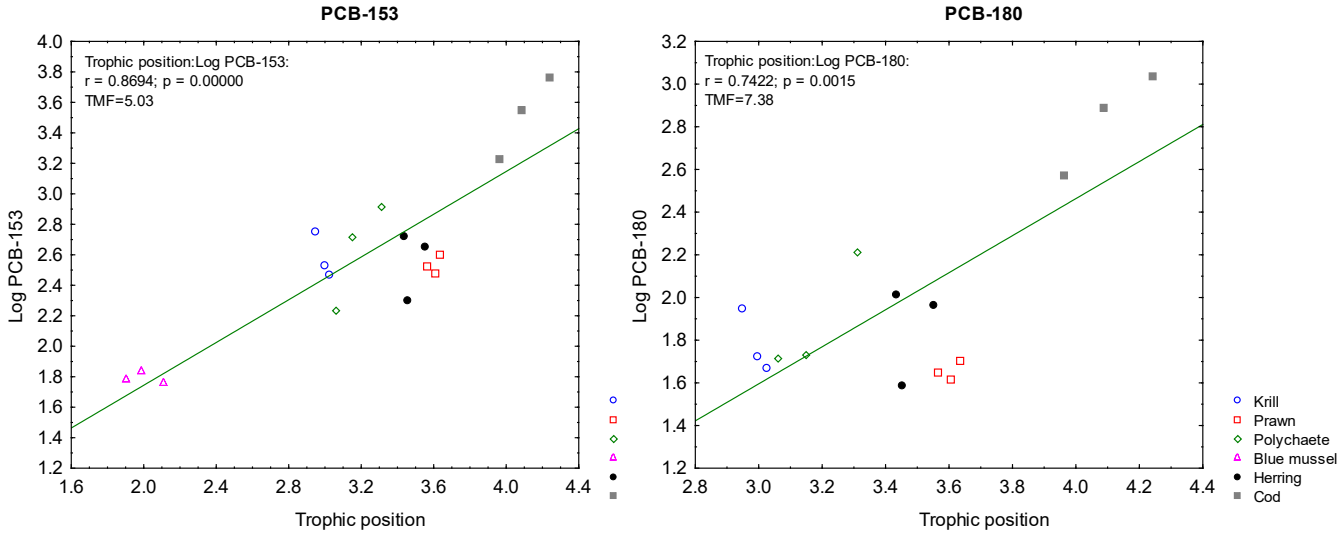
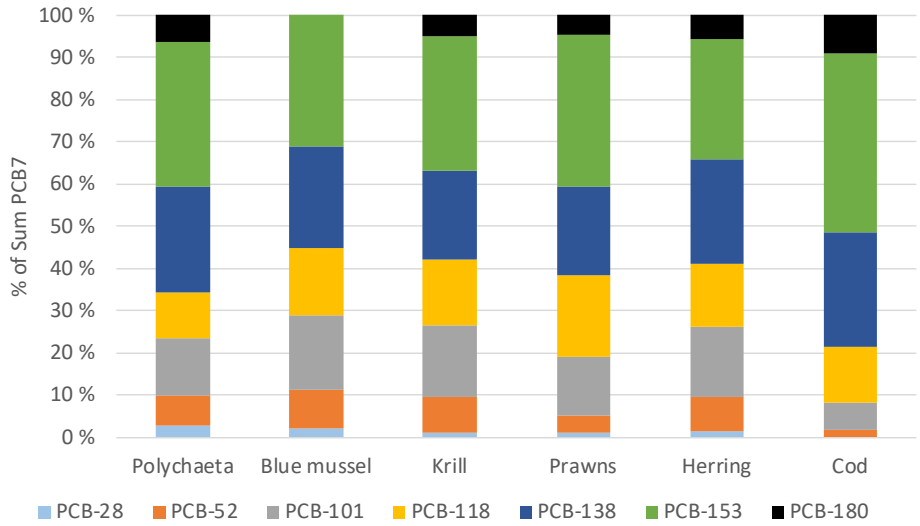


Figure 9. Trophic position against concentrations (ng/g lipid wt.; log-transformed) of PCB-153 and PCB-180 in the studied Inner Oslofjord food web. Note different scales on axes.

The relative contribution (%) of PCB-congeners to the sum of PCB7 was similar among the species of the Inner Oslofjord food web, with PCB-153 constituting the highest percentage (**Figure 10**).



	PCB-28	PCB-52	PCB-101	PCB-118	PCB-138	PCB-153	PCB-180
Polychaete	0.261	0.661	1.28	1.08	2.41	3.30	0.610
Blue mussel	0.033	0.131	0.247	0.227	0.345	0.443	n.d.
Krill	0.105	0.698	1.46	1.32	1.78	2.68	0.422
Prawn	0.037	0.131	0.433	0.609	0.653	1.12	0.148
Herring	0.715	3.89	8.50	7.62	12.3	14.6	2.88
Cod	5.91	38.8	173	321	643	992	204

Figure 10. Relative contribution (%) of PCB-congeners to the sum of PCB7 in the species of the Inner Oslofjord food web. Concentrations (ng/g wet wt.; mean) are given in the associated table.

The following polybrominated diphenyl ethers (PBDEs) showed statistically significant biomagnification: BDE-47, -49 (TMF= 3.83; **Figure 11**), -100, -126 and -154 (TMF= 3.39; **Figure 11**). However, the compounds were not detected in several of the samples (see electronix appendix). Some PBDEs also showed trophic dilution: BDE-99, and -153. Biomagnification of polybrominated diphenyl ethers corresponds to previous observations in the "Urban fjord" programme (Ruus et al. 2016; Ruus et al. 2017; Ruus et al. 2019; The Norwegian Environment Agency M-601, M-812 and M-1131). Furthermore, biomagnification of PBDEs has previously been shown in marine systems (e.g. Hallanger et al. 2011).

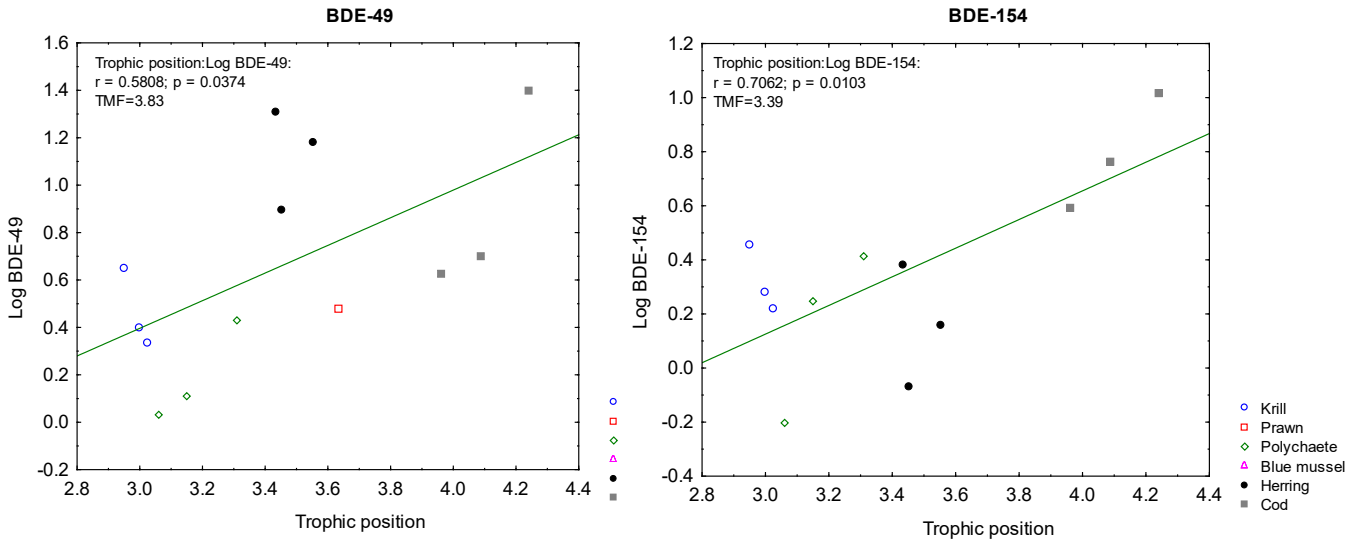
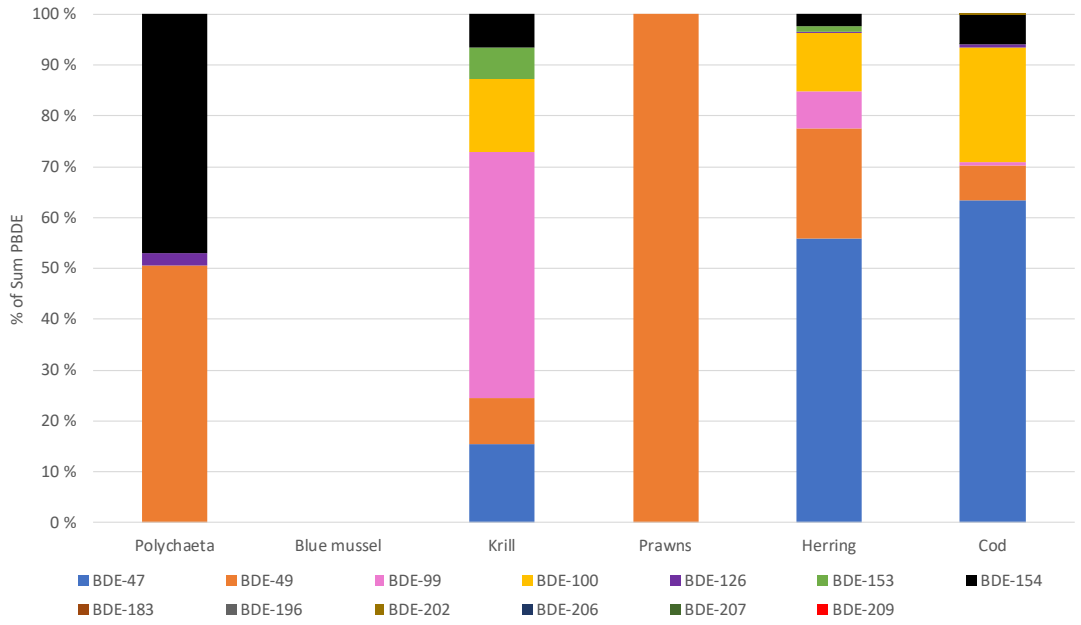


Figure 11. Trophic position against concentrations (ng/g lipid wt.; log-transformed) of BDE-49 and -154 in the studied Inner Oslofjord food web. Note different scales on axes.

The relative contribution (%) of BDE-congeners to the sum of PBDEs appeared somewhat different among the species of the Inner Oslofjord food web (**Figure 12**). BDE-47 constituted the highest percentage in herring and cod, while BDE-49 constituted the highest percentage in polychaetes and Prawns (BDE-49 was the only detected PBDE-congener in prawns; **Figure 12**). BDE-99 was the major constituent in krill (**Figure 12**), as previously observed (Ruus et al. 2019; The Norwegian Environment Agency M-1131). Also as previously (Ruus et al. 2019; The Norwegian Environment Agency M-1131), only a few BDE-congeners were detected in blue mussel (see electronic Appendix). In 2018, none of the selected (see **Table 5**) congeners were detected (**Figure 12**), only BDE-71, -77 and -119.



	Polychaete	Blue mussel	Krill	Prawn	Herring	Cod
BDE-47	n.d.	n.d.	0.055	n.d.	1.397	29.884
BDE-49	0.012	n.d.	0.020	0.003	0.536	3.929
BDE-99	n.d.	n.d.	0.109	n.d.	0.178	0.392
BDE-100	n.d.	n.d.	0.033	n.d.	0.287	9.639
BDE-126	0.001	n.d.	n.d.	n.d.	0.004	0.146
BDE-153	n.d.	n.d.	0.014	n.d.	0.027	0.073
BDE-154	0.011	n.d.	0.015	n.d.	0.056	1.874
BDE-183	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
BDE-196	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
BDE-202	n.d.	n.d.	n.d.	n.d.	n.d.	0.048
BDE-206	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
BDE-207	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
BDE-209	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

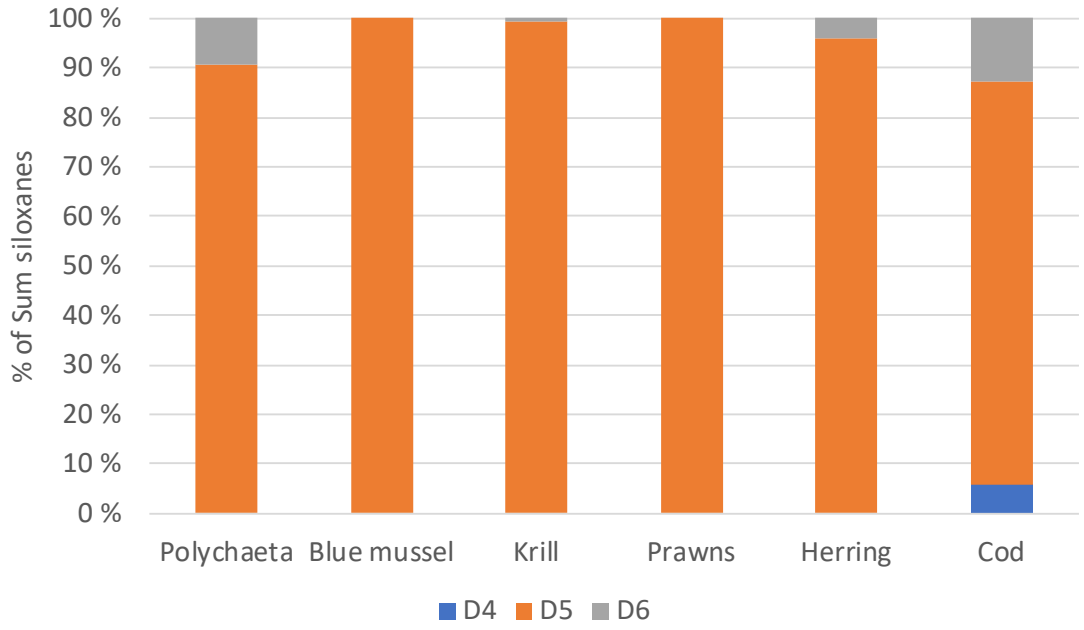
Figure 12. Relative contribution (%) of selected BDE-congeners (see **Table 5**) to the sum of those PBDEs in the species of the Inner Oslofjord food web. Concentrations (ng/g wet wt.; mean; non-detected components were assigned a value of zero) are given in the associated table. Components that were not detected in any replicate samples of a species are noted n.d.

Dechlorane plus was detected in one polychaete sampled from the Inner Oslofjord food web (only the anti- isomers), as well as in cod (mostly the anti-isomer; see electronic appendix). Furthermore,

dechlorane 602 and 603 were detected in polychaetes and cod. Dechlorane 602 was also detected in herring (see electronic appendix).

The concentrations of siloxanes (D4, D5 and D6) displayed no significant relationship with trophic position. There have previously been some divergences in reports of the biomagnifying properties of siloxanes in different systems (e.g. Borgå et al. 2012 and references therein). By compiling data from different surveys from the period 2010-2017, Jartun et al. (2018; The Norwegian Environment Agency M-1106) demonstrated biomagnification of D5 in the lakes Mjøsa and Randsfjorden with a common TMF of 2.05, and biomagnification of D6 with a common TMF of 1.26. D5 appeared in the highest concentrations (Jartun et al. 2018; The Norwegian Environment Agency M-1106). On the other hand, Powel et al (2018) found no biomagnification of D4, D5 and D6 across demersal and pelagic food webs in the Oslofjord.

Of the siloxanes analysed in the present study, D5 also appeared in the highest concentrations in all species of the food web (**Figure 13**).



	D4	D5	D6
Polychaete	n.d.	99.44	9.25
Blue mussel	n.d.	13.78	n.d.
Krill	n.d.	190.03	1.10
Prawn	n.d.	15.25	n.d.
Herring	n.d.	137.84	5.74
Cod	65.79	1169.17	149.46

Figure 13. Relative contribution (%) of D4, D5 and D6 to the sum of siloxanes in the species of the Inner Oslofjord food web. Concentrations (ng/g wet wt.; mean) are given in the associated table. Components that were not detected in any replicate samples of a species are noted n.d.

Mercury displayed statistically significant biomagnification (TMF=4.62; **Figure 14**) in the Inner Oslofjord food web, as previously observed in the "Urban fjord" programme (Ruus et al. 2016; Ruus et al. 2017; Ruus et al. 2019; The Norwegian Environment Agency M-601, M-812 and M-1131). The biomagnifying properties of Hg (particularly methylmercury, MeHg) are well known (e.g. Jaeger et al. 2009; Ruus et al. 2015). It should be noted that the proportion of total Hg that is MeHg in the different organism is not known and likely differs.

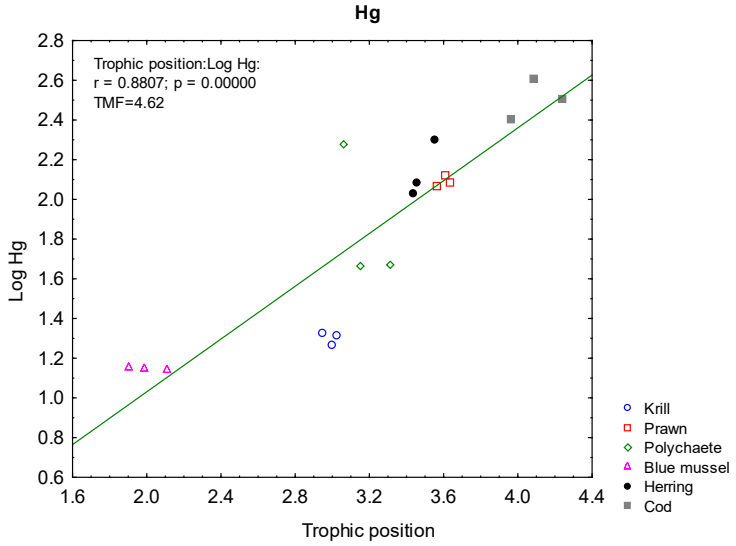


Figure 14. Trophic position against concentrations (ng/g wet wt.; log-transformed) of mercury (Hg) in the studied Inner Oslofjord food web.

Furthermore, also the elements As (TMF=3.46; **Figure 15**) and Ag (TMF=11.00; **Figure 16**) again displayed statistically significant positive relationships between (log) concentrations and trophic position (as in 2015, 2016 and 2017). It should be mentioned again that in this programme, total As was measured (not only inorganic As), and most of the arsenic found in fish, and marine animals in general, is present as arsenical arsenobetaine, which is regarded as non-toxic (Amlund, 2005 and references therein). Arsenobetaine is rapidly absorbed over the gastrointestinal tract (Amlund, 2005 and references therein). There is little evidence of biomagnification of Ag in marine systems, and according to a review by Fisher and Wang (1998), trophic transfer of Ag has been shown to be insignificant in several aquatic animals but more important in others. Maneekarn et al. (2014) studied bioaccumulation and biomagnification of nano Ag^0 particles (AgNPs) in a model food chain containing green algae (*Chlorella sp.*), water flea (*Moina macroscopa*), blood worm (*Chironomus spp.*) and silver barb *(Barbonys gonionotus*). They found that food chain transfer of AgNPs occurred only from *Chlorella sp.* to *M. macroscopa*. Hg, As and Ag were detected in sediment from the Inner Oslofjord, as well as in storm water (Hg only in the particulate phase) entering the fjord (see electronic Appendix). Ag (the only element analysed) was not detected in effluent water from Bekkelaget STP (<0.006 ng/ml). Silver nanoparticles (AgNP) are used in several consumer products (*inter alia* textiles) for their antimicrobial properties, however, their possible influence on the observed results is unknown. Wang et al (2014) showed that the marine polychaete *Nereis virens* accumulated Ag in the forms of AgNP-citrate, AgNP-polyvinylpyrrolidone and as a salt ($AgNO_3$).

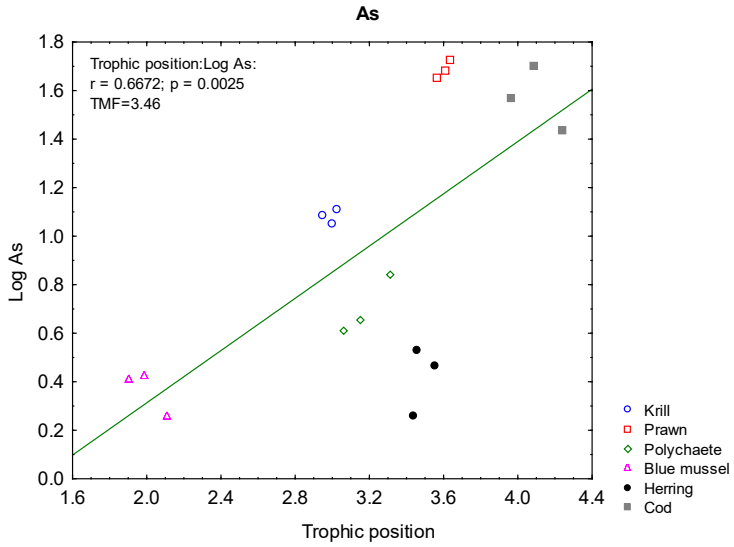


Figure 15. Trophic position against concentrations (µg/g wet wt.; log-transformed) of arsenic (As) in the studied Inner Oslofjord food web.

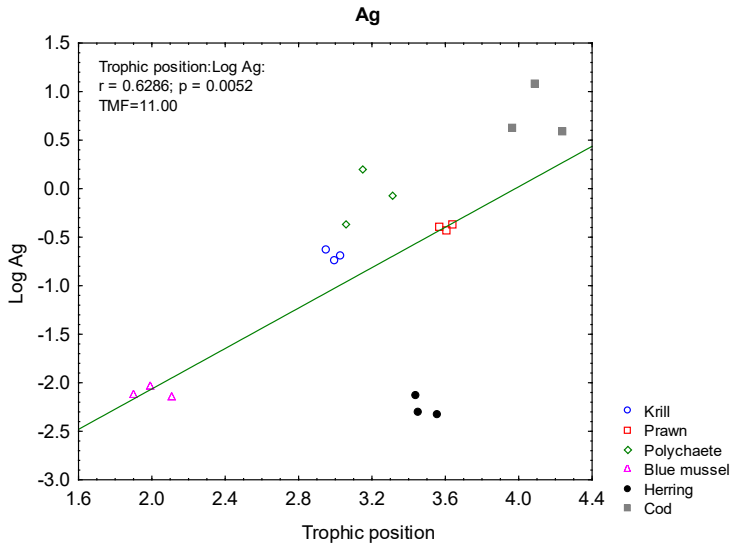


Figure 16. Trophic position against concentrations (µg/g wet wt.; log-transformed) of silver (Ag) in the studied Inner Oslofjord food web.

