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Miljøgifter i en urban fjord, 2016
Environmental Contaminants in an Urban Fjord, 2016

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Summary

This programme, “Environmental Contaminants in an Urban Fjord” has covered sampling and analysis of sediment and organisms in a marine food web of the Inner Oslofjord, in addition to samples of blood and eggs from herring gull. The programme also included inputs of pollutants via surface water (storm water). 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. 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. Furthermore, this report presents relationships between the contaminant concentrations and various biological variables.

4 emneord

Miljøgifter, urban, næringskjede, bioakkumulering

4 subject words

Contaminants, Urban areas, Food web, Bioaccumulation

Front page photo

Anders Ruus

Foreword

The programme covers sampling and analysis of organisms in a marine food web of the Oslofjord in 2016 in addition to samples of blood and eggs of herring gull. The programme also includes inputs of pollutants via surface water (storm water). This monitoring program adds to results from other monitoring programmes such as "Contaminants in coastal areas" (MILKYS) and "Riverine inputs and direct discharges to Norwegian coastal waters" (RID). Results from other input measurements to the inner Oslofjord also exist, such as measurements of contaminants at sewage treatment plants. These are referred to, when relevant. 2016 represents the fourth year of the Urban Fjord programme. Some changes/improvements were made in the design from 2014 to 2015. 2016 is a follow-up of the 2015-programme. In 2016 there was an addition to the programme, as a student conducted her MSc-thesis measuring DNA-damage in the herring gulls of the Oslofjord, in addition to measuring DNA-damage and selected contaminants in herring gulls of a remote colony (Hornøya, Northern Norway).

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 was done with assistance from the University of Oslo (Morten Helberg, Centre for Ecological and Evolutionary Synthesis).

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Oslo, oktober 2017

Anders Ruus
Forsker I, Marin Forurensning

Sammendrag

Dette programmet, "Miljøgifter i en Urban Fjord" har omfattet prøvetaking og analyse av sediment og organismer i en marin næringskjede i Indre Oslofjord i 2016, i tillegg til prøver av blod og egg fra gråmåke. Programmet omfattet også undersøkelser av tilførsler av miljøgifter via overvann.

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. 2016 er det fjerde året "Miljøgifter i en Urban Fjord" har vært gjennomført. Det ble gjort noen forandringer/forbedringer i design/innhold av programmet fra 2014 til 2015. 2016 var en oppfølging av 2015-programmet. I 2016 var det et tillegg til programmet: En MSc-student målte DNA-skade (Comet-assay) i måkene fra Oslofjorden, samt at DNA-skade og konsentrasjoner av utvalgte miljøgifter ble målt i en rural koloni (Hornøya i nord-Norge).

Bioakkumuleringspotensialet til de ulike miljøgiftene i Oslofjord-næringsnettet er undersøkt. Eksponering for/akkumulering av disse stoffene er også undersøkt i gråmåke, som representant som «urban innbygger». 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. Videre presenterer denne rapporten noen sammenhenger mellom konsentrasjoner av ulike stoffer og forskjellige biologiske variabler.

Analyser av stabile isotoper viste nær identiske resultater/trofiske interaksjoner som i 2015, og støtter opp om at endringene i innsamlingsprogrammet etter 2014 har vært fordelaktige. 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.

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 ble også funnet for

flere av stoffene. Noen stoffer (vannregionspesifikke stoffer: D5, PCB7, Zn og As; EUs prioriterte stoffer: Ni, Hg og PFOS) overskred miljøkvalitetsstandarder.

De følgende biologiske effektparameterne ble målt i torsk: Gonade-histopatologi, vitellogenin i blodplasma, micronucleii (i blodceller), aktivitet av acetylkolinesterase (AChE) i muskel (mikrosomal fraksjon), samt de fysiologiske parameterne leversomatisk indeks (LSI) og gonadosomatisk indeks (GSI). Angående gonade-histopatologi ble det konkludert med at det bare var tre individer (hun-fisk) med patologiske forandringer i gonadene. Som forventet var konsentrasjoner av VTG tilsynelatende høyere i hunner, enn i hanner, og variasjonen var høy (det var bare 3 hanner i materialet). Det var en positiv sammenheng mellom GSI og VTG hos hunner. Det ble kun funnet opp til 1 mikronukleus (markør for kromosombrudd/gentoksisitet) per 4000 undersøkte celler i fire undersøkte individer.

Aktivitet av acetylkolinesterase (AChE) i torskemuskel viste en negativ sammenheng med vekt av torsk. Det ble ikke funnet en negativ sammenheng mellom AChE og lengde av torsk, eller mellom AChE og konsentrasjon av kvikksølv (i lever), slik som ble observert i 2015 (da ble kvikksølv analysert i muskel). Aktiviteten av AChE viste imidlertid negativ sammenheng med konsentrasjonen av enkelte andre stoffer, men noen kausalitet er vanskelig å vise til, på grunn av ko-variasjon mellom flere variabler (inkludert størrelse på fisken).

Som tidligere observert ble en positiv sammenheng funnet mellom eggeskalltykkelse og trofisk posisjon av måkeegg, noe som tyder på at skalltykkelsen av egg ikke ble påvirket negativt av stoffer som øker i konsentrasjon med høyere nivå i næringskjeden. Det er kjent fra tidligere at eksponering for enkelte stoffer med bioakkumulerende potensiale (DDT) i høye konsentrasjoner fører til tynnere eggeskall hos rovfugl.

Som rapportert tidligere viste konsentrasjonene av enkelte stoffer funnet i gråmåkeegg fra Oslofjordområdet i 2016 interessante forskjeller fra konsentrasjoner funnet i gråmåkeegg fra mer fjerntliggende marine kolonier (Sklinna og Røst, 2012). I 2016 ble måker (blod) fra Oslofjorden og måker (blod) fra Hornøya sammenlignet og resultatene viste høyere konsentrasjoner av HCB og PCB på Hornøya, enn i Oslofjorden, mens konsentrasjonene av siloksaner tilsynelatende var høyest i måker fra Oslofjorden.

Det ble funnet høyere frekvens av DNA-skade i gråmåke fra Oslofjordområdet, enn i gråmåke fra den mer rurale kolonien på Hornøya. Dette kan tyde på høyere stress assosiert med urban innflytelse, men det er vanskelig å knytte dette direkte til miljøgifter.

Voksne hunn-måker og egg ble prøvetatt fra samme rede (altså mor og fremtidig avkom), og statistisk signifikante forhold mellom ratioer av stabile isotoper ($\delta^{13}C$, $\delta^{15}N$ and $\delta^{34}S$), samt konsentrasjoner av flere forbindelser i blod og i egg ble observert. Dette tyder på at egg i en viss grad kan gjenspeile forurensningsmønstre i måke.

En potensiell risiko (kumulativ risiko/blandingstoksisitet) for sekundær forgiftning ble påvist for fugler som kan beite på blåskjell, børstemark og sild. Relevante grenseverdier for sekundærforgiftning var ikke tilgjengelig for alle stoffer, og flere detekterte forbindelser ble derfor utelatt fra estimering av kumulativ risiko. Summen av PBDE (BDE-28, -47, -49, -100, -153 og -154) og summen av PCB7 var de viktigste risikofaktorene i alle byttedyr, i tillegg til Cd i børstemark og blåskjell. Grenseverdiene for sekundærforgiftning brukt for summen av PBDE

og summen av PCB7 betraktes som konservative (avledet ved forskjellige metoder enn for de andre stoffene), og resultatene bør tolkes med forsiktighet.

Beregning av den kombinerte risikoen for toksiske effekter i egg fra gråmåke viste at det er en risiko for effekt av PCB alene. De viktigste bidragsyterne til den kumulative risikoen, i tillegg til summen av PCB, var Cu og Ni.

Samlet sett viste vurderingene av kumulativ risiko at sjøfugl er utsatt for potensielle negative effekter, med summen av PCB7, samt metaller, som de viktigste bidragsyterne når konsentrasjoner i byttedyr og i egg tas i betraktning. Selv om summen av PBDE også ble identifisert som hovedbidragsyter til risiko fra byttedyr, er grenseverdien for sekundærforgiftning som brukes for disse forbindelsene utledet for å beskytte human helse og er mer konservative enn grenseverdier for sekundærforgiftning for predatorer. Ettersom det er brukt en blanding av grenseverdier for sekundærforgiftning for human helse og for predatorer bør resultatene tolkes med forsiktighet.

Summary

This programme, “Environmental Contaminants in an Urban Fjord” has covered sampling and analysis of sediment and organisms in a marine food web of the Inner Oslofjord in 2016, in addition to samples of blood and eggs from herring gull. The programme also included inputs of pollutants via surface water (storm water).