Regarding PFAS compounds, there were many non-detects for most compounds. PFOSA, however, was detected in all species, and PFOS was detected in all species but blue mussel. Both PFOSA and PFOS displayed significant positive relationships between (log) concentration and trophic position (TMF= 2.91 and TMF=7.01, respectively; **Figure 17**; **Figure 18**). If eider duck (egg) is included in the food web, there is still a significant, and higher, TMF for PFOS (TMF=9.87; **Figure 19**), while PFOSA no longer displayed a significant relationship between (log) concentration and trophic position (p=0.11). Previously, PFOSA (Ruus et al. 2019; The Norwegian Environment Agency M-1131) and PFOS (Ruus et al. 2017; The Norwegian Environment Agency M-812) also showed significant biomagnification in the Inner Oslofjord marine food web. Biomagnification of PFOSA and PFOS has previously been shown in

marine food webs (e.g. Kelly et al. 2009; Houde et al. 2011), However, Franklin (2015), points to the great variability in field derived biomagnification estimates of PFAS compounds.

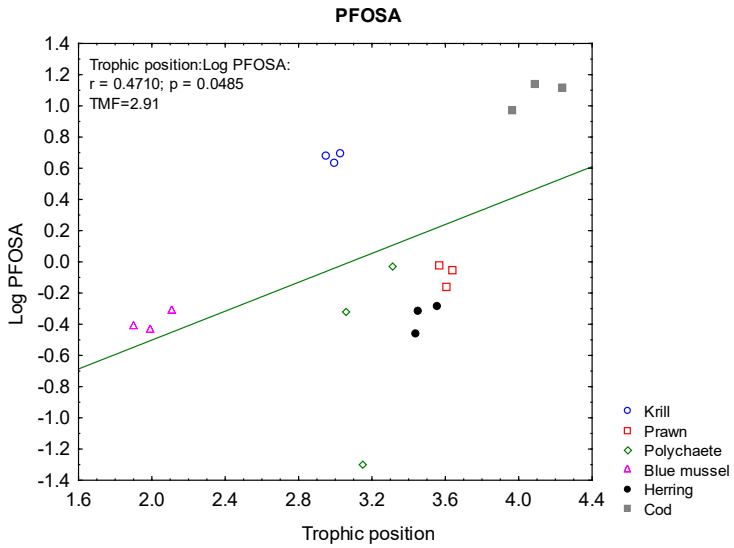


Figure 17. Trophic position against concentration (ng/g wet wt.; log-transformed) of PFOSA in the studied Inner Oslofjord food web.

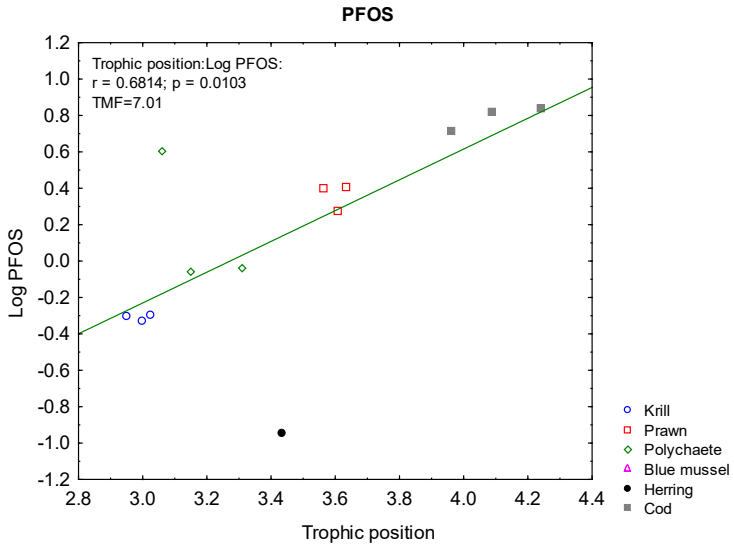


Figure 18. Trophic position against concentration (ng/g wet wt.; log-transformed) of PFOS in the studied Inner Oslofjord food web.

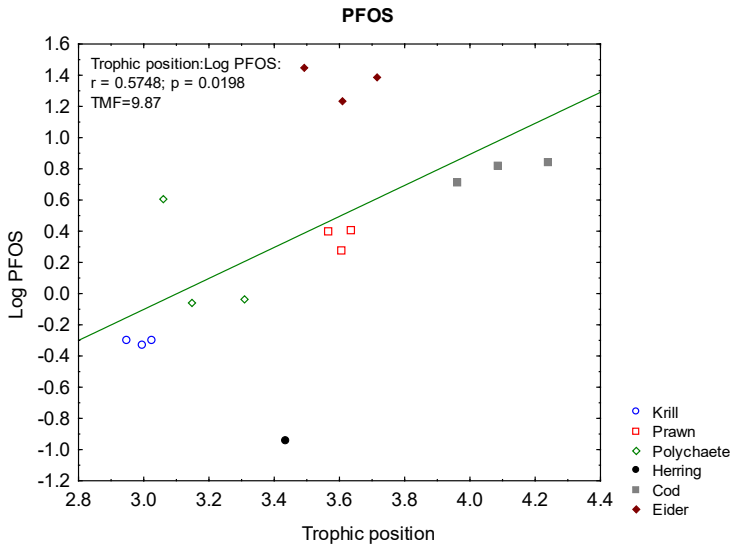
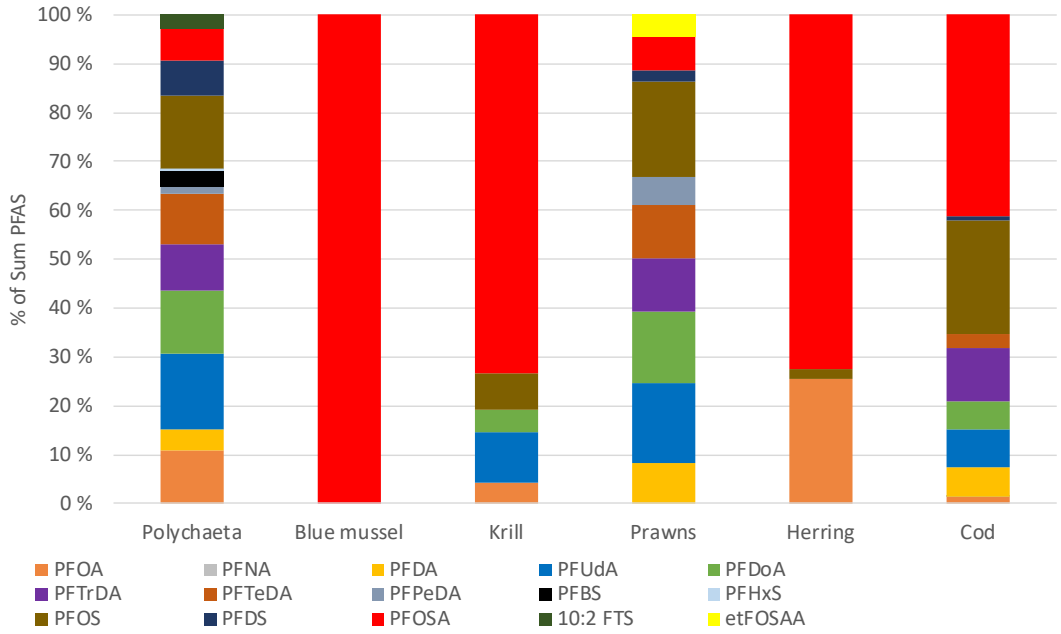


Figure 19. Trophic position against concentration (ng/g wet wt.; log-transformed) of PFOS in the studied Inner Oslofjord food web when eider duck (egg) is included.

PFOSA constituted the highest percentage (of sum PFAS) in blue mussel, krill, herring and cod (**Figure 20**), as previously observed (Ruus et al. 2017; Ruus et al. 2019; The Norwegian Environment Agency M-812 and M-1131). PFOS was also an important constituent in cod (constituting >20% of sum PFAS; **Figure 20**).



	Polychaete	Blue mussel	Krill	Prawn	Herring	Cod
PFOA	0.91	n.d.	0.32	n.d.	0.51	0.34
PFNA	n.d.	n.d.	n.d.	n.d.	n.d.	0.07
PFDA	0.94	n.d.	n.d.	0.99	n.d.	1.60
PFUdA	2.28	n.d.	0.67	1.96	n.d.	2.18
PFDoA	1.62	n.d.	0.29	1.73	n.d.	1.59
PFTrDA	0.96	n.d.	n.d.	1.35	n.d.	3.04
PFTeDA	1.00	n.d.	n.d.	1.30	n.d.	0.86
PFPeDA	0.38	n.d.	n.d.	0.66	n.d.	n.d.
PFBS	0.17	n.d.	n.d.	n.d.	n.d.	n.d.
PFHxS	0.05	n.d.	n.d.	n.d.	n.d.	n.d.
PFOS	1.94	n.d.	0.49	2.31	0.04	6.23
PFDS	0.97	n.d.	n.d.	0.27	n.d.	0.30
PFOSA	0.49	0.42	4.73	0.84	0.45	12.10
10:2 FTS	0.41	n.d.	n.d.	n.d.	n.d.	n.d.
etFOSAA	n.d.	n.d.	n.d.	0.52	n.d.	n.d.

Figure 20. Relative contribution (%) of PFAS compounds to the sum of (detected) PFASs in the species of the Inner Oslofjord food web. Concentrations (ng/g wet wt.; mean; non-detected components were assigned a value of zero) of detected components are given in the associated table. Components that were not detected in any replicate samples of a species are noted n.d.

UV chemicals were detected in several samples from the Inner Oslofjord marine food web (see electronic Appendix), hower no compounds showed biomagnification.

As previously in the Urban fjord programme (Ruus et al. 2017; Ruus et al. 2019; The Norwegian Environment Agency M-812 and M-1131), no phenolic compounds were detected in more than a few (here ≤4) samples of the Inner Oslofjord food web (see electronic appendix).

3.2.3 Cod

Environmental contaminants were analysed in 15 cod individuals. Pooled samples of cod, 3 samples constituted of 5 individuals each sorted by their length, were constructed mathematically to obtain 3 samples of each species, for evaluation of biomagnifying behaviour in the Inner Oslofjord food web.

Biological effect parameters were also measured in cod, and these are dealt with in Chapter 3.5.

Concentrations (mean and range) for all compounds and elements analysed in cod liver are presented **Table 11**, as well as in Appendix. Phenolic compounds were analysed in bile, and very few compounds were detected in only a few samples (see electronic appendix).

Table 11. Lipid content (%) and concentrations of the different analytes (see **Table 5**) in cod liver from the Inner Oslofjord. Concentrations are ng/g wet wt., except for concentrations of Ni, Cu, Ag, Cd, Pb, Cr, Fe, Zn, As and Sb, which are expressed as µg/g wet wt. Arithmetic mean and range are presented (n=15). In calculations of mean, non-detected components were assigned a value of zero (0). Phenolic compounds were analysed in bile (see electronic appendix).

Analyte	Mean	Range	Detected in no. of samples
Lipid content (%), liver	33.7	10.8 - 53.8	15
PeCB	0.6	0.2 – 1.0	15
HCB	6.2	1.1 - 14.8	15
Dechlorane	**Mean**	**Range**	**Detected in no. of samples**
Dechlorane 602	0.896	0.268 - 2.64	15
Dechlorane 603	0.319	0.064 - 0.911	15
Dechlorane 604	n.d.	<1.61 - <4.72	0
Dechlorane 601	n.d.	<0.062 - <0.143	0
Dechlorane plus syn	0.029	<0.417 - 0.434	1
Dechlorane plus anti	0.531	<0.609 - 1.09	10
PCBs (PCB7)	**Mean**	**Range**	**Detected in no. of samples**
PCB-28	5.9	1.0 - 19.9	15
PCB-52	38.8	6.0 - 178	15
PCB-101	172.8	40.3 - 682	15
PCB-118	321.4	98.3 - 863	15
PCB-138	643.4	225 - 1510	15
PCB-153	991.9	377 - 2190	15
PCB-180	204.3	78.9 - 435	15
Sum-PCB_7	2378.5	827 - 5878	15
Brominated comp.	**Mean**	**Range**	**Detected in no. of samples**
BDE-47	29.884	6.41 - 128	15
BDE-49	3.929	0.307 - 26	15
BDE-99	0.392	<0.902 - 2.47	3
BDE-100	9.639	1.54 - 35.5	15
BDE-126	0.146	0.028 - 0.401	15
BDE-153	0.073	<0.077 - 0.372	7
BDE-154	1.874	0.577 - 4.49	15

BDE-183	n.d.	<0.055 - <0.055	0
BDE-196	n.d.	<0.128 - <0.128	0
BDE-202	0.048	<0.159 - 0.204	4
BDE-206	n.d.	<0.294 - <0.294	0
BDE-207	n.d.	<0.255 - <0.255	0
BDE-209	n.d.	<2.23 - <2.23	0
ATE (TBP-AE)	0.011	<0.155 - 0.166	1
a-TBECH	n.d.	<0.379 - <0.379	0
b-TBECH	n.d.	<0.267 - <0.267	0
g/d-TBECH	0.009	<0.118 - 0.134	1
BATE	0.008	<0.05 - 0.0698	2
PBT	n.d.	<0.254 - <0.254	0
PBEB	n.d.	<0.343 - <0.343	0
PBBZ	0.165	0.095 - 0.279	15
HBB	0.219	<0.286 - 0.39	10
DPTE	n.d.	<0.047 - <0.047	0
EHTBB	n.d.	<0.138 - <0.138	0
BTBPE	0.190	<0.137 - 0.313	11
TBPH (BEH /TBP)	n.d.	<0.386 - <0.386	0
DBDPE	77.846	29.8 - 153	13
Chloroparaffins	**Mean**	**Range**	**Detected in no. of samples**
SCCP	399.5	236.6 - 728.4	15
MCCP	317.0	102.5 - 750.3	15
Siloxanes	**Mean**	**Range**	**Detected in no. of samples**
D4	65.8	16.2 - 129.6	15
D5	1169.2	91.4 - 2729.8	15
D6	149.5	38.3 - 367.2	15
Metals	**Mean**	**Range**	**Detected in no. of samples**
Cr	0.029	0.008 - 0.091	15
Fe	30.854	7.855 - 84.699	15
Ni	0.156	0.021 - 0.297	15

Cu	6.048	1.501 - 10.532	15
Zn	23.923	13.384 - 34.123	15
As	38.254	5.418 - 78.776	15
Ag	6.722	0.903 - 30.468	15
Cd	0.198	0.02 - 0.859	15
Sb	0.014	0.001 - 0.083	15
Pb	0.104	0.01 - 0.43	15
Hg	326.774	112.962 - 752.628	15
PFAS compounds	**Mean**	**Range**	**Detected in no. of samples**
PFPA	n.d.	<0.5 - <0.5	0
PFHxA	n.d.	<0.5 - <0.5	0
PFHpA	n.d.	<0.5 - <0.5	0
PFOA	0.342	<0.5 - 1.806	3
PFNA	0.070	<0.5 - 1.055	1
PFDA	1.600	0.464 - 3.998	15
PFUdA	2.178	0.37 - 4.121	15
PFDoA	1.592	0.298 - 2.57	15
PFTrDA	3.045	0.616 - 5.087	15
PFTeDA	0.862	<0.4 - 2.088	13
PFPeDA	n.d.	<0.4 - <0.4	0
PFBS	n.d.	<0.2 - <0.2	0
PFPS	n.d.	<0.2 - <0.2	0
PFHxS	n.d.	<0.1 - <0.1	0
PFHpS	n.d.	<0.2 - <0.2	0
PFOS	6.228	2.997 - 15.882	15
8Cl-PFOS	n.d.	<0.2 - <0.2	0
PFNS	n.d.	<0.2 - <0.2	0
PFDS	0.301	<0.2 - 0.59612	13
PFDoS	n.d.	<0.2 - <0.2	0
PFOSA	12.103	2.25 - 29.973	15
me-FOSA	n.d.	<0.3 - <0.3	0

et-FOSA	n.d.	<0.3 - <0.3	0
me-FOSE	n.d.	<5 - <5	0
et-FOSE	n.d.	<5 - <5	0
4:2 FTS	n.d.	<0.3 - <0.3	0
6:2 FTS	n.d.	<0.3 - <0.3	0
8:2 FTS	n.d.	<0.5 - <0.5	0
10:2 FTS	n.d.	<0.3 - <0.3	0
me-FOSAA	n.d.	<0.3 - <0.3	0
Et-FOSAA	n.d.	<0.3 - <0.3	0
UV-chemicals	**Mean**	**Range**	**Detected in no. of samples**
BP3	4.232	<1 - 30.637	8
EHMC-Z	0.314	<0.2 - 0.997	6
EHMC-E	0.929	<0.4 - 2.605	7
Sum EHMC	1.243	<0.6 - 3.602	7
OC	5.400	<8 - 81	1

Of the substances analysed for which (biota) quality standards exist (for EU priority substances or Norwegian river basin specific substances; Direktoratsgruppen vanndirektivet 2018), mean concentrations of Hg, PBDEs, PCB7 and MCCPs exceeded the EQS, as in 2017 (Ruus et al. 2019; The Norwegian Environment Agency M-1131). Note that the biota quality standards relate to (whole) fish, but that an alternative biota taxon, or another matrix, may be monitored instead, as long as the quality standard applied provides an equivalent level of protection.

No individual D5 concentration exceeded the quality standard of 15217 ng/g (The Norwegian Environment Agency; M-608). In the present study, the mean D5 concentration in the cod liver on a lipid weight basis (3356 ng/g ± 1600 standard deviation) was higher than that in trout from Lake Mjøsa in 2017 (877 ± 655; Jartun et al. 2018; The Norwegian Environment Agency M-1106). In previous studies of cod from the Inner Oslofjord (e.g. Powell et al. 2018; Schlabach et al. 2007), D5 was, as in the present study, detected as the dominating siloxane compound.

As in 2017 (Ruus et al. 2019; The Norwegian Environment Agency M-1131), there was no statistically significant relationship (p=0.65) between Hg in cod and the length of cod (**Figure 21**). Previously such a positive relationship was found in the Urban fjord programme (Ruus et al. 2016; Ruus et al. 2017; The Norwegian Environment Agency M-601 and M-812). Co-variation between fish length and Hg-concentrations is well known (e.g. Eikenberry et al. 2015; Green and Knutzen, 2003; Jones et al. 2013; Julshamn et al. 2013; Sackett et al. 2013), and. Jones et al. (2013) have also argued that detecting the influence of changes in Hg exposure will depend on how well fish biotmetrics (length, age and growth rates) are considered.

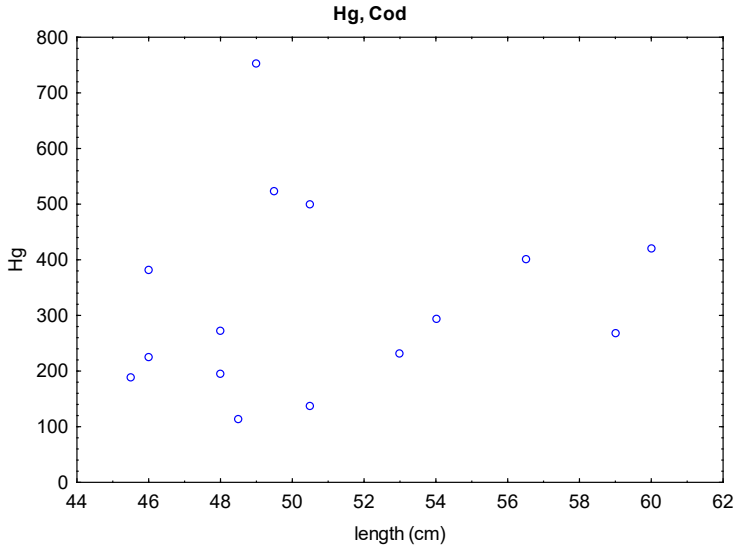


Figure 21. Concentrations (ng/g wet wt.) of mercury (Hg) in muscle of cod against length (cm) in cod from the Inner Oslofjord.

As previously (Ruus et al. 2017; Ruus et al. 2019; The Norwegian Environment Agency M-812 and M-1131), the flame retardant decabromodiphenyl ethane (DBDPE) was found in elevated concentrations in cod (**Table 11** and electronic appendix). DBDPE is a flame retardant for various applications, such as plastic and rubber materials, electrical and electronic equipment, adhesives and sealants (an alternative to deca-BDE). BDE-209 was not detected in cod liver.

UV chemicals were detected in some of the liver samples (**Table 11**). No UV chemicals were detected in more than approximately 50% of the samples.

Some dechlorane compounds were detected in cod liver (**Table 11**). On a lipid weight basis, the concentrations of dechlorane plus (sum of *syn*- and *anti*-isomers; 2.06 ± 2.32 ng/g lipid wt) were approximately a factor 2 higher than found in brown trout (*salmo trutta*) from Lake Mjøsa in 2017 (Jartun et al. 2018; The Norwegian Environment Agency M-1106). Furthermore, those were higher than found in trout from Lake Ontario, Canada (Feo et al. 2012). In the same review (Feo et al. 2012) it is shown that dechlorane plus was not detected (<0.003 ng/g lipid wt) in Atlantic cod from Faroe Islands.

Phenolic compounds were analysed in bile of cod. Only two compounds were detected, but only in two individuals (see electronic appendix).

3.2.4 Herring gull

Inner Oslofjord
Both blood and egg were sampled from herring gull. Adult female blood and egg was sampled from the same nest (i.e. mother and future offspring).

Concentrations (mean and range; wet wt. basis) for all compounds and elements analysed in herring gull (blood and egg) are presented in **Table 12**. The number of samples in which the substance was detected is also shown in **Table 12**.

Table 12. Lipid content (%) and concentrations of the different analytes in herring gull blood and egg from the Inner Oslofjord. Concentrations are ng/g wet wt., except for concentrations of Ni, Cu, Ag, Cd, Pb, Cr, Fe, Zn, As and Sb, which are expressed as µg/g wet wt. Arithmetic mean and range (minimum and maximum) are presented (n=15). In calculations of mean, non-detected components were assigned a value of zero (0). Det. no. is the number of samples in which the substance was detected (blood/egg).

Analyte	Blood Mean	Blood Range	Egg Mean	Egg Range	Det. no.
Lipid content (%)	1.48	0.3 - 3.1	8.80	6.9 - 9.8	15/15
PeCB	0.017	<0.030 - 0.073	0.209	<0.113 - 0.627	6/13
HCB	0.336	0.138 - 0.768	3.243	0.911 - 8.38	15/15
MB1	n.d.	<20.0 - <23.0	n.d.	<75.0 - <75.0	0/0
Dechlorane	**Blood Mean**	**Blood Range**	**Egg Mean**	**Egg Range**	**Det. no.**
Dechlorane 602	0.002	<0.007 - 0.0155	0.043	<0.007 - 0.137	3/14
Dechlorane 603	n.d.	<0.007 - <0.014	0.012	<0.007 - 0.0693	0/5
Dechlorane 604	n.d.	<0.322 - <0.694	n.d.	<0.322 - <1.42	0/0
Dechlorane 601	n.d.	<0.012 - <0.021	n.d.	<0.012 - <0.041	0/0
Dechlorane plus syn	0.013	<0.083 - 0.104	0.137	<0.083 - 0.73	2/8
Dechlorane plus anti	0.119	<0.122 - 0.19	0.423	<0.122 - 2.2	11/11
PCBs (PCB7)	**Blood Mean**	**Blood Range**	**Egg Mean**	**Egg Range**	**Det. no.**
PCB-28	0.062	0.023 - 0.235	0.958	0.195 - 2.22	15/15
PCB-52	0.061	<0.035 - 0.536	1.076	0.192 - 5.47	7/15
PCB-101	0.131	<0.075 - 0.697	2.879	0.875 - 10.3	9/15
PCB-118	2.187	0.345 - 9.17	32.551	5.32 - 85.8	15/15
PCB-138	4.089	0.751 - 16.9	66.700	13.8 - 157	15/15
PCB-153	6.131	1.21 - 24.3	100.347	20.4 - 237	15/15
PCB-180	1.797	0.4 - 6.67	29.036	7.5 - 60	15/15
Sum-PCB_7	14.459	2.729 – 58.508	233.546	48.44 – 548.79	15/15
Brominated comp.	**Blood Mean**	**Blood Range**	**Egg Mean**	**Egg Range**	**Det. no.**
BDE-47	0.336	0.106 - 1.3	5.209	1.15 - 23.7	15/15
BDE-49	0.003	<0.005 - 0.023	0.038	0.015 - 0.136	2/15

BDE-99	0.377	0.071 - 2.12	9.833	1.02 - 49.3	15/15
BDE-100	0.092	0.024 - 0.363	2.245	0.272 - 9.5	15/15
BDE-126	0.003	<0.003 - 0.024	0.041	<0.004 - 0.221	3/6
BDE-153	0.098	0.015 - 0.653	1.678	0.217 - 12.4	15/15
BDE-154	0.029	<0.008 - 0.125	0.452	0.102 - 2.27	14/15
BDE-183	0.028	<0.005 - 0.195	0.416	0.065 - 2.93	14/15
BDE-196	0.025	<0.012 - 0.224	0.306	<0.013 - 1.92	6/13
BDE-202	0.004	<0.014 - 0.039	0.095	0.035 - 0.312	2/15
BDE-206	0.054	<0.022 - 0.249	0.288	0.023 - 0.989	10/15
BDE-207	0.225	0.024 - 1.47	2.375	0.113 - 12.4	15/15
BDE-209	1.756	<0.233 - 8.6	13.292	0.356 - 61	13/15
ATE (TBP-AE)	n.d.	<0.031 - <0.031	0.023	<0.031 - 0.089	0/8
a-TBECH	n.d.	<0.076 - <0.076	0.011	<0.015 - 0.089	0/2
b-TBECH	n.d.	<0.053 - <0.053	0.025	<0.053 - 0.085	0/6
g/d-TBECH	n.d.	<0.023 - <0.023	0.009	<0.023 - 0.044	0/5
BATE	0.004	<0.01 - 0.017	0.020	<0.01 - 0.081	4/9
PBT	n.d.	<0.051 - <0.051	0.008	<0.01 - 0.068	0/2
PBEB	n.d.	<0.069 - <0.069	n.d.	<0.014 - <0.069	0/0
PBBZ	0.023	0.015 - 0.038	0.042	0.009 - 0.122	15/15
HBB	0.024	<0.057 - 0.061	0.053	<0.057 - 0.141	6/8
DPTE	n.d.	<0.009 - <0.009	0.007	<0.009 - 0.059	0/6
EHTBB	n.d.	<0.027 - <0.027	0.005	<0.006 - 0.072	0/1
BTBPE	0.045	<0.027 - 0.066	0.079	<0.005 - 0.236	13/10
TBPH (BEH /TBP)	n.d.	<0.077 - <0.077	0.030	<0.077 - 0.366	0/2
DBDPE	6.393	<5.71 - 12.2	4.149	<5.71 - 12.9	11/8
Chloroparaffins	**Blood Mean**	**Blood Range**	**Egg Mean**	**Egg Range**	**Det. no.**
SCCP	35.10	20.76 - 59.25	97.42	11.22 - 162.68	15/15
MCCP	35.30	15.26 - 128.91	231.29	15.81 - 1111.19	15/15
Siloxanes	**Blood Mean**	**Blood Range**	**Egg Mean**	**Egg Range**	**Det. no.**
D4	n.d.	<3.8 - <3.8	1.36	<1.0 - 6.45	0/12

D5	1.90	<15 - 28.5	99.96	14.11 - 720.55	1/15
D6	1.44	<0.8 - 2.82	34.36	4.48 - 197.21	13/15
M3T(Ph)	n.d.	<0.2 - <0.6	-	-	0/-
Phenolic compounds	**Blood Mean**	**Blood Range**	**Egg Mean**	**Egg Range**	**Det. no.**
Bisphenol A	n.d.	<5.0 - <5.0	n.d.	<95.0 - <95.0	0/0
Bisphenol FL	n.d.	<5.0 - <5.0	n.d.	<10.0 - <10.0	0/0
Bisphenol B	n.d.	<5.0 - <5.0	n.d.	<15.0 - <15.0	0/0
Bisphenol E	n.d.	<3.0 - <3.0	n.d.	<10.0 - <10.0	0/0
Bisphenol S	n.d.	<1.0 - <1.0	n.d.	<40.0 - <40.0	0/0
4,4-bisphenol F	n.d.	<3.0 - <3.0	1.76	<7.0 - 26.39	0/1
2,2-bisphenol F	n.d.	<1.0 - <1.0	1.15	<5.0 - 17.22	0/1
Bisphenol M	n.d.	<5.0 - <5.0	n.d.	<2.0 - <2.0	0/0
Bisphenol Z	n.d.	<12.0 - <12.0	n.d.	<15.0 - <15.0	0/0
Bisphenol AF	n.d.	<3.0 - <3.0	n.d.	<2.0 - <2.0	0/0
Bisphenol AP	n.d.	<8.0 - <8.0	n.d.	<10.0 - <10.0	0/0
TBBPA	n.d.	<5.0 - <5.0	n.d.	<30.0 - <30.0	0/0
4-tert-octylphenol	n.d.	<8.0 - <8.0	n.d.	<50.0 - <50.0	0/0
4-octylphenol	n.d.	<8.0 - <8.0	n.d.	<40.0 - <40.0	0/0
4-nonylphenol	n.d.	<5.0 - <5.0	n.d.	<80.0 - <80.0	0/0
Metals	**Blood Mean**	**Blood Range**	**Egg Mean**	**Egg Range**	**Det. no.**
Cr	n.d.	<0.003 - <0.003	0.022	0.002 - 0.074	0/15
Fe	471.886	2.181 - 564.591	28.589	18.75 - 36.824	15/15
Ni	1.047	<0.06 - 10.401	0.036	0.012 - 0.081	11/15
Cu	0.446	<0.006 - 0.580	0.761	0.651 - 0.928	14/15
Zn	5.392	0.196 - 6.806	13.388	10.449 - 15.815	15/15
As	0.112	<0.002 - 0.846	0.027	0.007 - 0.072	14/15
Ag	0.000	<0.0002 - 0.0006	0.002	0.001 - 0.003	2/15
Cd	0.001	0.001 - 0.002	0.000	0.0001 - 0.0002	15/15
Sb	0.000	<0.00003 - 0.00059	0.000	0.0001 - 0.0004	6/15

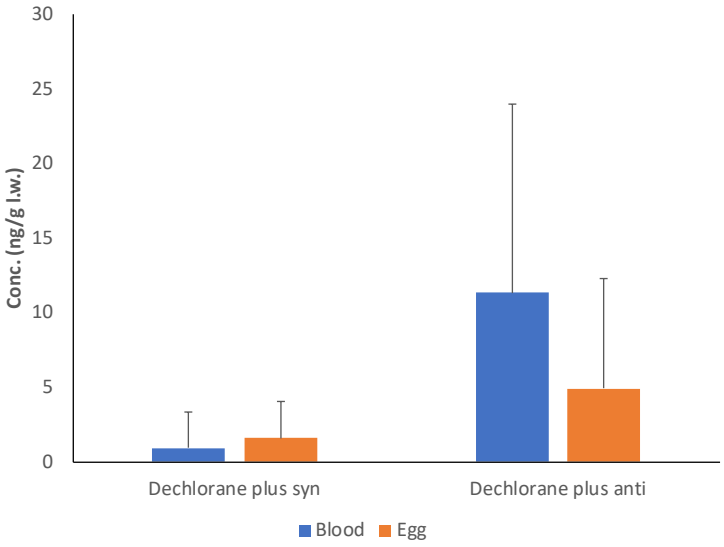
Pb	0.107	0.041 - 0.238	0.019	0.007 - 0.049	15/15
Hg	90.883	20.011 - 247.376	55.568	9.394 - 150.475	15/15
PFAS compounds	**Blood Mean**	**Blood Range**	**Egg Mean**	**Egg Range**	**Det. no.**
PFPA	n.d.	<0.5 - <0.5	n.d.	<0.5 - <0.5	0/0
PFHxA	0.45	<0.5 - 2.04	n.d.	<0.5 - <0.5	5/0
PFHpA	n.d.	<0.5 - <0.5	n.d.	<0.5 - <0.5	0/0
PFOA	n.d.	<0.5 - <0.5	n.d.	<0.5 - <0.5	0/0
PFNA	0.26	<0.5 - 3.35	0.23	<0.5 - 2.03	2/3
PFDA	0.96	<0.5 - 3.62	0.70	<0.5 - 1.46	12/12
PFUdA	0.75	<0.4 - 2.86	0.76	<0.4 - 1.59	11/12
PFDoA	0.99	<0.4 - 2.66	0.80	<0.4 - 1.91	11/12
PFTrDA	0.82	<0.4 - 2.08	0.41	<0.4 - 1.09	11/10
PFTeDA	0.65	<0.4 - 2.02	0.75	<0.4 - 1.54	10/13
PFPeDA	0.13	<0.4 - 0.64	0.33	<0.4 - 1.20	4/7
PFBS	0.07	<0.2 - 0.55	0.06	<0.2 - 0.52	3/3
PFPS	n.d.	<0.2 - <0.2	n.d.	<0.2 - <0.2	0/0
PFHxS	0.62	0.11 - 2.67	0.36	<0.1 - 2.50	15/12
PFHpS	0.17	<0.2 - 0.65	0.02	<0.2 - 0.26	6/1
PFOS	33.49	1.68 - 151.1	16.45	5.6 - 32.07	15/15
8Cl-PFOS	n.d.	<0.2 - <0.2	n.d.	<0.2 - <0.2	0/0
PFNS	n.d.	<0.2 - <0.2	n.d.	<0.2 - <0.2	0/0
PFDS	0.44	<0.2 - 1.88	0.19	<0.2 - 0.79	7/6
PFDoS	n.d.	<0.2 - <0.2	n.d.	<0.2 - <0.2	0/0
PFOSA	0.13	<0.1 - 1.68	n.d.	<0.1 - <0.1	3/0
me-FOSA	n.d.	<0.3 - <0.3	n.d.	<0.3 - <0.3	0/0
et-FOSA	n.d.	<0.3 - <0.3	n.d.	<0.3 - <0.3	0/0
me-FOSE	n.d.	<5 - <5	n.d.	<5 - <5	0/0
et-FOSE	n.d.	<5 - <5	n.d.	<5 - <5	0/0
4:2 FTS	n.d.	<0.3 - <0.3	n.d.	<0.3 - <0.3	0/0
6:2 FTS	n.d.	<0.3 - <0.3	n.d.	<0.3 - <0.3	0/0
8:2 FTS	n.d.	<0.5 - <0.5	n.d.	<0.5 - <0.5	0/0

10:2 FTS	n.d.	<0.3 - <0.3	0.15	<0.3 - 0.57	0/5
me-FOSAA	n.d.	<0.3 - <0.3	n.d.	<0.3 - <0.3	0/0
Et-FOSAA	n.d.	<0.3 - <0.3	n.d.	<0.3 - <0.3	0/0
UV-chemicals	**Blood Mean**	**Blood Range**	**Egg Mean**	**Egg Range**	**Det. no.**
BP3	n.d.	<1 - <1	n.d.	<5 - <5	0/0
EHMC-Z	n.d.	<0.2 - <0.2	0.19	<1 - 1.57	0/2
EHMC-E	n.d.	<0.3 - <0.3	n.d.	<2 - <2	0/0
Sum EHMC	n.d.	<0.5 - <0.5	n.d.	<3 - <3.6	0/0
OC	6.65	<10 - 14.83	0.82	<4 - 7.40	8/2

Concentrations of selected contaminants, specifically dechlorane plus (lipid wt. basis), PBDEs (lipid wt. basis), siloxanes (lipid wt. basis) and PFAS compounds (wet wt. basis) in herring gull (blood and egg) are also presented in **Figure 22** to **Figure 25**. The figures include tables with concentrations (on relevant basis: wet wt. or lipid wt.).

Dechlorane plus was found in eggs of herring gull and the variability was high (**Table 12**). Dechlorane plus is marketed as a flame retardant alternative to deca-BDE. The concentrations were higher in eggs, than in blood and the anti-isomer was found in higher concentrations than the syn-isomer (**Figure 22**). The concentrations of dechlorane plus in the eggs appeared a factor of approximately 3-5 lower than those in eggs of herring gull from the Laurentian Great Lakes (North America; Gauthier and Letcher, 2009; Feo et al. 2012), and even lower compared to eggs of herring gull from Niagara River, closer to a dechlorane plus manufacturing plant (Gauthier and Letcher, 2009).

A.



B.

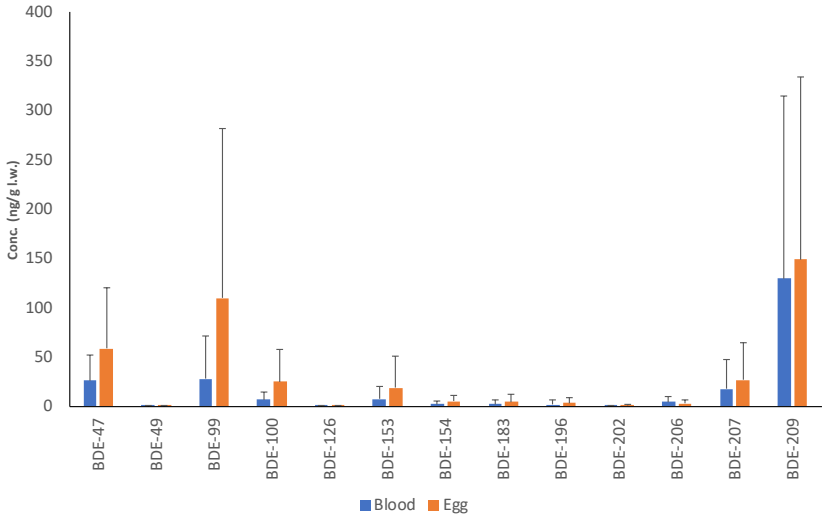
Analyte	Blood Mean	Blood Range	Egg Mean	Egg Range	Det. no.
Lipid content (%)	1.48	0.3 – 3.1	8.80	6.9 – 9.8	15/15
Dechlorane plus					
Dechlorane plus syn	0.923	n.d. – 7.172	1.585	n.d. – 9.125	2/7
Dechlorane plus anti	11.323	n.d. – 50.667	4.912	n.d. – 27.5	11/11

Figure 22. Concentrations of dechlorane plus (syn- and anti- isomers; ng/g lipid wt.) in herring gull (blood and eggs) from the Inner Oslofjord (mean and standard deviation; n=15; non-detects are assigned values of zero). B. Lipid content (%) and concentrations of dechlorane plus (syn- and anti-isomers) in herring gull blood and egg from the Inner Oslofjord (ng/g lipid wt.) presented in a table. Arithmetic mean and range are presented (n=15). In calculations of mean, non-detected components were assigned a value of zero (0). Det. no. is the number of samples in which the substance was detected (blood/egg).

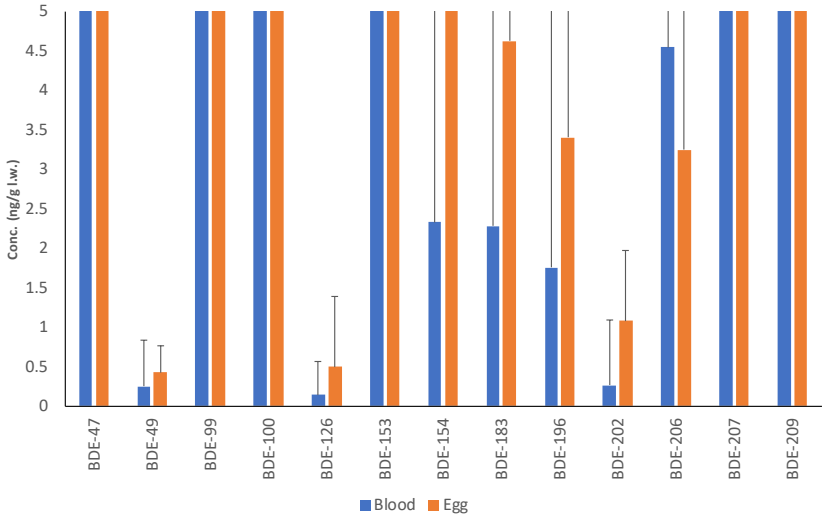
The PBDE congeners displaying the highest concentrations in herring gull from the Inner Oslofjord (both blood and eggs) were BDE-209, -47 and -99, although variability was high (**Figure 23**). This corresponds with previous observations from the Urban fjord programme (Ruus et al. 2019; Ruus et al. 2017; Ruus et al. 2016; Ruus et al. 2015; Ruus et al. 2014; The Norwegian Environment Agency M-1131, M-812, M-601, M-375 and M-205). In blood, concentrations of DBDPE were even higher than the above mentioned PBDE congeners (**Table 12**). DBDPE is a substitute for BDE-209 in the market. The same was observed in 2016 and 2017 (Ruus et al. 2017; Ruus et al. 2019; The Norwegian Environment Agency M-812 and M-1131) and future monitoring will indicate potential temporal trends. As also observed/mentioned earlier (Ruus et al. 2015; Ruus et al. 2016; Ruus et al. 2017; Ruus et al. 2019; The Norwegian Environment Agency M-375, M-601, M-812 and M-1131), the

concentrations of PBDEs (e.g. BDE-47 and -209) in herring gull eggs from the present study displayed concentrations that were higher than those observed in herring gull eggs from remote colonies in Norway (Sklinna and Røst; Huber et al. 2015) a few years ago, indicating urban influence. It can also be mentioned that according to Gentes et al. (2015), intraspecific forage strategies have strong influence on the PBDE accumulation in gulls, and that foraging on waste management facilities particularly results in higher BDE-209 exposure. As also noted previously, some PBDE congeners, such as BDE-209 in the herring gull eggs appeared somewhat higher than what was observed in eggs of sparrow hawk (a small bird of prey feeding on small to medium sized birds) from the Oslo area (Heimstad et al. 2018; The Norwegian Environment Agency M-1076).

A.



B.



C.

Analyte	Blood Mean	Blood Range	Egg Mean	Egg Range	Det. no.
Lipid content (%)	1.48	0.3 – 3.1	8.80	6.9 – 9.8	15/15
PBDEs					
BDE-47	26.079	7.194 - 86.667	58.737	12.778 - 241.837	15/15
BDE-49	0.252	n.d. - 1.743	0.429	0.165 - 1.528	2/15
BDE-99	28.209	5.129 - 169.6	109.934	11.461 - 547.778	15/15
BDE-100	7.135	1.69 - 24.88	25.148	2.925 - 105.556	15/15
BDE-126	0.146	n.d. - 1.587	0.499	n.d. - 2.947	3/6
BDE-153	7.526	1.042 - 52.24	18.612	2.438 - 126.531	15/15
BDE-154	2.331	n.d. - 10	5.150	1.146 - 23.163	14/15
BDE-183	2.280	n.d. - 15.6	4.626	0.68 - 29.898	14/15
BDE-196	1.755	n.d. - 17.92	3.405	n.d. - 19.592	6/13
BDE-202	0.268	n.d. - 3.136	1.082	0.364 - 3.184	2/15
BDE-206	4.548	n.d. - 19.92	3.249	0.263 - 10.092	10/15
BDE-207	17.843	1.475 - 117.6	26.824	1.27 - 126.531	15/15
BDE-209	129.563	n.d. - 688	149.242	4 - 622.449	13/15

Figure 23. A. Concentrations of PBDEs (ng/g lipid wt.) in herring gull (blood and eggs) from the Inner Oslofjord (mean and standard deviation; n=15; non-detects are assigned values of zero). B. Magnification of the lower part (0-5) of the concentration axis in A. C. Lipid content (%) and concentrations of PBDEs in herring gull blood and egg from the Inner Oslofjord (ng/g lipid wt.) presented in a table. Arithmetic mean and range (minimum and maximum) are presented (n=15). In calculations of mean, non-detected components were assigned a value of zero (0). Det. no. is the number of samples in which the substance was detected (blood/egg).