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 Water Framework Directive (The Water Regulation/“Vannforskriften”). 2016 represents the third year of the Urban Fjord programme. Some changes/improvements were made in the design from 2014 to 2015. 2016 is a follow-up of the 2015-programme. In 2016 there was an addition to the programme, as a student conducted her MSc-thesis measuring DNA-damage in the herring gulls of the Oslofjord, in addition to measuring DNA-damage and selected contaminants in herring gulls of a remote colony (Hornøya, Northern Norway).

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. 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. Furthermore, this report presents some relationships between the contaminant concentrations and various biological variables.

Analyses of stable isotopes showed nearly identical results/trophic interactions as in 2015 and corroborate that the changes in the sampling programme after 2014 have been advantageous. The biomagnifying potential of contaminants were 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.

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 for several of the compounds is also shown. Some compounds (river basin

specific substances: D5, PCB7, Zn and As; EU priority substances: Ni, Hg and PFOS) exceeded environmental quality standards.

The following biological effect parameters were measured in cod: Gonad histopathology, vitellogenin (VTG) in blood plasma, micronucleii (in blood cells), acetylcholinesterase (AChE) activity in muscle (microsomal fraction), as well as the physiological parameters liversomatic index (LSI) and gonadosomatic index (GSI). Regarding gonad histopathology, it was concluded that there were only 3 individuals (females) with pathological changes in gonads. As expected, concentrations of VTG appeared higher in females, than in males, and variation was high (there were only 3 males in the material). There was a positive relationship between GSI and VTG in females. No more than 1 micronucleus (marker for chromosome break/genotoxicity) was found per 4000 counted cells in 4 individuals studied.

Acetylcholinesterase (AChE) activity in the muscle of cod showed a negative relationship with weight of cod. No negative relationship was found between AChE and length of cod, or between AchE and concentrations of mercury (in liver), as were observed in 2015 (then mercury was analysed in muscle). The activity of AChE did, however, show negative relationships with the concentrations of some compounds, but any causality is difficult to show to, because of the co-variation between variables (including the size of the fish).

As previously observed, a positive relationship was found between the eggshell thickness and the trophic position of the herring gull eggs, suggesting that the shell thickness of eggs in the present study was not affected negatively by compounds that increase in concentration with higher trophic position. It is known from previous studies that exposure to specific compounds with bioaccumulative potential (DDT) in high concentrations lead to eggshell thinning in birds of prey.

Som rapportert tidligere viste konsentrasjonene av enkelte stoffer funnet i gråmåkeegg fra Oslofjordområdet i 2016 interessante forskjeller fra konsentrasjoner funnet i gråmåkeegg fra mer fjerntliggende marine kolonier (Sklinna og Røst, 2012). I 2016 ble måker (blod) fra Oslofjorden og måker (blod) fra Hornøya sammenlignet og resultatene viste høyere konsentrasjoner av HCB og PCB på Hornøya, enn i Oslofjorden, mens konsentrasjonene av siloksaner tilsynelatende var høyest i måker fra Oslofjorden.

As previously reported, concentrations of specific compounds in eggs of herring gull from the Oslo area showed interesting differences from concentrations in herring gull eggs from more remote marine colonies (Sklinna and Røst, 2012). In 2016, gulls (blood) from the Oslofjord and gulls (blood) from Hornøya were compared, and the results showed higher concentrations of HCB and PCBs at Hornøya, than in the Oslofjord, while concentrations of siloxanes were apparently highest in gulls from the Oslofjord.

Higher frequency of DNA-damage was found in herring gulls from the Inner Oslofjord, compared to the rural colony at Hornøya. This suggest higher stress associated with urban influence, although it is difficult to relate this to contaminants, specifically.

Adult female gulls and eggs were sampled from the same nest (i.e. mother and future offspring), and statistically significant relationships between the stable isotope ratios ($\delta^{13}C$, $\delta^{15}N$ and $\delta^{34}S$), as well as concentrations of several compounds, in the blood and in the egg

were observed. This suggest that eggs to some degree may reflect maternal contaminant patterns.

A potential risk (cumulative risk/mixture toxicity) of secondary poisoning was identified for birds preying on blue mussels, polychaetes and herring. Proper toxicity data were not available for all substances, thus several detected compounds were excluded from the cumulative risk estimation. The sum of PBDEs (BDE-28, -47, -99, -100, -153 and -154) and the sum of PCB7 were the main risk drivers in all food sources and with the addition of Cd in polychaetes and blue mussels. The toxicity data used for the sum of PBDE and the sum of PCB7 are considered conservative (derived by different methods than for the other substances) and the results should be interpreted with caution.