Siloxanes were detected in eggs and blood of herring gull from the Inner Oslofjord (**Figure 24**). D5 displayed the highest concentrations but the variability was high. This corresponds with previous observations from the Urban fjord programme (Ruus et al. 2019; Ruus et al. 2017; Ruus et al. 2016; Ruus et al. 2015; Ruus et al. 2014; The Norwegian Environment Agency M-1131, M-812, M-601, M-375 and M-205). In 2018, M3T(Ph) was not detected in blood (and not analysed in eggs; (**Figure 24**).

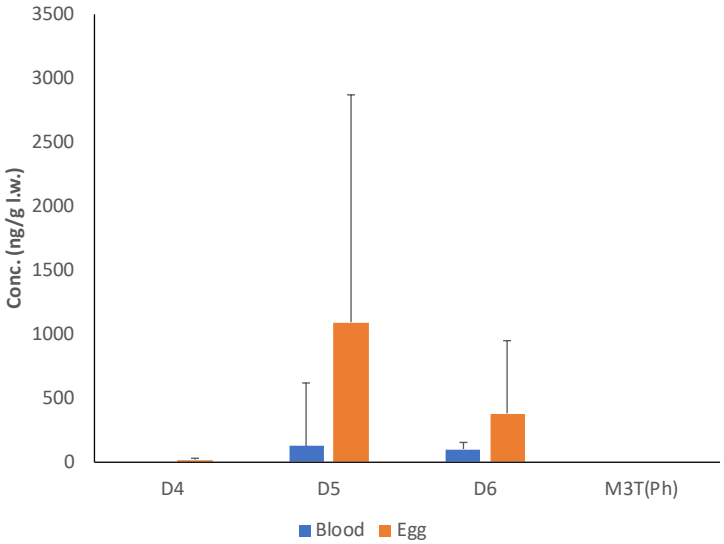
As observed/mentioned earlier (Ruus et al. 2015; Ruus et al. 2016; Ruus et al. 2017; Ruus et al. 2019; The Norwegian Environment Agency M-375, M-601, M-812 and M-1131), mean D5 concentration in eggs from the Oslofjord area (present study) was notably higher (a factor of ~66) than those observed in herring gull eggs from remote colonies in Norway (Sklinna and Røst; Huber et al. 2015) a few years ago, indicating urban influence. As earlier observed (Ruus et al. 2019; Ruus et al. 2017; The Norwegian Environment Agency M-1131 and M-812), the mean concentration of siloxanes in the

herring gull eggs from the Oslofjord area also appeared higher than in eggs of sparrow hawk (*Accipiter nisus*) from the Oslo area (Heimstad et al. 2018; The Norwegian Environment Agency M-1076). This may also reflect that while the sparrow hawk feeds mostly on birds, the herring gull might feed on human waste and leftovers.

As previously observed (Ruus et al. 2019; Ruus et al. 2017; The Norwegian Environment Agency M-1131 and M-812), concentrations of "legacy" contaminants, such as PCB-153 and SumPCB7 appeared lower in the eggs from Oslofjorden, than those observed in herring gull eggs from remote colonies in Norway (Sklinna and Røst; Huber et al. 2015). This suggests that these contaminants (associated with diffuse pollution) accumulate to somewhat higher concentrations in gulls foraging to a larger degree on marine prey organisms. However, the concentrations of PCBs in the sparrow hawk eggs from the Oslo area (Heimstad et al. 2018; The Norwegian Environment Agency M-1076) appeared higher than in the herring gull eggs from the Oslofjord area (**Table 12**). This was also observed in 2016 and 2017 (Ruus et al. 2017; Ruus et al. 2019; The Norwegian Environment Agency M-812 and M-1131).

The consistent herring gull results between years in the "Urban fjord" programme, suggest the suitability of this species to study urban influence. In this regard, it is important to acknowledge that with the opportunistic feeding habits of herring gull, urbanisation implies a shift towards less marine diet items and more diet items of terrestrial/anthropogenic origin.

A.



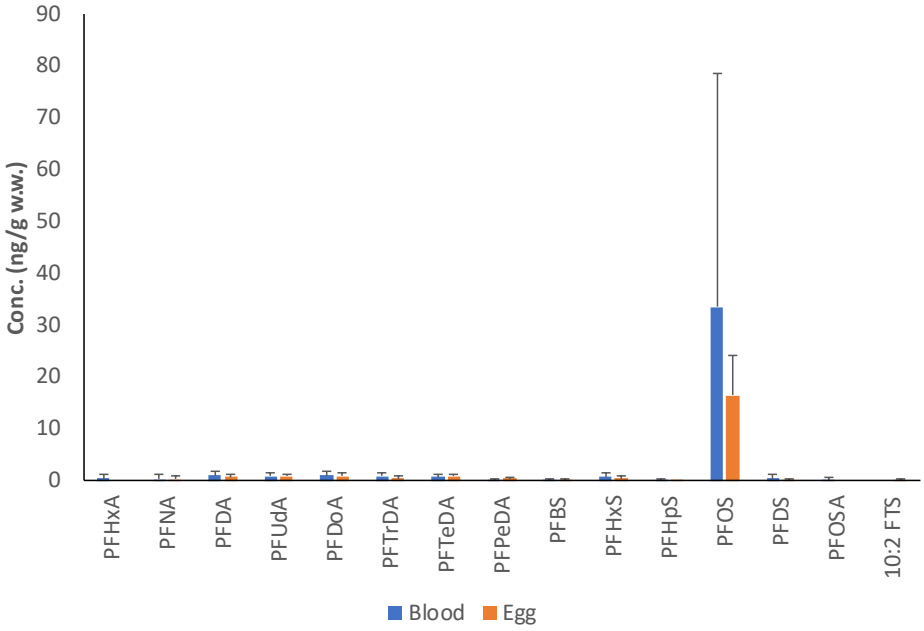
B.

Analyte	Blood Mean	Blood Range	Egg Mean	Egg Range	Det. no.
Lipid content (%)	1.48	0.3 – 3.1	8.80	6.9 – 9.8	15/15
Siloxanes					
D4	n.d.	-	15.38	n.d. – 66.44	0/12
D5	126.67	n.d. – 1900	1092.05	158.51 – 7428.38	1/15
D6	97.28	n.d. – 188.24	378.71.	50.38 – 2033.13	13/15
M3T(Ph)	n.d.	-	-	-	0/-

Figure 24. A. Concentrations of siloxanes (ng/g lipid wt.) in herring gull (blood and eggs) from the Inner Oslofjord (mean and standard deviation; n=15; non-detects are assigned values of zero). B. Lipid content (%) and concentrations of siloxanes in herring gull blood and egg from the Inner Oslofjord (ng/g lipid wt.) presented in a table. Arithmetic mean and range (minimum and maximum) are presented (n=15). In calculations of mean, non-detected components were assigned a value of zero (0). Det. no. is the number of samples in which the substance was detected (blood/egg).

PFAS compounds were also detected in eggs and blood of herring gull from the Inner Oslofjord (**Figure 25**). PFOS constituted the highest concentrations in both matrices. The variability was high. This corresponds with previous observations from the Urban fjord programme (Ruus et al. 2019; Ruus et al. 2017; Ruus et al. 2016; Ruus et al. 2015; Ruus et al. 2014; The Norwegian Environment Agency M-1131, M-812, M-601, M-375 and M-205). PFOS was also the dominating PFAS compound in sparrow hawk eggs from the Oslo area (Heimstad et al. 2018; The Norwegian Environment Agency M-1076). As previously noted (Ruus et al. 2017; Ruus et al 2019; The Norwegian Environment Agency M-812 and M-1131) the PFOS concentrations appeared higher in sparrow hawk eggs, than in herring gull eggs (**Table 12**).

A.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PFHxA
PFNA
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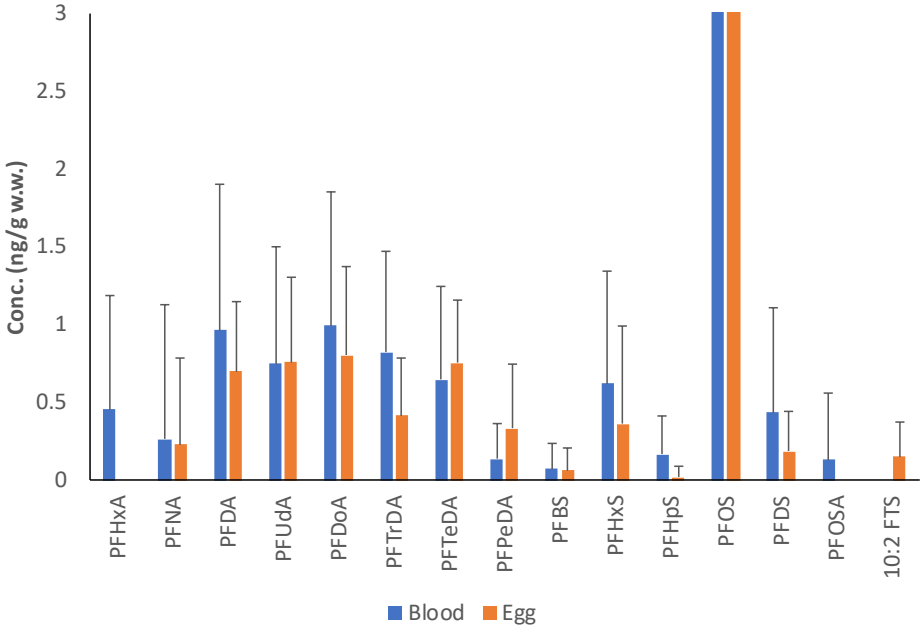
PFUdA
PFDoA
PFTrDA
PFTeDA
PFPeDA
PFBS
PFHxS
PFHpS
PFOS
PFDS
PFOSA
10:2 FTS
Blood
Egg

B.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Conc. (ng/g w.w.)
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PFNA
PFDA
PFUdA
PFDoA
PFTrDA
PFTeDA
PFPeDA
PFBS
PFHxS
PFHpS
PFOS
PFDS
PFOSA
10:2 FTS
Blood
Egg

C.

Analyte	Blood Mean	Blood Range	Egg Mean	Egg Range	Det. no.
Lipid content (%)	1.48	0.3 – 3.1	8.80	6.9 – 9.8	15/15
PFAS Compounds					
PFHxA	0.45	<0.5 - 2.04	n.d.	<0.5 - <0.5	5/0
PFNA	0.26	<0.5 - 3.35	0.23	<0.5 - 2.03	2/3
PFDA	0.96	<0.5 - 3.62	0.70	<0.5 - 1.46	12/12
PFUdA	0.75	<0.4 - 2.86	0.76	<0.4 - 1.59	11/12
PFDoA	0.99	<0.4 - 2.66	0.80	<0.4 - 1.91	11/12
PFTrDA	0.82	<0.4 - 2.08	0.41	<0.4 - 1.09	11/10
PFTeDA	0.65	<0.4 - 2.02	0.75	<0.4 - 1.54	10/13
PFPeDA	0.13	<0.4 - 0.64	0.33	<0.4 - 1.20	4/7
PFBS	0.07	<0.2 - 0.55	0.06	<0.2 - 0.52	3/3
PFHxS	0.62	0.11 - 2.67	0.36	<0.1 - 2.50	15/12
PFHpS	0.17	<0.2 - 0.65	0.02	<0.2 - 0.26	6/1
PFOS	33.49	1.68 - 151.1	16.45	5.6 - 32.07	15/15
PFDS	0.44	<0.2 - 1.88	0.19	<0.2 - 0.79	7/6
PFOSA	0.13	<0.1 - 1.68	n.d.	<0.1 - <0.1	3/0
10:2 FTS	n.d.	<0.3 - <0.3	0.15	<0.3 - 0.57	0/5

Figure 25. A. Concentrations (ng/g wet wt.) of PFAS in herring gull (blood and eggs) from the Inner Oslofjord (mean and standard deviation; n=15; non-detects are assigned values of zero). B. Magnification of the lower part (0-3) of the concentration axis in A. C. Lipid content (%) and concentrations of PFAS in herring gull blood and egg from the Inner Oslofjord (ng/g wet wt.) presented in a table. Arithmetic mean and range (minimum and maximum) are presented (n=15). In calculations of mean, non-detected components were assigned a value of zero (0). Det. no. is the number of samples in which the substance was detected (blood/egg). The following compounds were detected in neither blood, nor egg: PFPA, PFHpA, PFOA, PFPS, 8Cl-PFOS, PFNS, PFDoS, meFOSA, etFOSA, meFOSE, etFOSE, 4:2 FTS, 6:2 FTS, 8:2 FTS, meFOSAA, etFOSAA.

3.2.5 Eider duck

Both blood and egg were sampled from eider duck in the Inner Oslofjord. Adult female blood and egg was sampled from the same nest (i.e. mother and future offspring).

Eider duck blood and eggs were analysed for PFAS compounds, and concentrations (mean and range; wet wt. basis) are presented in **Table 13**. The number of samples in which the compounds were

detected is also shown in **Table 13**. As for herring gull, PFOS constituted the highest concentrations in both matrices (**Figure 26**).

Table 13 Lipid content (%) and concentrations of the different analytes in eider duck blood and egg from the Inner Oslofjord. Concentrations are ng/g wet wt., except for concentrations of Ni, Cu, Ag, Cd, Pb, Cr, Fe, Zn, As and Sb, which are expressed as µg/g wet wt. Arithmetic mean and range (minimum and maximum) are presented (n=15). In calculations of mean, non-detected components were assigned a value of zero (0). Det. no. is the number of samples in which the substance was detected (blood/egg). Lipid content was not analysed in Eider duck samples.

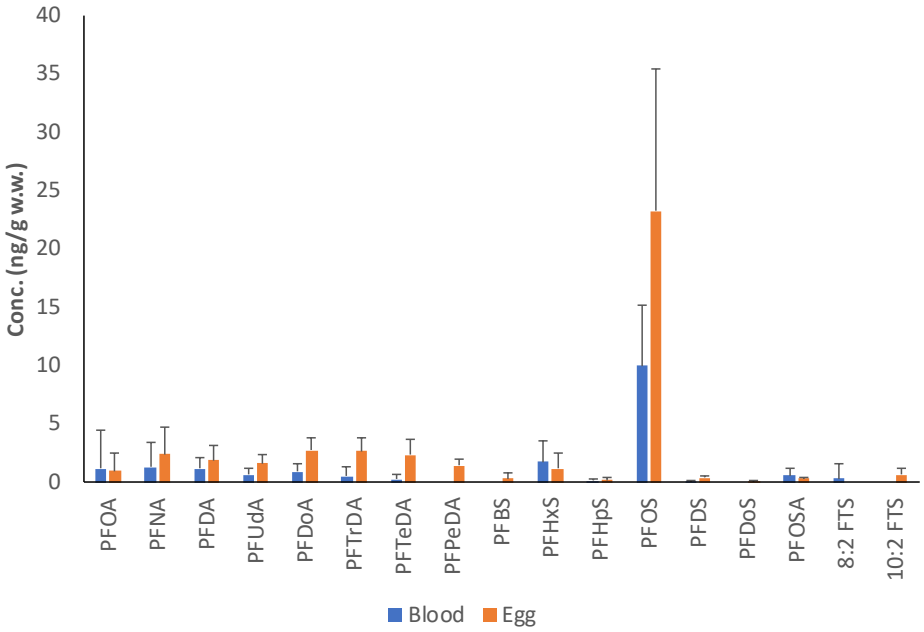
Analyte	Blood Mean	Blood Range	Egg Mean	Egg Range	Det. no.
Lipid content (%)	-	-	-	-	-
PFAS compounds	**Blood Mean**	**Blood Range**	**Egg Mean**	**Egg Range**	**Det. no.**
PFPA	n.d.	<0.5 - <0.5	n.d.	<0.5 - <0.5	0/0
PFHxA	n.d.	<0.5 - <0.5	n.d.	<0.5 - <0.5	0/0
PFHpA	n.d.	<0.5 - <0.5	n.d.	<0.5 - <0.5	0/0
PFOA	1.12	<0.5 - 12.75	0.95	<0.5 - 4.66	2/7
PFNA	1.28	<0.5 - 7.84	2.40	<0.5 - 7.66	7/14
PFDA	1.17	0.22 - 3.62	1.86	0.6 - 4.87	15/15
PFUdA	0.62	<0.4 - 2.17	1.60	0.8 - 3.02	10/15
PFDoA	0.89	<0.4 - 2.55	2.71	1.35 - 5.42	12/15
PFTrDA	0.50	<0.4 - 3	2.63	0.82 - 5.52	6/15
PFTeDA	0.22	<0.4 - 1.58	2.34	0.62 - 4.99	4/15
PFPeDA	n.d.	<0.4 - <0.4	1.30	<0.4 - 2.15	0/14
PFBS	n.d.	<0.2 - <0.2	0.33	<0.2 - 1.36	0/7
PFPS	n.d.	<0.2 - <0.2	n.d.	<0.2 - <0.2	0/0
PFHxS	1.76	0.55 - 7.3	1.18	0.37 - 5.56	15/15
PFHpS	0.09	<0.2 - 0.37	0.19	<0.2 - 0.87	6/7
PFOS	9.97	4.56 - 23.68	23.21	10.58 - 50.24	15/15
8Cl-PFOS	n.d.	<0.2 - <0.2	n.d.	<0.2 - <0.2	0/0
PFNS	n.d.	<0.2 - <0.2	n.d.	<0.2 - <0.2	0/0
PFDS	0.02	<0.2 - 0.31	0.35	<0.2 - 0.73	1/14
PFDoS	n.d.	<0.2 - <0.2	0.03	<0.2 - 0.21	0/2
PFOSA	0.58	<0.1 - 2.28	0.29	0.06 - 0.47	14/15

me-FOSA	n.d.	<0.3 - <0.3	n.d.	<0.3 - <0.3	0/0
et-FOSA	n.d.	<0.3 - <0.3	n.d.	<0.3 - <0.3	0/0
me-FOSE	n.d.	<5 - <5	n.d.	<5 - <5	0/0
et-FOSE	n.d.	<5 - <5	n.d.	<5 - <5	0/0
4:2 FTS	n.d.	<0.3 - <0.3	n.d.	<0.3 - <0.3	0/0
6:2 FTS	n.d.	<0.3 - <0.3	n.d.	<0.3 - <0.3	0/0
8:2 FTS	0.32	<0.5 - 4.76	n.d.	<0.5 - <0.5	1/0
10:2 FTS	n.d.	<0.3 - <0.3	0.64	<0.3 - 2.18	0/11
me-FOSAA	n.d.	<0.3 - <0.3	n.d.	<0.3 - <0.3	0/0
Et-FOSAA	n.d.	<0.3 - <0.3	n.d.	<0.3 - <0.3	0/0

As expected and indicated in Chapter 3.1, according to the results of the stable isotope analysis, the Inner Oslofjord eider ducks have a diet consisting of more marine items, compared to the diet of the herring gulls sampled in the Inner Oslofjord. Concentrations of PFAS compounds appeared higher in eggs, than in blood of eider duck (**Figure 26**). This was contrary to Herring gull, where concentrations appeared higher in blood, than eggs (**Figure 25**), although variability was high. Concentrations of most PFAS compounds (although not PFOS) were significantly higher in eider duck eggs, than in herring gull eggs (Mann-Whitney U; $p<0.03$).

See Chapter 3.2.2 for insight in how concentrations in the eider duck relates to other species of the Inner Oslofjord marine food web.

A.


Conc. (ng/g w.w.)
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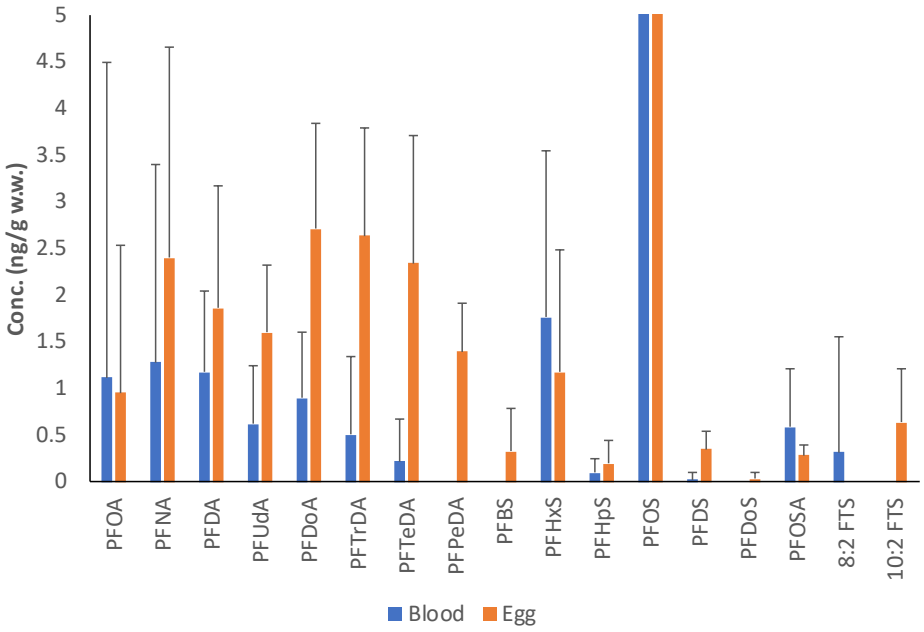
35
30
25
20
15
10
5
0
PFOA
PFNA
PFDA
PFUdA
PFDoA
PFTrDA
PFTeDA
PFPeDA
PFBS
PFHxS
PFHpS
PFOS
PFDS
PFDoS
PFOSA
8:2 FTS
10:2 FTS
Blood
Egg

B.


Conc. (ng/g w.w.)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
PFOA
PFNA
PFDA
PFUdA
PFDoA
PFTrDA
PFTeDA
PFPeDA
PFBS
PFHxS
PFHpS
PFOS
PFDS
PFDoS
PFOSA
8:2 FTS
10:2 FTS
Blood
Egg

C.