Calculations of the combined risk of effects in herring gull eggs showed that there is a risk of effects of PCBs alone. The main contributors to the cumulative risk, in addition to sum PCBs, were Cu and Ni.

Overall, the combined risk assessments showed that seabirds might be at risk to negative effects of contaminants, with the sum of PCBs and metals being the main contributors, when looking at concentrations in prey and in the eggs. Although the sum of PBDEs was also identified as main contributor in the prey, the toxicity data used for these compounds are very conservative, and the results should be interpreted with caution.

Content

Attachments:

1. *Appendix: Support parameters (Tables A1-A5); Herring gull data from the Oslofjord area (this study) and from Hornøya (Northern Norway; from Keilen, 2017); CAS-no.; report from IRIS on histopathological analysis of gonads in Atlantic cod.*

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

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: "RID - Riverine inputs and direct discharges to Norwegian coastal waters" and "MILKYS - Environmental contaminants in coastal areas".

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 Water Framework Directive (The Water Regulation/"Vannforskriften") regarding governmental basic monitoring as well as used in international chemical regulation. The present report (2016) represents the fourth year of the Urban Fjord project. Some changes/improvements were made in the design from 2014 to 2015. 2016 is a follow-up of the 2015-programme. In 2016 there was an addition to the programme, as a student conducted her MSc-thesis measuring DNA-damage in the herring gulls of the Oslofjord, in addition to measuring DNA-damage and selected contaminants in herring gulls of a remote colony (Hornøya, Northern Norway).

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 2016. Herring gull (blood and eggs) was also sampled within the programme, as a representative of an urban fjord inhabitant. Table 1 shows the sampling plan of the programme.

2.1.1 Sediment

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

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 cryopreservation and analysis. This was done in order to allow the worms to purge any residual sediment from the gut. 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: 69-101 mm) was collected.

Mussels were collected at Steilene (Figure 1) by standard procedures (as in "Contaminants in coastal areas", MILKYS; handpicked, using rake, or snorkelling). Three pooled samples (each of 20-21 shells; shell length 60 to 72 mm) was prepared.

Herring (*Clupea harengus*) were caught with trawl from RV Trygve Braarud at Midtmeie, southwest of Steilene (Figure 1). Material for three pooled samples (of 5 individuals in each; length: 23-28 cm, weight: 126-201 g) was collected.

[1] According to the Norwegian Environment Agency guidelines for risk assessment of contaminated sediment (TA-2802/2011).

Cod (*Gadus morhua*) were caught with trawl from RV Trygve Braarud at Midtmeie, southwest of Steilene (Figure 1). 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 by Morten Helberg (University of Oslo). Biometric data for the birds are given in Appendix. The birds and eggs were sampled at Søndre Skjælholmen (Nesodden municipality; 59.85317 N, 10.7281 E). The blood samples were taken from adult birds trapped by walk-in trap placed at the nest, and the blood samples (~5 ml) were taken from a vein under the wing. Adult female and egg was sampled from the same nest.

In 2016, there was an addition to the programme, as a student conducted her MSc-thesis measuring DNA-damage in the herring gulls of the Oslofjord, in addition to measuring DNA-damage and selected contaminants in herring gulls of a remote colony (Hornøya, Northern Norway). A description of the sampling of blood from the Hornøya colony is given by Keilen (2017).

2.1.4 Storm water

Storm water samples were collected at one occasion at four specific sampling points (Bryn Ring 3/E6, Breivoll/Alnabru terminal, Breivoll E6, downstream terminal and Hasle snow disposal site; 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)).

Table 1
Overview of samples collected for the "Urban Fjord" programme.