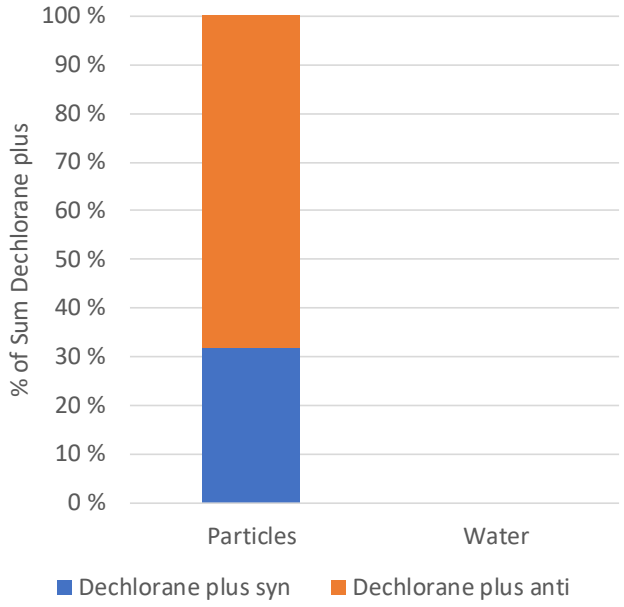
Analyte	Blood Mean	Blood Range	Egg Mean	Egg Range	Det. no.
Lipid content (%)	-	-	-	-	-
PFAS Compounds					
PFOA	1.12	<0.5 - 12.75	0.95	<0.5 - 4.66	2/7
PFNA	1.28	<0.5 - 7.84	2.40	<0.5 - 7.66	7/14
PFDA	1.17	0.22 - 3.62	1.86	0.6 - 4.87	15/15
PFUdA	0.62	<0.4 - 2.17	1.60	0.8 - 3.02	10/15
PFDoA	0.89	<0.4 - 2.55	2.71	1.35 - 5.42	12/15
PFTrDA	0.50	<0.4 - 3	2.63	0.82 - 5.52	6/15
PFTeDA	0.22	<0.4 - 1.58	2.34	0.62 - 4.99	4/15
PFPeDA	n.d.	<0.4 - <0.4	1.30	<0.4 - 2.15	0/14
PFBS	n.d.	<0.2 - <0.2	0.33	<0.2 - 1.36	0/7
PFHxS	1.76	0.55 - 7.3	1.18	0.37 - 5.56	15/15
PFHpS	0.09	<0.2 - 0.37	0.19	<0.2 - 0.87	6/7
PFOS	9.97	4.56 - 23.68	23.21	10.58 - 50.24	15/15
PFDS	0.02	<0.2 - 0.31	0.35	<0.2 - 0.73	1/14
PFDoS	n.d.	<0.2 - <0.2	0.03	<0.2 - 0.21	0/2
PFOSA	0.58	<0.1 - 2.28	0.29	0.06 - 0.47	14/15
8:2 FTS	0.32	<0.5 - 4.76	n.d.	<0.5 - <0.5	1/0
10:2 FTS	n.d.	<0.3 - <0.3	0.64	<0.3 - 2.18	0/11

Figure 26. A. Concentrations (ng/g wet wt.) of PFAS in eider duck (blood and eggs) from the Inner Oslofjord (mean and standard deviation; n=15; non-detects are assigned values of zero). B. Magnification of the lower part (0-5) of the concentration axis in A. C. Concentrations of PFAS in eider duck blood and egg from the Inner Oslofjord (ng/g wet wt.) presented in a table (lipid content was not analysed in eider duck samples). Arithmetic mean and range (minimum and maximum) are presented (n=15). In calculations of mean, non-detected components were assigned a value of zero (0). Det. no. is the number of samples in which the substance was detected (blood/egg). The following compounds were detected in neither blood, nor egg: PFPA, PFHxA, PFHpA, PFPS, 8Cl-PFOS, PFNS, meFOSA, etFOSA, meFOSE, etFOSE, 4:2 FTS, 6:2 FTS, meFOSAA, etFOSAA.

3.2.6 Storm water

The results of the chemical analysis of storm water can be found in the electronic Appendix. Dechlorane plus was found in concentrations of several ng/L, however only in the particulate fraction

(**Figure 27**). The anti-isomer was found in higher concentrations than the syn-isomer. The syn- and anti-isomers are present in the technical product in a ratio of approximately 1:3 (i.e. the anti-isomer constitutes ~75% of the sum). Furthermore, in a study of dechlorane plus in the sediments of the Lower Great lakes (North America), Sverko et al. (2008) suggested a stereoselective enrichment of the anti-isomer in the environment. On the other hand, Tomy et al. (2007) suggested an enrichment of the syn-isomer in some species of the Lake Ontario food web and attributed this to the structural conformation of the anti-isomer being more susceptible to biological degradation. In a study of dechlorane plus in eggs of herring gulls from the Great Lakes, Gauthier and Letcher (2009) reported essentially no stereoselective enrichment of either isomer.

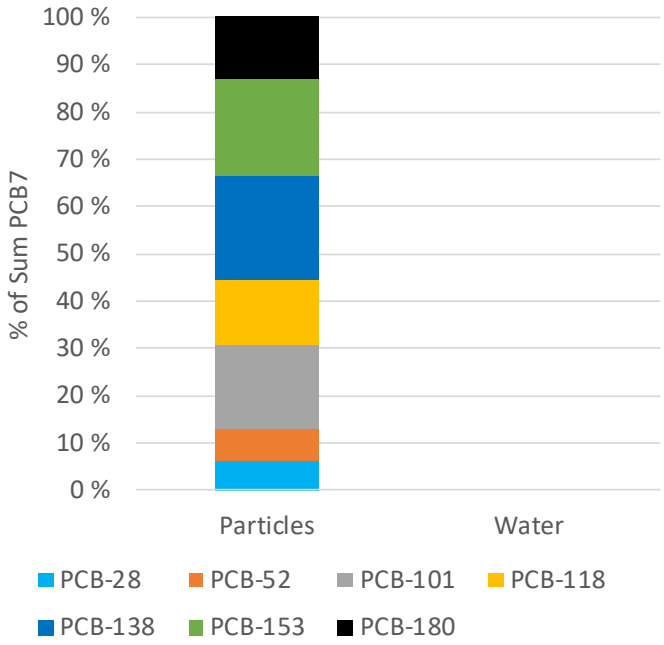


	Particles	Water
Dechlorane plus syn	1.85	n.d.
Dechlorane plus anti	4.69	n.d.

Figure 27. Relative contribution (%) of dechlorane plus syn- and anti-isomers to the sum of dechlorane plus in the particulate and dissolved fraction of storm water (mean of 2 samples.). Concentrations (ng/L; mean) are given in the associated table. Components that were not detected in any replicate samples of a fraction (particles or water) are noted n.d. Dechlorane plus syn and anti were the only dechlorane compounds detected in storm water.

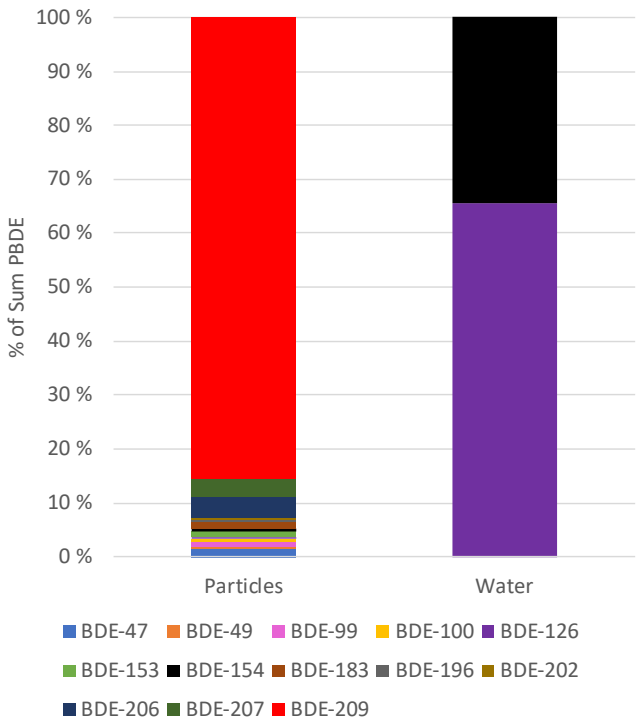
PCB-concentrations were highest also in the particulate fraction. PCBs were not detected in the dissolved fraction (**Figure 28**). Given the hydrophobic nature of PCBs, they have a high affinity for the particulate phase and are usually associated with particles. BDE-concentrations were also higher in the particulate fraction, than in the dissolved fraction, as most congeners were not detected in the dissolved fraction (**Figure 29**). BDE-209 constituted the highest percentage in the particulate fraction, as in 2016 and 2017 (**Figure 29**; Ruus et al. 2017; Ruus et al. 2019; The Norwegian Environment Agency M-812 and M-1131). Interestingly, DBDPE was higher than BDE-209 both in the dissolved and

in the particulate fraction, and DBDPE was higher in the particulate fraction, than in the dissolved fraction (concentrations of DBDPE were 84.2 ng/L and 22.6 ng/L, respectively). This was also noted in 2017 (Ruus et al. 2019; The Norwegian Environment Agency M-1131).



	Particles	Water
PCB-28	1.15	n.d.
PCB-52	1.23	n.d.
PCB-101	1.49	n.d.
PCB-118	0.95	n.d.
PCB-138	1.66	n.d.
PCB-153	1.79	n.d.
PCB-180	1.42	n.d.

Figure 28. Relative contribution (%) of PCB-congeners to the sum of PCB7 in the particulate and dissolved fraction of storm water (mean of 2 samples. Non-detected components were assigned values of zero). Concentrations (ng/L; mean; non-detected components were assigned a value of zero) are given in the associated table. Components that were not detected in any replicate samples of a fraction (particles or water) are noted n.d.



	Particles	Water
BDE-47	1.325	n.d.
BDE-49	0.277	n.d.
BDE-99	1.050	n.d.
BDE-100	0.510	n.d.
BDE-126	0.113	0.012
BDE-153	0.595	n.d.
BDE-154	0.396	0.011
BDE-183	0.656	n.d.
BDE-196	0.323	n.d.
BDE-202	0.396	n.d.
BDE-206	1.222	n.d.
BDE-207	1.258	n.d.
BDE-209	40.115	n.d.

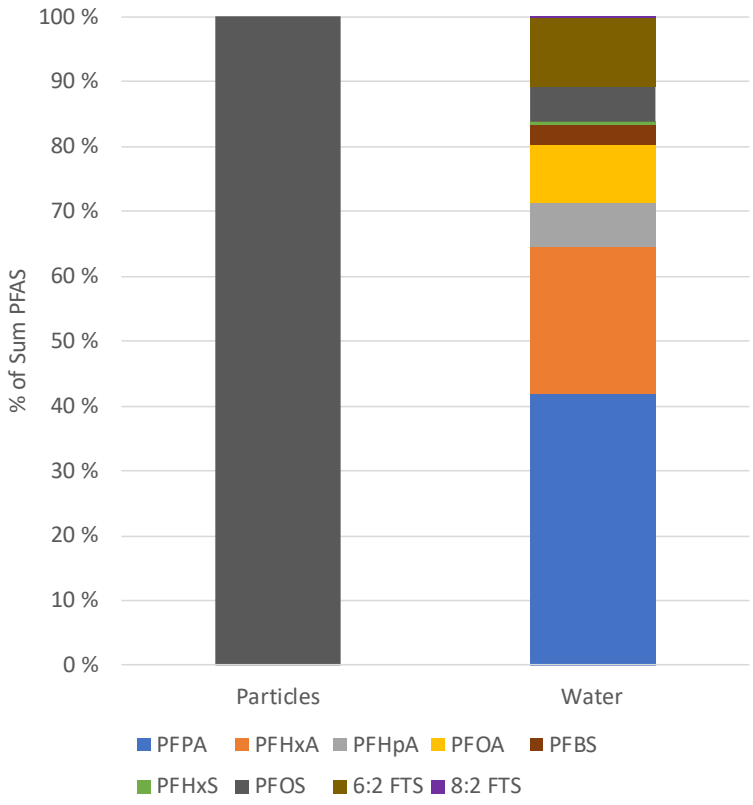
Figure 29. Relative contribution (%) of selected BDE-congeners (see **Table 5**) to the sum of those PBDEs in the particulate and dissolved fraction of storm water (mean of 2 samples. Non-detected components were assigned values of zero). Concentrations (ng/L; mean; non-detected components were assigned a value of zero) are given in the associated table. Components that were not detected in any replicate samples of a fraction (particles or water) are noted n.d.

PFAS compounds were mostly detected in the dissolved fraction of storm water (only PFOS detected in the particulate fraction; **Figure 30**). Nevertheless, inputs of several of the target compounds to the fjord via storm water are thus found. PFPA and PFHxA displayed the highest concentrations (**Figure 30**). In 2016 and 2017, PFPA and PFHxA were also among those that showed the highest concentration in the dissolved fraction of storm water (Ruus et al. 2017; Ruus et al. 2019; The Norwegian Environment Agency M-812 and M-1131).

For several compounds, environmental quality standards for water are given through Norwegian law (The Water Regulation/"Vannforskriften"), according to the requirements of the Water Framework Directive. Furthermore, quality standards are given for even more compounds (Direktoratsgruppen vanndirektivet 2018). For the target compounds of this study of which quality standards exist, the water concentrations (dissolved fraction) and EQSs are compared in **Table 14** (EQSs for coastal water used, to elucidate the potential of surface water as source of contaminants to parts of the fjord).

Concentrations of bisphenol A, MCCPs, copper, zinc, arsenic and PFOS exceeded the quality standards, reflecting runoff from the surrounding (urban) area. Zinc, arsenic and PFOS also exceeded the quality standards for sediment from station Cm21 (see chapter 3.2.1). It should be mentioned that for copper and zinc, the concentrations in the dissolved fraction of storm water did not only exceed the Annual Average (AA-)EQS, but also the Maximum Allowable Concentration (MAC-)EQS. Furthermore, for several compounds, the concentrations were higher in the particulate phase that in the dissolved fraction (see Appendix).

Kaste et al. (2018; The Norwegian Environment Agency M-1168) and Allan et al. (2018; The Norwegian Environment Agency M-1166), have estimated the input of contaminants to the fjord from River Alna, such as: 0.03 ton/yr As, 0.16 ton/yr Pb, 0.01 ton/yr Cd, 0.43 ton/yr Cu, 1.85 ton/yr Zn, 0.11 ton/yr Ni, 0.10 ton/yr Cr and 0.07 ton/yr Hg (Kaste et al. 2018; The Norwegian Environment Agency M-1168), as well as 9.6 g/yr HCB, 10.7 g/yr ΣPBDE, 1.8 kg/yr SCCPs and 1.7 kg/yr MCCPs (Allan et al. 2018; The Norwegian Environment Agency M-1166). As such, there are several pathways of these studied contaminants to the Inner Oslofjord.



	Particles	Water
PFPA	n.d.	330.30
PFHxA	n.d.	181.95
PFHpA	n.d.	22.20
PFOA	n.d.	8.95
PFBS	n.d.	2.53
PFHxS	n.d.	1.39
PFOS	1.37	4.35
6:2 FTS	n.d.	134.33
8:2 FTS	n.d.	0.35

Figure 30. Relative contribution (%) of PFAS compounds to the sum of (detected) PFASs in the particulate and dissolved fraction of storm water (mean of 2 samples. Non-detected components were assigned values of zero). Concentrations (ng/L; mean; non-detected components were assigned a value of zero) of detected components are given in the associated table. Components that were not detected in any replicate samples of a fraction (particles or water) are noted n.d.

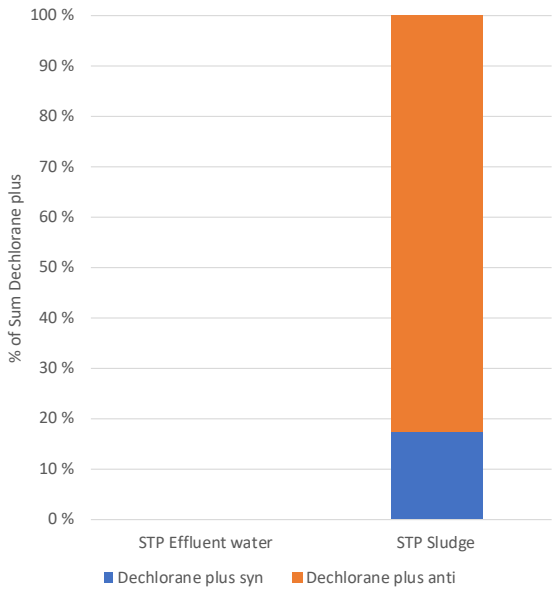
Table 14. Concentrations of contaminants (µg/L) in storm water (dissolved fraction) and STP effluent water of which Norwegian quality standards (Direktoratsgruppen vanndirektivet 2018) exist in coastal water. Red numbers indicate concentrations exceeding the quality standard.

River basin specific compounds	AA-EQS (µg/L)	Storm water conc. (dissolved; µg/L)	Effluent water (STP) conc. (µg/L),
Bisphenol A	0.15	0.97	0.09
Decamethylcyclopentasiloxane (D5)	0.17	n.a.	0.03
Medium chained chloroparafins (MCCPs)	0.05	0.13	0.09
Copper (Cu)	2.6	4.9	n.a.
PCB7	0.0000024	<0.002****	n.a.
PFOA	9.1	0.009	0.015
Zinc (Zn)	3.38	10.0	n.a.
TBBPA	0.254	<0.120	<0.050
Arsenic (As)	0.6	0.7	n.a.
Chromium (Cr)	3.4	2.1	n.a.
EU priority substances			
Cadmium (Cd)	0.2	0.1	n.a.
Lead (Pb)	1.3	0.3	n.a.
Nickel (Ni)	8.6	3.5	n.a.
Mercury (Hg)	0.07 ***	<0.002	n.a.
Brominated diphenyl ethers *	0.014 ***	<0.0018	<0.0012
Hexachlorobenzene	0.05 ***	<0.00033	n.a.
C10-13 chloroalkanes **	0.4	0.05	0.07
Pentachlorobenzene	0.0007	<0.00036	n.a.
Nonylphenol (4-)	0.3	<0.53 ***	<0.05
Oktylphenol (4-*tert*-)	0.01	<0.30 ***	<0.05 ***
PFOS	0.00013	0.0044	0.0012

* Sum of BDE-28, -47, -99, -100, -153 and -154.
** Short chained chloroparaffins (SCCPs)
*** No AA-EQS for these substances, thus this is the MAC-EQS (M-608)
**** Too high limit of detection to evaluate

3.2.7 Sewage treatment plant (STP)

The results of the chemical analyses of effluent water and sludge from Bekkelaget STP can be found in the electronic Appendix. Dechlorane plus was found in the sludge (mean concentration, sum of *syn*- and *anti*-isomers, n=2, 14.2 ng/g dry wt.; **Figure 31**).



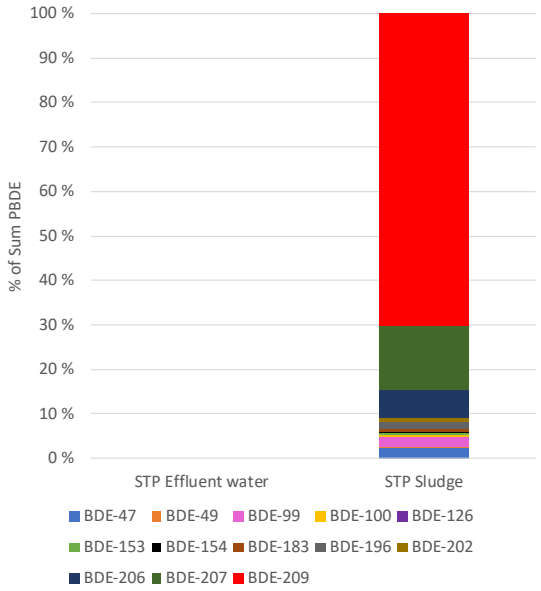
	STP Effluent water (ng/L)	STP Sludge (ng/g)
Dechlorane plus syn	n.d.	2.480
Dechlorane plus anti	n.d.	11.745

Figure 31. Relative contribution (%) of dechlorane plus syn- and anti-isomers to the sum of dechlorane plus in effluent water and sludge from a sewage treatment plant in the Inner Oslofjord (mean of 2 samples). Concentrations (ng/L or ng/g; mean) are given in the associated table. Components that were not detected in any replicate samples of a fraction (effluent water or sludge) are noted n.d. Dechlorane plus syn and anti were the only dechlorane compounds detected in STP water or sludge.

Of the PBDEs, BDE-209 showed, by far, the highest concentration in the sludge (**Figure 32**). Given the hydrophobic nature of these compounds, they have a high affinity for the particulate phase, thus they were detected here. Finding BDE-209 in the highest concentrations in sludge corresponds with other recent findings (Aigars et al. 2017; Ruus et al. 2019; The Norwegian Environment Agency M-1131) and with the historic market demand for deca-BDE mixtures (McGrath et al. 2017). As the main component of these mixtures, BDE-209 has been the most prevalent congener in a large majority of soil samples (McGrath et al. 2017).

Another notable result of the analysis of the STP samples was that the alternative/"new" brominated flame retardants TBPH (BEH/TBP) and DBDPE were found in conspicuous concentrations (**Figure 33**),

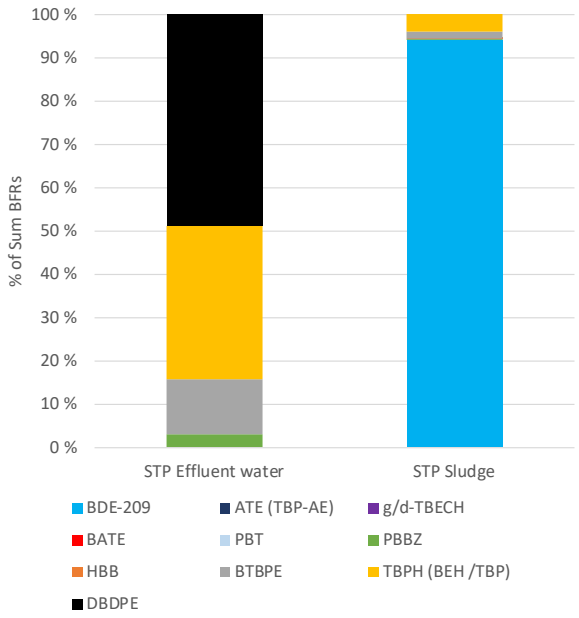
although not as high as the previous year (Ruus et al. 2019; The Norwegian Environment Agency M-1131).



	Effluent water (ng/L)	Sludge (ng/g)
BDE-47	n.d.	4.685
BDE-49	n.d.	0.759
BDE-99	n.d.	4.240
BDE-100	n.d.	1.067
BDE-126	n.d.	n.d.
BDE-153	n.d.	0.591
BDE-154	n.d.	0.463
BDE-183	n.d.	1.095
BDE-196	n.d.	3.035
BDE-202	n.d.	1.262
BDE-206	n.d.	13.550
BDE-207	n.d.	28.550
BDE-209	n.d.	158.950

Figure 32. Relative contribution (%) of selected BDE-congeners (see **Table 5**) to the sum of those PBDEs in effluent water and sludge from a sewage treatment plant in the Inner Oslofjord (mean of 2 samples. Non-detected components were assigned values of zero). Concentrations (ng/L or ng/g; mean; non-detected components were assigned a value of zero) of detected components are given

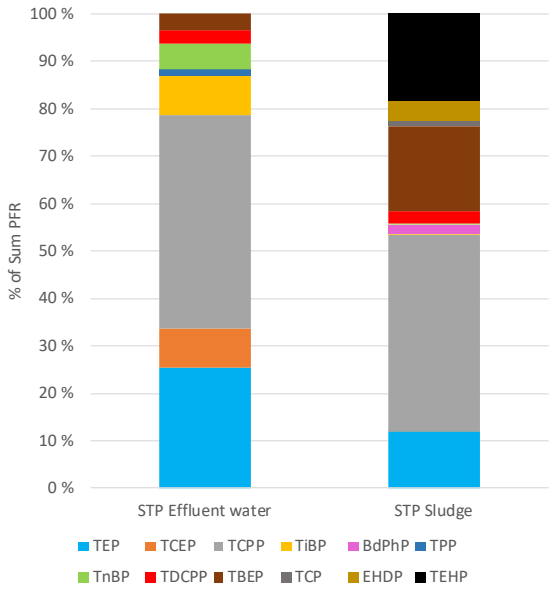
in the associated table. Components that were not detected in any replicate samples of a fraction (effluent water or sludge) are noted n.d.



	Effluent water (ng/L)	Sludge (ng/g)
BDE-209	n.d.	158.950
ATE (TBP-AE)	n.d.	0.038
g/d-TBECH	n.d.	0.042
BATE	n.d.	0.030
PBT	n.d.	0.066
PBBZ	0.019	0.152
HBB	n.d.	0.208
BTBPE	0.091	1.700
TBPH (BEH/TBP)	0.275	9.100
DBDPE	8.150	-

Figure 33. Relative contribution (%) of Brominated flame retardants (BFRs) to the sum of (detected) BFRs in effluent water and sludge from a sewage treatment plant in the Inner Oslofjord (mean of 2 samples. Non-detected components were assigned values of zero). Concentrations (ng/L or ng/g; mean; non-detected components were assigned a value of zero) of detected components are given in the associated table. Components that were not detected in any replicate samples of a fraction (effluent water or sludge) are noted n.d. PBDEs are represented by BDE-209, the congener displaying the highest concentrations (see **Figure 31**). DBDPE was not quantified in sludge.

PFR compounds were present in both effluent water and sludge from Bekkelaget sewage treatment plant (**Figure 34**). TCPP was found in the highest concentration in both fractions (**Figure 34**). TBEP was found in the second highest concentration in the sludge (**Figure 34**). The pattern was thus very similar to what was observed the previous year of the Urban fjord programme (Ruus et al. 2019; The Norwegian Environment Agency M-1131).

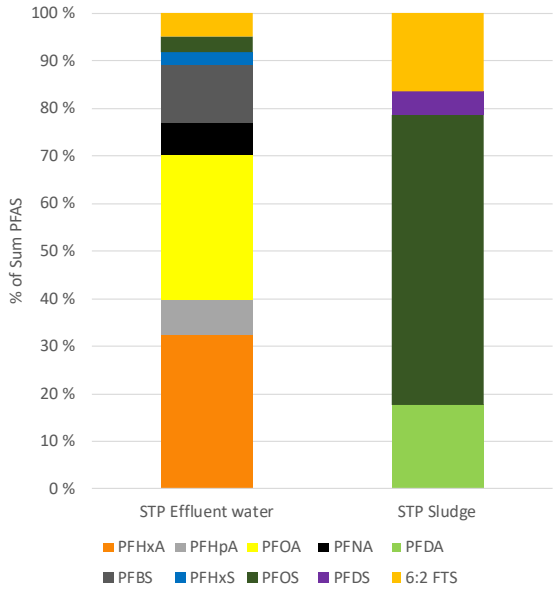


	Effluent water (ng/L)	Sludge (ng/g)
TEP	236.06	395.54
TCEP	74.74	2.01
TCPP	398.76	1338.78
TiBP	76.58	7.36
BdPhP	n.d.	56.50
TPP	13.42	n.d.
TnBP	48.00	4.08
TDCPP	26.22	70.74
TBEP	33.93	510.11
TCP	n.d.	29.54
EHDP	n.d.	117.10
TEHP	n.d.	501.58

Figure 34. Relative contribution (%) of PFR compounds to the sum of (detected) PFRs in effluent water and sludge from a sewage treatment plant in the Inner Oslofjord (Non-detected components were assigned values of zero). Concentrations (ng/L or ng/g) of detected components are given in the

associated table. Components that were not detected in a fraction (effluent water or sludge) are noted n.d.

A number of PFAS compounds were detected in both effluent water and sludge from Bekkelaget sewage treatment plant (**Figure 35**). PFHxA and PFOA constituted large proportions of the sum of PFAS compounds in the effluent water, while PFDA and PFOS constituted large proprtions of the sum og PFAS compounds in the sludge (**Figure 35**), as observed the previous year of the Urban fjord programme (Ruus et al. 2019; The Norwegian Environment Agency M-1131).

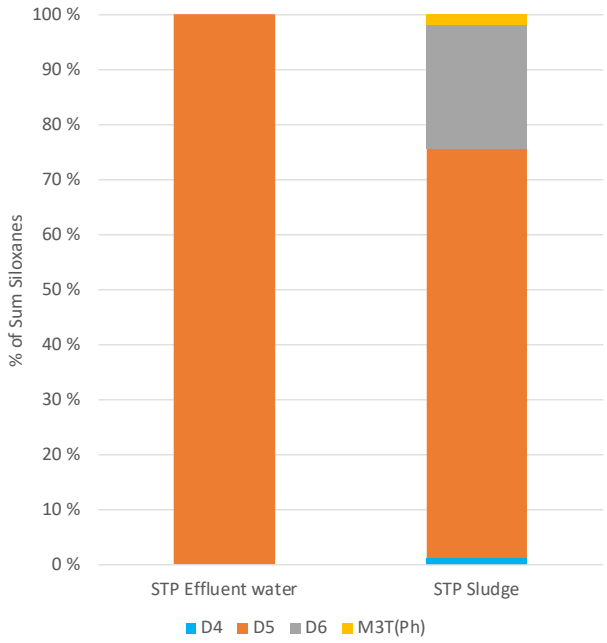


	Effluent water (ng/L)	Sludge (ng/g)
PFHxA	16.15	n.d.
PFHpA	3.75	n.d.
PFOA	15.05	n.d.
PFNA	3.35	n.d.
PFDA	n.d.	0.65
PFBS	6.15	n.d.
PFHxS	1.24	n.d.
PFOS	1.63	1.54
PFDS	n.d.	0.18
6:2 FTS	2.50	0.26

Figure 35. Relative contribution (%) of PFAS compounds to the sum of (detected) PFASs in effluent water and sludge from a sewage treatment plant in the Inner Oslofjord (mean of 2 samples. Non-detected components were assigned values of zero). Concentrations (ng/L or ng/g; mean; non-

detected components were assigned a value of zero) of detected components are given in the associated table. Components that were not detected in any replicate samples of a fraction (effluent water or sludge) are noted n.d.

Siloxanes were detected in both effluent water and sludge from Bekkelaget sewage treatment plant (**Figure 36**). As in the other matrices analysed in this programme, D5 was present in the highest concentrations in both effluent water and sludge (D5 was the only siloxane detected in effluent water; **Figure 36**). The concentrations of D5 in effluent water from Bekkelaget STP were a factor of ~20 lower than observed in 2017 (Ruus et al. 2019; The Norwegian Environment Agency M-1131), and thus comparable to concentrations previously observed in effluent water from HIAS STP (Ottestad, on Lake Mjøsa; mean 99 ng/L) and Rambekk STP (Gjøvik, on lake Mjøsa; mean 31 ng/L; van Bavel et al. 2016; The Norwegian Environment Agency M-596). Concentrations in sludge, on the other hand were a factor of ~4 higher than observed in 2017 (Ruus et al. 2019; The Norwegian Environment Agency M-1131), however still lower than those observed in sludge from HIAS STP (mean 7900 ng/g) and Rambekk STP (mean 6059 ng/g; van Bavel et al. 2016; The Norwegian Environment Agency M-596).



	Effluent water (ng/L)	Sludge (ng/g)
D4	n.d.	57.45
D5	32.55	3920.61
D6	n.d.	1215.77
M3T(Ph)	n.d.	96.03

Figure 36. Relative contribution (%) of siloxanes to the sum of siloxanes in effluent water and sludge from a sewage treatment plant in the Inner Oslofjord (mean of 2 samples for effluent water). Concentrations (ng/L or ng/g) of components are given in the associated table.

UV-chemicals (benzophenone, ethylhexylmethoxycinnamate and especially octocrylene) were detected in notable concentrations in samples from Bekkelaget sewage treatment plant, and especially sludge (see electronic appendix). This corresponds with findings from previous year (Ruus et al. 2019; The Norwegian Environment Agency M-1131). Furthermore, UV-329, UV328 and UV-327 were detected in notable concentrations, especially in the sludge (see electronic appendix). These findings reflect the use of UV-chemicals in sunscreens and other cosmetics.

The antioxidant MB1 was not detected in neither STP effluent water (<50 ng/L), nor sludge (<50 ng/g). Previously, concentrations of 25 to ~130 ng/L were observed in effluent water from HIAS STP (Ottestad, on Lake Mjøsa) and Rambekk STP (Gjøvik, on lake Mjøsa; van Bavel et al. 2016; The Norwegian Environment Agency M-596).

The last annual report from VEAS sewage treatment plant (STP) is from 2018 and they reported a discharge of 46 kg As, 39 kg Pb, 4.5 kg Cd, 434 kg Cu, 48 kg Cr, 0.33 kg Hg, 247 kg Ni and 1857 kg Zn that year (more than 90% of the measurements were below the limit of detection for Cd, Cr and Hg, and half of the LoD was reported for these; VEAS 2019). In 2017, the discharges were 50 kg As, 36 kg Pb, 4.8 kg Cd, 414 kg Cu, 49 kg Cr, 0.25 kg Hg, 288 kg Ni and 1924 kg Zn (more than 90% of the measurements were below the limit of detection for Cd, Cr and Hg, and half of the LoD was reported for these; VEAS 2018).

As such, effluent water from the sewer of the population in the urban environment of Oslo is also a pathway of several compounds to the Inner Oslofjord marine environment. The concentrations measured in STP effluent water in this study represent 1 day averages and are merely “snap shots” of what can be observed in this matrix. The above mentioned yearly discharges of metals from VEAS STP show very similar amounts for several elements (such as As, Cu and Zn) as those transported by river Alna (see chapter 3.2.6 and Kaste et al. 2018; The Norwegian Environment Agency M-1166).

As mentioned, for several compounds, environmental quality standards (EQS) for water are given through Norwegian law (The Water Regulation/“Vannforskriften”), according to the requirements of the Water Framework Directive. Furthermore, quality standards are given for even more compounds (Direktoratsgruppen vanndirektivet 2018). For the target compounds of this study of which quality standards exist, the concentrations in effluent water from Bekkelaget STP and the EQSs are also compared in **Table 14** (EQSs for coastal water used, to elucidate the potential of surface water as source of contaminants to parts of the fjord). MCCPs and PFOS exceeded AA-EQS.

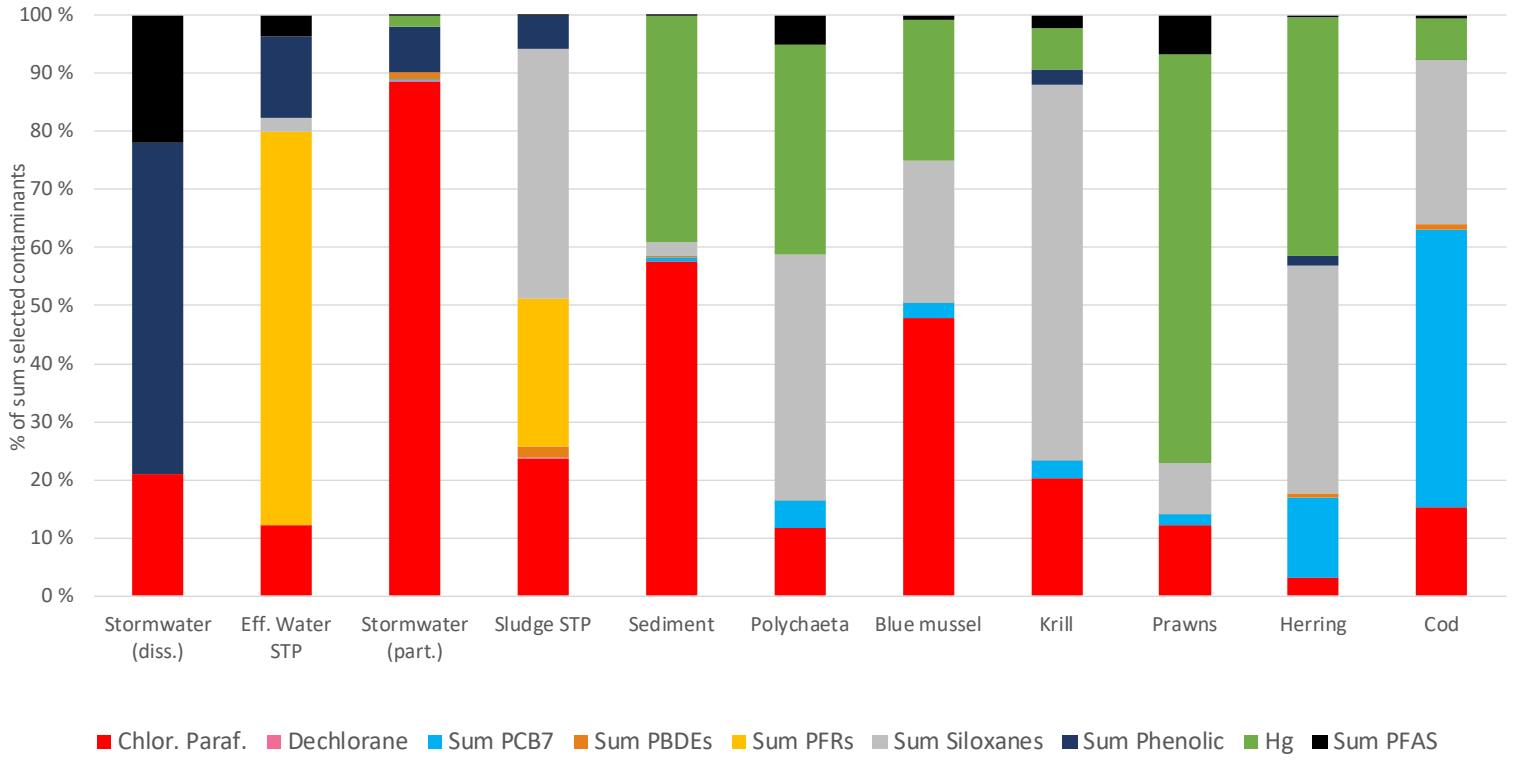
3.3 Interspecies and matrix comparisons

In terms of sources and sinks of contaminants in the marine ecosystem of the Inner Oslofjord, it is of interest to give general impression of the dominating contaminants/groups of contaminants in the different species and matrices analysed. **Figure 37** shows relative contribution of selected contaminants/groups of contaminants to the sum of these contaminants/groups of contaminants in storm water (dissolved and particulate fractions) entering the Oslofjord, sediments of the Inner Oslofjord, and polychaetes, blue mussel, krill, prawns, herring and cod (liver) from the Inner Oslofjord, as well as in effluent water (entering the Oslofjord) and sludge from Bekkelaget STP. The selected contaminants were chlorinated paraffins (sum of SCCPs and MCCPs), dechlorane

compounds, sum PCB7, sum PBDEs, sum PFRs, sum siloxanes, sum phenolic compounds, Hg and sum PFAS compounds.

Chlorinated paraffins apparently constitute major proportions of the sum of contaminants in all species/matrices, especially in the particulate fraction of stormwater and sediments, as well as in mussels (**Figure 37**). PCBs and PBDEs do not constitute very high (<5 %) proportions of the sum of contaminants, except for PCBs in the lipid rich tissues herring muscle and cod liver (PCBs were not analysed in samples from the STP; **Figure 37**). PFRs were only analysed in samples from the STP where they apparently constituted a major proportion, especially in the effluent water (**Figure 37**). Siloxanes (not analysed in storm water) constituted major proportions of the sum of contaminants in sludge from the STP, as well as in organisms in the Inner Oslofjord marine food web. Siloxanes were the major constituent of the sum of contaminants in krill (**Figure 37**). Phenolic compounds constituted major proportions of the sum of contaminants in storm water (especially the dissolved fraction), and to some degree in samples from the STP (effluent water and sludge; **Figure 37**). Hg (not analysed in samples from the STP) constituted major proportions of the sum of contaminants in sediments and organisms from the Inner Oslofjord, especially in prawns (**Figure 37**). PFAS compounds were only notable constituents of the sum of contaminants in the dissolved phase of storm water, as well as in polychaetes and prawns (**Figure 37**). As such, the pattern was similar to that observed in 2017 (Ruus et al. 2019; The Norwegian Environment Agency M-1131).

A.


100 %
90 %
80 %
70 %
60 %
50 %
40 %
30 %
20 %
10 %
0 %
% of sum selected contaminants
Stormwater (diss.)
Eff. Water STP
Stormwater (part.)
Sludge STP
Sediment
Polychaeta
Blue mussel
Krill
Prawns
Herring
Cod
Chlor. Paraf.
Dechlorane
Sum PCB7
Sum PBDEs
Sum PFRs
Sum Siloxanes
Sum Phenolic
Hg
Sum PFAS

B.

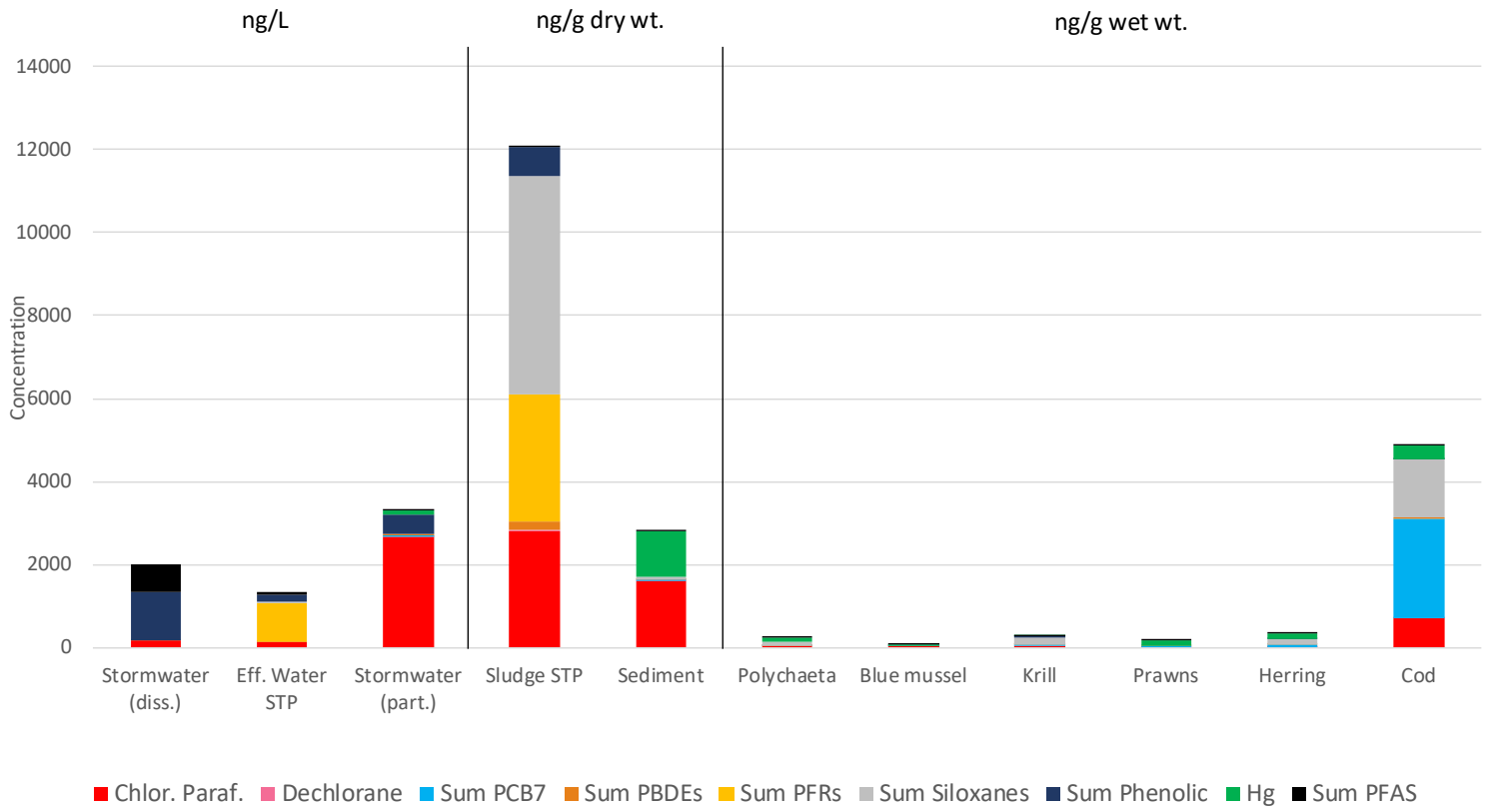


Figure 37. Relative contribution of selected contaminants/groups of contaminants to the sum of these contaminants/groups of contaminants (A.), as well as concentrations (B.), in storm-water (dissolved and particulate fractions) entering the Oslofjord, sediments of the Inner Oslofjord, and polychaetes, blue mussel, krill, prawns, herring and cod from the Inner Oslofjord, as well as in effluent water (entering the Oslofjord) and sludge from Bekkelaget STP. Note that PFRs were only analysed in samples from the STP, siloxanes were not analysed in storm water, and PCBs and Hg were not analysed in samples from the STP. Note: Dechlorane is dechlorane plus (syn- and anti-isomers), in addition to dechlorane 602 and 603 which were detected in some samples). In herring muscle tissue is analysed, while in cod Hg is analysed in muscle, phenolic compounds are analysed in bile, and other compounds are analysed in liver.

3.4 Support parameters

Miscellaneous support parameters were measured for the different matrices/samples/organisms: Particle fraction <63 µm (% dry wt.) and TOC (µg/mg dry wt.) in sediment, suspended solids (mg/L) in stormwater and effluent water from Bekkelaget STP, TOC (µg/mg dry wt) in sludge from Bekkelaget STP, $\delta^{13}C$, $\delta^{15}N$, C:N (W%), trophic position (deduced from $\delta^{15}N$,) and weight of egg (g) for herring gull eggs and eider duck eggs from the Inner Oslofjord, $\delta^{13}C$, $\delta^{15}N$, C:N (W%), trophic position (deduced from $\delta^{15}N$), wing length (mm), head length (mm) and body mass (g) for herring gulls and eder ducks (blood; not head length of eider ducks) from the Inner Oslofjord, $\delta^{13}C$, $\delta^{15}N$, C:N (W%), trophic position (deduced from $\delta^{15}N$), age (yr), body length (cm), body mass (g), liver weight (g), gonad weight (g) and sex of cod from the Inner Oslofjord, and $\delta^{13}C$, $\delta^{15}N$, C:N (W%) and trophic position (deduced from $\delta^{15}N$) of the organisms of the Inner Oslofjord food web. The measurements of these support parameters are presented in Tables A1-A9 in the Appendix. The lipid content of all biological samples is given in the electronic Appendix.

3.5 Biological effect parameters

Acetylcholinesterase (AChE) activity in muscle (microsomal fraction) was measured in cod, as well as the physiological parameters liversomatic index (LSI) and gonadosomatic index (GSI). These parameters are presented in **Table 15**.

In vertebrates acetylcholine (ACh) acts as an excitatory transmitter in the somatic nervous system. ACh also serves as both a pre ganglionic and a post ganglionic transmitter in the parasympathetic nervous system. Cholinesterase enzymes (ChE) are responsible for the removal of ACh from the synaptic cleft by hydroxylation. AChE may be inhibited by various substances/contaminants in the aquatic environment, such as organophosphates (Burgeot et al., 2012; Assis et al. 2010; Di Tuoro et al., 2011).

Table 15. Biological effect parameters measured for cod from the Inner Oslofjord.

Sample no.	Sex	AChE *	GSI	LSI
1	M	10.06	0.10	2.26
2	F	4.45	0.32	2.80
3	F	13.29	1.03	1.64
4	F	11.53	1.18	3.30
5	M	9.72	0.13	2.50
17	M	n.a.	0.04	2.88
7	F	12.03	1.55	3.32
8	M	9.85	0.49	2.24
9	F	9.01	0.98	2.61
10	M	9.07	0.35	2.63
11	F	9.96	1.26	2.64
12	F	10.64	0.31	1.84
19	M	n.a.	n.a.	3.17
14	F	10.03	0.50	3.00
15	F	7.69	0.77	2.63
***Acetylcholinesterase activity (nmol ATC/min/mg protein)**				

In the 2015 "Urban fjord" programme, a statistically significant negative relationship (log-log) was observed between the concentration of Hg (analysed in muscle) and AChE in cod (Ruus et al. 2016; The Norwegian Environment Agency M-601). This finding was interesting, since inhibition of AChE is a known marker of exposure to organophosphate pesticides, but the role of Hg as an anticholinesterase agent is not as well established. Shaw and Panigrahi (1990) did however show a significant negative correlation between brain residual Hg levels and AChE activity in fish. They suggested that Hg might be exerting its influence by combining with the SH-group of the enzyme leading to conformational changes and thus inactivation. Vieira et al. (2009) also found that Hg inhibited AChE activity in the head of the common goby (*Pomatoschistus microps*), also leading to decreased swimming performance. However, in 2015, AChE activity in the muscle of cod also showed statistically significant negative relationships with length, weight and age of cod (Ruus et al. 2016; The Norwegian Environment Agency M-601), and since Hg was shown to correlate with length and weight of cod, the results were inconclusive regarding likely causality (Ruus et al. 2016; The Norwegian Environment Agency M-601). In 2016, AChE activity did not show a statistically significant negative relationship with the length of cod, or between AChE activity and Hg liver concentrations (Ruus et al. 2017; The Norwegian Environment Agency M-812).

In 2017, there was a significant negative relationship between AChE-activity and the length of cod, while there was no significant relationship between AChE-activity and muscle Hg-concentration (Ruus et al. 2019; The Norwegian Environment Agency M-1131). The same was observed in the present study (**Figure 38**; **Figure 39**). Note also that there was no statistically significant relationship (p=0.65) between mercury in cod and the length of cod (**Figure 21**). As such, it is possible that the

negative relationship between AChE-activity and the length of cod may be a result of lower AChE:muscle protein-ratio in larger cod, and sometimes there is covariation with Hg concentration without any causal relationship.

Interestingly, in the present study, there were significant negative relationships between AChE activity in cod muscle and concentrations of some dechlorane-, PCB- and PBDE-compounds in cod liver (illustrated by dechlorane 602 in **Figure 40**). However, again most of these compounds also showed a significant positive relationship with cod length (illustrated by dechlorane 602 in **Figure 41**), thus no causal relationship between the compounds and AChE activity can be suggested.

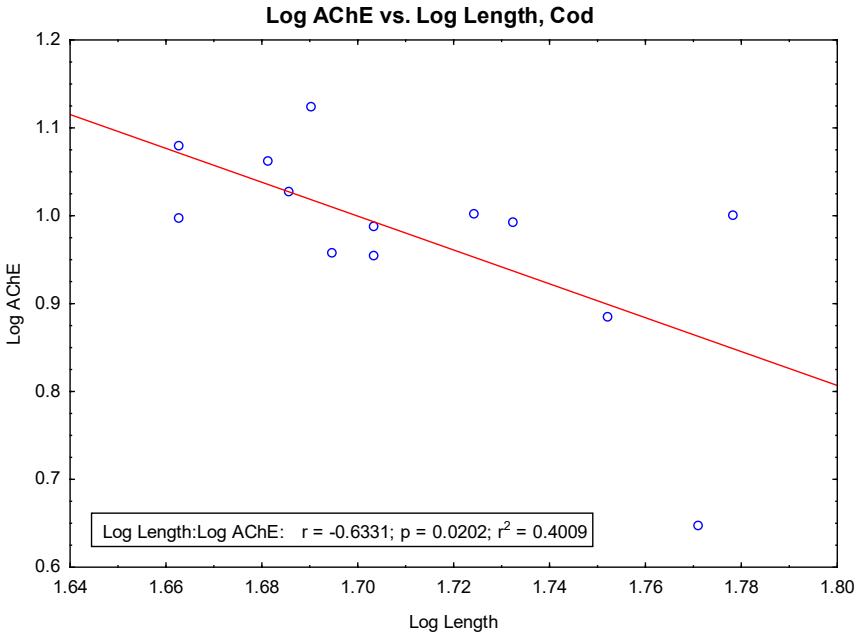


Figure 38. Acetylcholinesterase (AChE) activity (nmol ATC/min/mg protein; log-transformed) in muscle of cod from the Inner Oslofjord against length (cm: log-transformed) of cod.

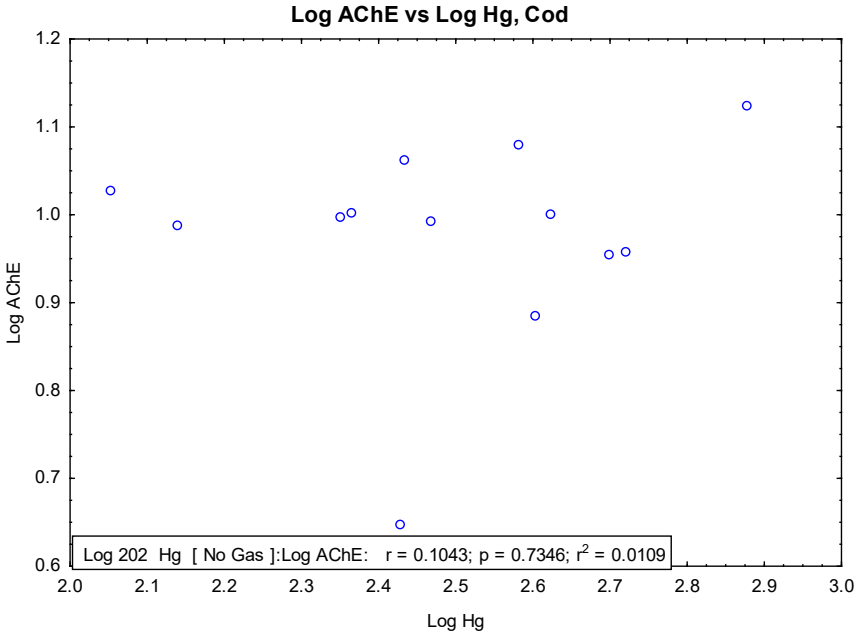


Figure 39. Acetylcholinesterase (AchE) activity (nmol ATC/min/mg protein; log-transformed) in muscle of cod from the Inner Oslofjord against Hg-concentration (ng/g wet wt.; log-transformed) in muscle of cod.

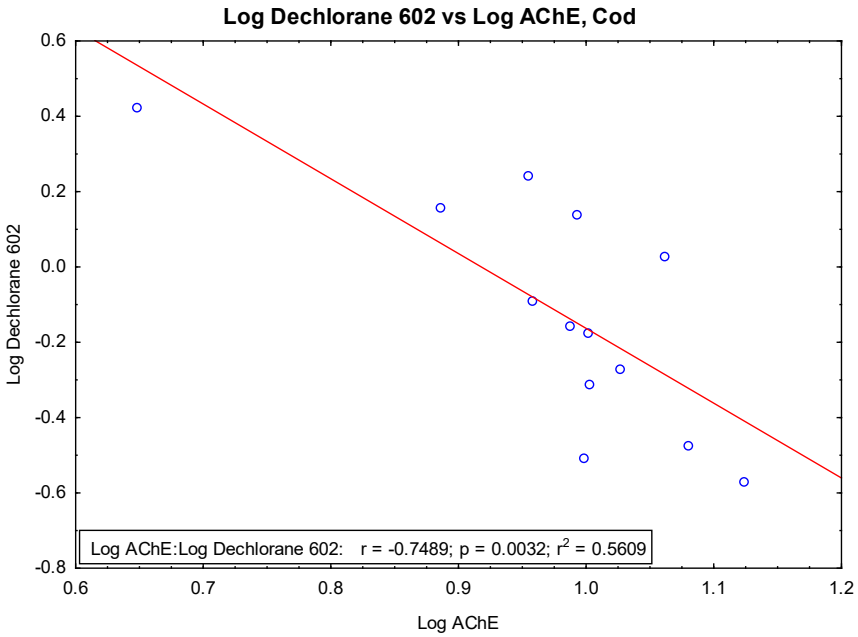


Figure 40. Acetylcholinesterase (AchE) activity (nmol ATC/min/mg protein; log-transformed) in muscle of cod from the Inner Oslofjord against dechlorane 602-concentration (ng/g wet wt.; log-transformed) in liver of cod.
figur

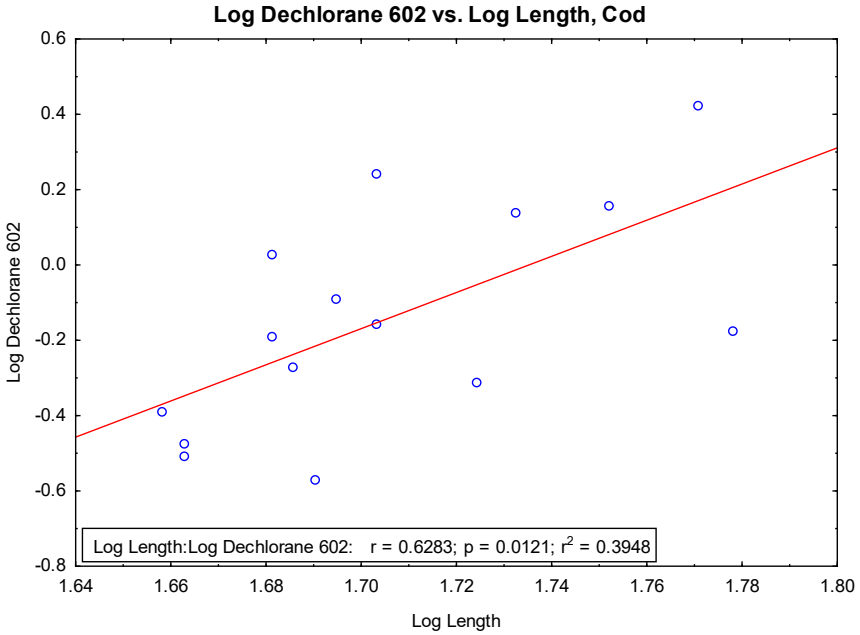


Figure 41. Concentrations (ng/g wet wt.) of dechlorane 602 in liver of cod against length (cm) in cod from the Inner Oslofjord.

4 Concluding remarks

In this programme, a large number of chemical parameters have been quantified, in addition to a few biological effect parameters and support parameters. Concentrations of various chemicals in different compartments of the Inner Oslofjord marine ecosystem are documented.

The sediments of the inner Oslofjord is a potential source of contaminants to organisms living in and on the sediments. As such, the contaminants may enter the food chain. Several of the target compounds were found in the sediment, such as PCBs, PBDEs and other brominated flame retardants (e.g. DBDPE), S/MCCPs, siloxanes, metals, PFOS, UV chemicals and dechlorane plus. Inputs to the fjord via storm water and STP effluent water for several of the compounds is also shown, including also phenolic compounds, and PFRs (only STP effluent). DBDPE was found in higher concentrations than any PBDE-congener in both sediment and storm water. Some compounds exceeded environmental quality standards. These were in sediments: PCB7, Zn, As, Ni, Hg and PFOS, in storm water: Bisphenol A, MCCPs, Cu, Zn, As and PFOS, and in STP effluent water: MCCPs and PFOS.

In 2018 the programme included additional sampling of eider duck (eggs and blood) in the Inner Oslofjord, as in 2017. The aquatic food web sampled was identical to that in 2015-2017. The results of the stable isotope analysis suggest that the marine species (fish and invertebrates) represent members of the marine food web of the Inner Oslofjord. The differences in $\delta^{15}N$ seem to reflect expected trophic relationships; blue mussel (filters particulate organic matter from the water) < zooplankton (herbivore) < polychaetes (different modes of living, largely detritivorous) < herring (pelagic fish feeding on zooplankton) ≈ prawns (some scavenging behaviour) < cod (mesopelagic fish, predator on fish and benthic organisms). The food web spans over 2 to 3 (~2.1) trophic levels with blue mussel defined at trophic level 2. Furthermore, the isotopic signatures of the eider duck correspond much better with a member of the Inner Oslofjord Marine food web, compared to herring gull, because of their marine diet. In both herring gull and eider duck (blood and eggs), PFOS was found in the highest concentrations of the PFAS compounds.

The biomagnification potential of contaminants was evaluated by calculation of Trophic Magnification Factors (TMFs). Especially legacy contaminants with well-known biomagnifying properties displayed a positive significant relationship between (log_{10}-)concentrations and trophic position (deduced from the $\delta^{15}N$ isotopic ratio) in the studied Inner Oslofjord marine food web. This suggests that the selected food web is suitable for studying biomagnification in the Oslo fjord. PFOS, PFOSA, As and Ag were also compounds/elements that displayed a significant TMF>1. For PFOS, this was the case also when eider duck was included in the food web indicating biomagnification in the marine food web. In the literature, there is little evidence of biomagnification of Ag in marine systems.

Dechlorane plus is used as a flame retardant in plastics and polymers, such as nylon, polyurethane, polypropylene, neoprene and silicone rubber. Dechlorane plus was found in particulate phases, more specific the particulate fraction in storm water, in sewage sludge and in sediment. Furthermore, it was detected in polychaetes, cod and herring gull (both blood and eggs). The concentration in the sediment appeared in the same range as concentrations found in sediments of the North American Great Lakes, and 1-2 orders of magnitude lower than in sediments of Lake Ontario, close to a dechlorane plus manufacturing plant in the city of Niagara Falls. Moreover, the concentrations found in in cod from the Inner Oslofjord appeared a factor ~2 higher than in brown trout from Lake Mjøsa, which were higher than found in trout from Lake Ontario, Canada. The concentrations in eggs of

herring gull appeared a factor of approximately 3-5 lower than those in herring gull eggs from the North American Great Lakes, however even lower compared to eggs of herring gull from Niagara River, closer to a dechlorane plus manufacturing plant.

4,4'-methylenebis[2,6-bis(1,1-dimethylethyl)-phenol (MB1) is used as an industrial anti-oxidant and additive to plastics. It was analysed in the Urban fjord programme in 2018. It was, however, not detected in any samples.

UV-chemicals (octocrylene, benzophenone and ethylhexylmethoxycinnamate) were found in notable concentrations in samples from Bekkelaget STP, and especially in sludge. In addition, UV-326, UV-328 and UV-329 were detected in notable concentrations. These findings reflect the use of UV-chemicals in sunscreens and other cosmetics.

The concentrations of PBDEs (e.g. BDE-47 and -209) and D5 in herring gull eggs from the present study (Inner Oslofjord) displayed concentrations that were higher than those previously observed in herring gull eggs sampled from remote colonies in Norway, indicating urban influence. On the other hand, concentrations of “legacy” contaminants, such as PCB-153 and sumPCB7 appeared lower in the eggs from Oslofjorden, probably reflecting a less marine diet. Interestingly, in blood of gulls, concentrations of DBDPE were higher than concentrations of any of the PBDE congeners, as also observed in 2016 and 2017. Moreover, the same was observed in sediments, storm water and cod liver. DBDPE is a substitute for BDE-209 and future monitoring will indicate potential temporal trends.

While the concentrations of PCBs in sparrow hawk eggs from the Oslo area appeared higher than in the herring gull eggs from the Inner Oslofjord area, BDE-209 and siloxanes appeared higher in the gull eggs than in the sparrow hawk eggs. This is possibly reflecting that while the sparrow hawk feeds mostly on birds, the herring gull might feed on human waste and leftovers.

A negative relationship between AChE-activity and the length of cod was found, as previously observed. This may be a result of lower AChE:muscle protein-ratio in larger cod. There were also significant negative relationships between AChE activity in cod muscle and concentrations of some dechlorane-, PCB- and PBDE-compounds in cod liver. However, most of these compounds also showed a significant positive relationship with cod length, thus no causal relationship between the compounds and AChE activity can be suggested.

In summary, it is shown that sediments and organisms in the inner Oslofjord contain various contaminants in different concentrations, both legacy contaminants and contaminants of more emerging concern. Some pathways for these contaminants into the fjord are also shown, such as storm water, and effluent water from sewage treatment plants. For instance, chlorinated paraffins apparently constitute major proportions in all species/matrices examined. PCBs constituted a large proportion of the sum of contaminants in the lipid rich herring and cod livers. Furthermore, siloxanes were important constituents of the sum of contaminants in cod liver, as in other species of the marine food web, especially krill.

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Appendix A.

Concentrations in individual samples and composition of (calculated) pooled samples of cod are available as electronic appendix.

Table A1.
Support parameters measured for sediment from the inner Oslofjord.

Area	<63 µm (% dry wt.)	TOC (µg/mg dry wt.)
Inner Oslofjord (station Cm21)	55	89

Table A2.
Support parameters measured for stormwater.

Sample	Suspended solids (mg/L)
Aln 125x	87.8
Aln 136X	3880

Table A3.
Support parameters measured for effluent water and sludge from Bekkelaget sewage treatment plant.

Sample	TOC (µg/mg dry wt.)	Suspended solids (mg/L)
Effluent water (June 25th)		3.3
Eflluent water (June 26th)		4.3
Sludge (June 25th)	245	
Sludge (June 26th)	150	

Table A4.
Support parameters measured for herring gull eggs from the Inner Oslofjord area.

Sample no.	Specimen/ nest	$\delta^{34}S$	$\delta^{13}C$	$\delta^{15}N$	C:N (W%)	Trophic position	Weight, egg (g)	Eggshell thickness (mm)
1	JCL14	n.a.	-26.91	9.75	7.50	2.83	84.01	n.a.
2	JCL28	n.a.	-26.06	10.29	6.69	2.97	88.01	n.a.
3	JCX96	n.a.	-26.97	9.16	7.33	2.67	77.77	n.a.
4	JEX59	n.a.	-26.88	9.74	7.37	2.82	86.93	n.a.
5	JCL73	n.a.	-26.32	8.85	7.19	2.59	83.84	n.a.
6	JCL76	n.a.	-27.38	8.38	7.61	2.47	85.53	n.a.
7	JJX31	n.a.	-27.12	8.89	7.45	2.60	90.09	n.a.
8	JJX32	n.a.	-27.07	7.68	7.73	2.28	76.5	n.a.
9	JEZ88	n.a.	-27.09	8.84	7.81	2.59	65.76	n.a.
10	JEZ90	n.a.	-26.54	9.69	7.57	2.81	88.44	n.a.
11	JJX33	n.a.	-27.66	9.17	8.24	2.67	72.12	n.a.
12	JJX36	n.a.	-24.70	8.93	7.00	2.61	72.79	n.a.
13	JJX38	n.a.	-27.41	10.62	7.64	3.05	71.54	n.a.
14	JJX45	n.a.	-26.59	8.30	7.56	2.44	76.43	n.a.
15	JJX48	n.a.	-27.30	7.66	8.08	2.28	75.49	n.a.

Table A5.
Support parameters measured for herring gull blood from the Inner Oslofjord.

Sample no.	Specimen/ nest	$\delta^{34}S$	$\delta^{13}C$	$\delta^{15}N$	C:N (W%)	Trophic position	Wing (mm)	Head (mm)	Weight (g)
1	JCL14	n.a.	-23.48	9.12	3.63	2.66	420	120.2	920
2	JCL28	n.a.	-24.25	8.89	3.51	2.60	430	118.8	940
3	JCX96	n.a.	-24.67	7.63	3.56	2.27	430	117.4	970
4	JEX59	n.a.	-24.61	8.49	3.60	2.49	423	119.5	890
5	JCL73	n.a.	-23.49	9.09	3.60	2.65	419	121.6	930
6	JCL76	n.a.	-25.10	7.66	3.63	2.28	425	117.4	840
7	JJX31	n.a.	-23.95	9.38	3.67	2.73	415	116	820
8	JJX32	n.a.	-24.62	7.18	3.59	2.15	411	116.9	920
9	JEZ88	n.a.	-24.50	7.67	3.54	2.28	445	120.6	1020
10	JEZ90	n.a.	-22.91	10.08	3.57	2.91	412	117.2	870
11	JJX33	n.a.	-24.27	9.12	3.75	2.66	431	117.4	930
12	JJX36	n.a.	-23.99	7.92	3.63	2.34	425	19.6	820
13	JJX38	n.a.	-23.85	9.55	3.65	2.77	417	111.2	830
14	JJX45	n.a.	-24.77	8.11	3.70	2.40	439	117.8	890
15	JJX48	n.a.	-24.64	7.60	3.70	2.26	392	112.2	765

Table A6.
Support parameters measured for eider duck eggs from the Inner Oslofjord area.

Sample no.	Specimen/ nest	$\delta^{34}S$	$\delta^{13}C$	$\delta^{15}N$	C:N (W%)	Trophic position	Weight, egg (g)	Eggshell thickness (mm)
1	CA...21507	n.a.	-24.43	11.78	10.08	3.36	87	n.a.
2	CA...21509	n.a.	-24.18	12.51	8.84	3.55	119	n.a.
3	CA...21513	n.a.	-24.17	11.83	7.57	3.37	124	n.a.
4	CA...21515	n.a.	-24.63	12.50	8.62	3.55	114	n.a.
5	CA...21517	n.a.	-23.55	13.11	8.84	3.71	104	n.a.
6	CA...21518	n.a.	-21.65	14.03	8.65	3.95	115	n.a.
7	CA...21519	n.a.	-21.53	12.43	8.42	3.53	122	n.a.
8	CA...21521	n.a.	-22.25	13.36	8.24	3.78	129	n.a.
9	CA...21522	n.a.	-24.90	12.59	9.01	3.57	117	n.a.
10	CA...21527	n.a.	-22.96	14.15	8.26	3.98	107	n.a.
11	CA...21528	n.a.	-25.10	11.27	7.93	3.23	122	n.a.
12	CA...21529	n.a.	-22.40	13.20	8.39	3.73	92	n.a.
13	CA...21533	n.a.	-22.42	12.96	8.47	3.67	97	n.a.
14	CA...21534	n.a.	-24.40	12.41	8.62	3.53	114	n.a.
15	CA...21535	n.a.	-21.28	12.59	6.94	3.57	98	n.a.

Table A7.
Support parameters measured for eider duck blood from the Inner Oslofjord.

Sample no.	Specimen/ nest	$\delta^{34}S$	$\delta^{13}C$	$\delta^{15}N$	C:N (W%)	Trophic position	Wing (mm)	Head (mm)	Weight (g)
1	CA...21507	n.a.	-16.93	11.38	4.54	3.26	294	n.a.	1390
2	CA...21509	n.a.	-16.11	11.94	4.57	3.40	309	n.a.	1910
3	CA...21513	n.a.	-16.50	10.71	5.17	3.08	312	n.a.	2090
4	CA...21515	n.a.	-18.89	11.68	4.40	3.33	302	n.a.	1905
5	CA...21517	n.a.	-17.81	12.08	4.16	3.44	302	n.a.	2080
6	CA...21518	n.a.	-17.71	12.32	4.43	3.50	305	n.a.	1970
7	CA...21519	n.a.	-16.93	11.73	4.56	3.35	306	n.a.	2120
8	CA...21521	n.a.	-17.23	12.68	4.42	3.60	33	n.a.	2110
9	CA...21522	n.a.	-19.11	12.19	4.80	3.47	305	n.a.	1840
10	CA...21527	n.a.	-18.22	12.37	4.56	3.51	304	n.a.	1840
11	CA...21528	n.a.	-19.90	10.99	4.81	3.15	313	n.a.	930
12	CA...21529	n.a.	-17.81	11.51	4.54	3.29	311	n.a.	1840
13	CA...21533	n.a.	-16.58	12.36	4.18	3.51	303	n.a.	1640
14	CA...21534	n.a.	-18.14	11.99	4.20	3.42	312	n.a.	2010
15	CA...21535	n.a.	-16.92	12.85	4.78	3.64	296	n.a.	1630

Table A8.
Support parameters measured for Cod from the Inner Oslofjord.

Sample no.	$\delta^{13}C$	$\delta^{15}N$	C:N (W%)	Trophic position	Age (yr)	Length (cm)	Weight (g)	Liver weight (g)	Gonad weight (g)	Sex
1	-18.30	16.69	3.35	4.28	3	53	1460	33	1.5	M
2	-17.64	16.37	3.50	4.20	3	59	2360	66	7.5	F
3	-17.47	16.76	3.24	4.30	6	49	1160	19	12	F
4	-17.09	15.00	2.89	3.84	7	48	1060	35	12.5	F
5	-18.00	15.24	3.28	3.90	2	50.5	1160	29	1.5	M
17	-17.45	15.18	3.09	3.89	2	48	1160	33.4	0.5	M
7	-17.69	16.81	3.33	4.32	4	46	920	30.5	14.3	F
8	-17.81	16.46	3.29	4.22	4	54	1630	36.5	8	M
9	-17.74	16.45	3.29	4.22	5	50.5	1280	33.4	12.5	F
10	-17.99	16.84	3.34	4.32	5	49.5	1140	30	4	M
11	-17.69	14.76	3.15	3.78	3	46	900	23.8	11.3	F
12	-18.00	14.41	3.01	3.68	2	48.5	1030	19	3.2	F
19	-18.15	15.59	3.36	4.00		45.5	1010	32		M
14	-17.58	16.64	3.23	4.27	5	60	2000	60	10	F
15	-17.67	16.48	3.15	4.23	5	56.5	1790	47.1	13.8	F

Table A9.
Support parameters measured for compartments of the Inner Oslofjord marine food web; polychaetes, blue mussel, krill, prawns, herring, cod (mathematically derived pooled samples).

Species	Sample sub no.	$\delta^{13}C$	$\delta^{15}N$	C:N (W%)	Trophic position
Polychaeta	1	-19.28	12.38	4.08	3.15
Polychaeta	2	-20.35	12.04	5.31	3.06
Polychaeta	3	-20.10	12.99	5.41	3.31
Blue mussel	1	-21.23	8.43	4.82	2.11
Blue mussel	2	-21.64	7.64	5.30	1.90
Blue mussel	3	-20.88	7.97	5.23	1.99
Krill	1	-22.14	11.62	4.22	2.95
Krill	2	-22.29	11.90	4.22	3.02
Krill	3	-22.13	11.80	4.18	3.00
Prawns	1	-21.71	14.12	4.17	3.61
Prawns	2	-18.99	13.96	3.44	3.56
Prawns	3	-20.32	14.23	3.79	3.64
Herring	1	-20.91	13.46	4.01	3.43
Herring	2	-22.52	13.53	5.41	3.45
Herring	3	-21.74	13.90	4.65	3.55
Cod (pool 1)	1	-17.61	15.47	3.16	3.96
Cod (pool 2)	2	-17.84	15.94	3.23	4.09
Cod (pool 3)	3	-17.80	16.53	3.31	4.24

Table B1.
Compounds and elements that are/have been included in the Urban fjord programme. Chemspider ID and/or CAS are given.

Compound	Name	Chemspider ID	CAS
SCCP	Short chain chlorinated paraffins		85535-84-8
MCCP	Medium chain chlorinated paraffins		85535-85-9
Dibromoaldrin			20389-65-5
Dechlorane 602		32870	31107-44-5
Dechlorane 603		22803316	13560-92-4
Dechlorane 604			34571-16-9
Dechlorane plus syn	bis(hexachlorocyclopentadieno)cyclooctane		135821-03-3
Dechlorane 601			13560-90-2
Dechlorane plus anti	bis(hexachlorocyclopentadieno)cyclooctane		135821-74-8
PeCB	Pentachlorobenzene	21106570	608-93-5
HCB	Hexachlorobenzene	8067	118-74-1
PCB-18	2,2',5-Trichlorobiphenyl	34664	37680-65-2
PCB-28	2,4,4'-Trichlorobiphenyl	21924	7012-37-5
PCB-31	2,4',5-Trichlorobiphenyl	26011	16606-02-3
PCB-33	2,3',4'-Trichlorobiphenyl	34870	
PCB-37	3,4,4'-Trichlorobiphenyl	34873	
PCB-47	2,2',4,4'-Tetrachlorobiphenyl	16182	2437-79-8
PCB-52	2,2',5,5'-Tetrachlorobiphenyl	34189	35693-99-3
PCB-66	2,3',4,4'-Tetrachlorobiphenyl	33279	32598-10-0
PCB-74	2,4,4',5-Tetrachlorobiphenyl	33304	
PCB-99	2,2',4,4',5-Pentachlorobiphenyl	34848	38380-01-7
PCB-101	2,2',4,5,5'-Pentachlorobiphenyl	34668	37680-73-2
PCB-105	2,3,3',4,4'-Pentachlorobiphenyl	33282	32598-14-4
PCB-114	2,3,4,4',5-Pentachlorobiphenyl	47913	74472-37-0
PCB-118	2,3',4,4',5-Pentachlorobiphenyl	32952	31508-00-6
PCB-122	2,3,3',4',5'-Pentachlorobiphenyl	82828	76842-07-4
PCB-123	2,3',4,4',5'-Pentachlorobiphenyl	43353	65510-44-3
PCB-128	2,2',3,3',4,4'-Hexachlorobiphenyl	34853	38380-07-3

PCB-138	2,2',3,4,4',5'-Hexachlorobiphenyl	33984	35065-28-2
PCB-141	2,2',3,4,5,5'-Hexachlorobiphenyl	36771	52712-04-6
PCB-149	2,2',3,4',5',6-Hexachlorobiphenyl	34851	38380-04-0
PCB-153	2,2',4,4',5,5'-Hexachlorobiphenyl	33983	35065-27-1
PCB-156	2,3,3',4,4',5-Hexachlorobiphenyl	34854	38380-08-4
PCB-157	2,3,3',4,4',5'-Hexachlorobiphenyl	46136	69782-90-7
PCB-167	2,3',4,4',5,5'-Hexachlorobiphenyl	36984	52663-72-6
PCB-170	2,2',3,3',4,4',5-Heptachlorobiphenyl	33986	35065-30-6
PCB-180	2,2',3,4,4',5,5'-Heptachlorobiphenyl	33985	35065-29-3
PCB-183	2,2',3,4,4',5',6-Heptachlorobiphenyl	36981	52663-69-1
PCB-187	2,2',3,4',5,5',6-Heptachlorobiphenyl	36980	52663-68-0
PCB-189	2,3,3',4,4',5,5'-Heptachlorobiphenyl	35108	39635-31-9
PCB-194	2,2',3,3',4,4',5,5'-Octachlorobiphenyl	34192	35694-08-7
PCB-206	2,2',3,3',4,4',5,5',6-Nonachlorobiphenyl	35206	40186-72-9
PCB-209	Decachlorobiphenyl	15484	2051-24-3
TBA	Tribromoanisole	21170966	
BDE-17	2,2',4-Tribromodiphenyl ether	10239061	
BDE-28	2,4,4'-Tribromodiphenyl ether	10239063	41318-75-6
BDE-47	2,2',4,4'-Tetrabromodiphenyl ether	85876	5436-43-1
BDE-49	2,2',4,5'-Tetrabromodiphenyl ether	21170704	123982-82-3
BDE-66	2,3',4,4'-Tetrabromodiphenyl ether	10239069	
BDE-71	2,3',4',6-Tetrabromodiphenyl ether	10239070	189084-62-6
BDE-77	3,3',4,4'-Tetrabromodiphenyl ether	10239072	
BDE-85	2,2',3,4,4'-Pentabromodiphenyl ether	154435	182346-21-0
BDE-99	2,2',4,4',5-Pentabromodiphenyl ether	33255	60348-60-9
BDE-100	2,2',4,4',6-Pentabromodiphenyl ether	135795	189084-64- 8
BDE-119	2,3',4,4',6-Pentabromodiphenyl ether	10239073	189084-66-0
BDE-126	3,3',4,4',5-Pentabromodiphenyl ether	21170703	366791-32-4
BDE-138	2,2',3,4,4',5'-Hexabromodiphenyl ether	10397336	182677-30-1
BDE-153	2,2',4,4',5,5'-Hexabromodiphenyl ether	136695	68631-49-2
BDE-154	2,2',4,4',5,6'-Hexabromodiphenyl ether	21170702	207122-15-4

BDE-156	2,3,3',4,4',5-Hexabromodiphenyl ether	28550781	
BDE-183	2,2',3,4,4',5',6-Heptabromodiphenyl ether	21170701	207122-16-5
BDE-184	2,2',3,4,4',6,6'-Heptabromodiphenyl ether	9105831	
BDE-191	2,3,3',4,4',5',6-Heptabromodiphenyl ether	30805224	
BDE-196	2,2',3,3',4,4',5',6-Octabromodiphenyl ether	28592527	32536-52-0
BDE-197	2,2',3,3',4,4',6,6'-Octabromodiphenyl ether	10141197	117964-21-3
BDE-202	2,2',3,3',5,5',6,6'-Octabromodiphenyl ether	2539191	67797-09-5
BDE-206	2,2',3,3',4,4',5,5',6-Nonabromodiphenyl ether	41371	63387-28-0
BDE-207	2,2',3,3',4,4',5,6,6'-Nonabromodiphenyl ether	9193547	437701-79-6
BDE-209	Decabromodiphenyl ether	13764	1163-19-5
ATE (TBP-AE)	allyl-2,4,6-tribromophenyl ether	69223	3278-89-5
a-TBECH	Tetrabromoethylcyclohexane		3322-93-8
b-TBECH	Tetrabromoethylcyclohexane		3322-93-8
g/d-TBECH	Tetrabromoethylcyclohexane		3322-93-8
BATE	2-bromoallyl 2,3,6-tribromophenylether		
PBT	Pentabromotoluene		87-83-2
PBEB	Pentabromoethylbenzene		85-22-3
HBB	Hexabromobenzene	6639	87-82-1
DPTE	2,3-dibromopropyl-2,4,6-tribromophenyl ether		35109-60-5
EHTBB	2-ethyl-hexyl tetrabromobenzoate	28419925	183658-27-7
BTBPE	1,1'-[1,2-Ethanediylbis(oxy)]bis(2,4,6-tribromobenzene)	34697	37853-59-1
TBPH (BEH /TBP)	bis(2-ethylhexyl) tetrabromophthalate	104816	26040-51-7
DBDPE	Decabromodiphenyl ethane	82781	84852-53-9
a-HCH	a-Hexachlorocyclohexane	10468511	319-84-6
b-HCH	b-Hexachlorocyclohexane	10468512	319-85-7
g-HCH	g-Hexachlorocyclohexane	10481896	58-89-9
d-HCH	d-Hexachlorocyclohexane	10430682	319-86-8
o,p'-DDE	1-Chloro-2-[2,2-dichloro-1-(4-chlorophenyl)vinyl]benzene	215802	3424-82-6
p,p'-DDE	1,1'-(2,2-Dichloro-1,1-ethenediyl)bis(4-chlorobenzene)	2927	72-55-9
o,p'-DDD	1-Chloro-2-[2,2-dichloro-1-(4-chlorophenyl)ethyl]benzene	4066	53-19-0
p,p'-DDD	1,1'-(2,2-Dichloro-1,1-ethanediyl)bis(4-chlorobenzene)	6057	72-54-8

o,p'-DDT	1-Chloro-2-[2,2,2-trichloro-1-(4-chlorophenyl)ethyl]benzene	12543	789-02-6
p,p'-DDT	1,1'-(2,2,2-Trichloro-1,1-ethanediyl)bis(4-chlorobenzene)	2928	50-29-3
TEP	Tetraethyl diphosphate	7585	107-49-3
TCEP	Tris(2-chloroethyl) phosphate	7994	115-96-8
TPrP	Tripropyl phosphate	10106	513-08-6
TCPP	Tris(1-chloropropyl) phosphate	10745879	13674-84-5
TiBP	Triisobutyl phosphate	29088	126-71-6
BdPhP	Butyl diphenyl phosphate	16714	2752-95-6
DBPhP	Dibutyl phenyl phosphate	16382	2528-36-1
TPP	Triphenyl phosphate	7988	115-86-6
TnBP	Tri-n-butyl phosphate	29090	126-73-8
TDCPP	Tris(1,3-dichloro-2-propyl)phosphate	24388	13674-87-8
TBEP	Tris(2-butoxyethyl) phosphate	6292	78-51-3
TCP	Tricresyl phosphate	21106216	1330-78-5
EHDP	2-Ethylhexyl diphenyl phosphate	14040	1241-94-7
TEHP	Tris(2-ethylhexyl) phosphate	6289	78-42-2
D4	2,2,4,4,6,6,8,8-Octamethyl-1,3,5,7,2,4,6,8-tetroxatetrasilocane	10696	556-67-2
D5	2,2,4,4,6,6,8,8,10,10-Decamethyl-1,3,5,7,9,2,4,6,8,10-pentoxapentasilecane	10451	541-02-6
D6	Dodecamethylcyclohexasiloxane	10449	540-97-6
M3T(Ph)	tris(trimethylsiloxy)phenylsilane	56211	2116-84-9
Cr	Chromium	22412	7440-47-3
Fe	Iron	22368	7439-89-6
Ni	Nickel	910	7440-02-0
Cu	Copper	22414	7440-50-8
Zn	Zinc	22430	7440-66-6
As	Arsenic	4514330	7440-38-2
Ag	Silver	22394	7440-22-4
Cd	Cadmium	22410	7440-43-9
Sb	Antimony	4510681	7440-36-0
Pb	Lead	4509317	7439-92-1

Hg	Mercury	22373	7439-9-76
Bisphenol FL	4,4'-(9H-Fluorene-9,9-diyl)diphenol	69174	3236-71-3
Bisphenol M	4,4'-(1,3-Phenylenedi-2,2-propanediyl)diphenol	2540817	13595-25-0
Bisphenol Z	4,4'-(1,1-Cyclohexanediyl)diphenol	202599	843-55-0
Bisphenol AF	4,4'-(1,1,1,3,3,3-Hexafluoro-2,2-propanediyl)diphenol	66498	1478-61-1
Bisphenol AP	4,4'-(1-Phenyl-1,1-ethanediyl)diphenol	541979	1571-75-1
Bisphenol S	4,4'-Sulfonyldiphenol	6374	80-09-1
4,4-bisphenol F	4,4'-Methylenediphenol	11614	620-92-8
2,2-bisphenol F	2,2'-Methylenediphenol	68100	2467-02-9
Bisphenol E	4,4'-(1,1-Ethanediyl)diphenol	528599	2081-08-5
Bisphenol A	4,4'-(2,2-Propanediyl)diphenol	6371	80-05-7
Bisphenol B	4,4'-(2,2-Butanediyl)diphenol	59553	77-40-7
4-tert-octylphenol	4-(2,4,4-Trimethyl-2-pentanyl)phenol	8483	
4-nonylphenol	4-Nonylphenol	1688	104-40-5
Dodekylphenol			27193-86-8
TBBPA	Tetrabromobisphenol A	6366	79-94-7
AO-MB1	4,4'-methylenebis[2,6-bis (1,1-dimethylethyl)-phenol	8069	118-82-1
PFPA	Perfluoropentanoic acid	68426	2706-90-3
PFHxA	Perfluorohexanoic acid	60864	307-24-4
PFHpA	Perfluoroheptanoic acid	61135	375-85-9
PFOA	Perfluorooctanoic Acid	9180	335-67-1
PFNA	Perfluorononanoic acid	61138	375-95-1
PFDA	Perfluorodecanoic acid	9181	335-76-2
PFUdA	Perfluoroundecanoic acid	69649	2058-94-8
PFDoA	Perfluorododecanoic acid	60867	307-55-1
PFTrDA	Perfluorotridecanoic acid	2285907	72629-94-8
PFTeDA	Perfluorotetradecanoic acid	61139	376-06-7
PFBS	Perfluorobutanesulfonic acid	61132	29420-49-3
PFPS	Perfluoropentane-1-sulfonic acid	68427	2706-91-4
PFHxS	Perfluorohexanesulfonic acid	61053	82382-12-5
PFHpS	Perfluoroheptanesulfonic acid	61137	375-92-8

PFOS	Perfluorooctanesulfonic acid	67068	4021-47-0
8Cl-PFOS	8-chloroperfluoro-1-octanesulfonate		
PFNS	Perfluorononanesulfonic acid	78474	17202-41-4
PFDS	Perfluorodecane sulfonic acid	60955	67906-42-7
PFDoS	perfluoro-1-dodecansulfonate		79730-39-5
PFOSA	Perfluorooctanesulfonamide	62984	754-91-6
meFOSA	N-methylperfluoro-1-octanesulfonamide	2298910	31506-32-8
etFOSA	N-Ethylperfluoroctansulfonamid	70194	4151-50-2
meFOSE	2-(N-methylperfluoro-1-octanesulfonamido)-ethanol	81716	24448-09-7
etFOSE	2-(N-ethylperfluoro-1-octanesulfonamido)-ethanol	13908688	1691-99-2
4:2 FTS	1H,2H-perfluorohexane sulfonate (4:2)	16166147	757124-72-4
6:2 FTS	1H,2H-perfluorooctane sulfonate (6:2)	106865	27619-97-2
8:2 FTS	1H,2H-perfluorodecane sulfonate (8:2)	2284056	481071-78-7
meFOSAA	2-(N-methylperfluoro-1-octanesulfonamido)acetic acid	11316301	2355-31-9
etFOSAA	2-(N-ethylperfluoro-1-octanesulfonamido)acetic acid	17128	2991-50-6
F53	potassium 1,1,2,2-tetrafluoro-2-(perfluorohexyloxy)ethane sulfonate		754925-54-7
F53B	potassium 2-(6-chloro-1,1,2,2,3,3,4,4,5,5,6,6-dodecafluorohexyloxy)-1,1,2,2-tetrafluoroethane sulfonate		73606-19-6
BP3	(2-Hydroxy-4-methoxyphenyl)(phenyl)methanone	4471	131-57-7
EHMC	2-Ethylhexyl (2E)-3-(4-methoxyphenyl)acrylate	4511170	5466-77-3
OC	Octocrylene	21165	6197-30-4
ATAC-C20			15809-05-9
ATAC-C22			17301-53-0
TCC	Triclocarban	7266	101-20-2
Triclosan	Triclosan	5363	3380-34-5

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