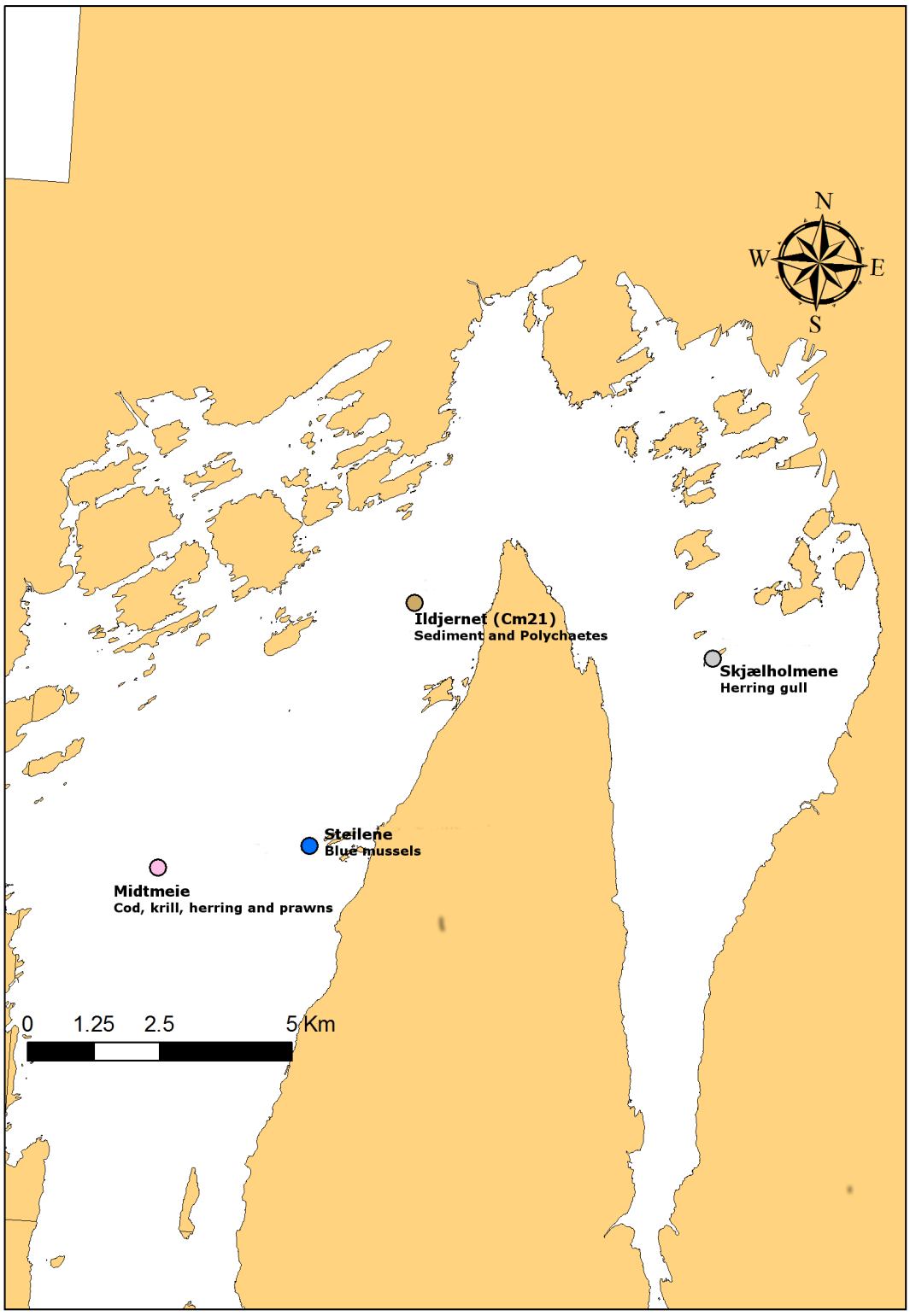
Species/matrix	Locality	Frequency	No. for analysis
Sediment	Cm21	Once per year	1
Polychaetes	Cm21	Once per year	3 pooled samples
Zooplankton	Midtmeie	Once per year	3 pooled samples
Prawns	Midtmeie	Once per year	3 pooled samples
Blue mussel	Steilene	Once per year	3 pooled samples
Herring	Midtmeie	Once per year	3 pooled samples
Cod	Midtmeie	Once per year	15 individuals
Herring gull (blood)	Søndre skjælholmen	Once per year	15 individuals
Herring gull (egg)	Søndre skjælholmen	Once per year	15 eggs
Inputs storm water	See Figure 1	Once per year	4 samples (4 samples of dissolved fraction plus 4 of particulate fraction)

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

	Inner Oslofjord (Cm21)		
	Repl. 1	**Repl. 2**	**Repl. 3**
P.crassa	36	29.2	23.9
Lumbrineridae	16.5	18	22.4
Terbellidae	40.5	25.3	51
Aphrodita aculeata	6.9	3.8	
Misc. *	23.1	26.6	29.1
Total (grams)	**123**	**102.9**	**126.4**

** Nepthys, Glycera, Goniadidae, Nereididae, Scalibregma inflatum, Polynoidae, Spiophanes kroyeri, Hesionidae, Maldanidae, Cirratulidae.*

A.


N
W
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Ildjernet (Cm21)
Sediment and Polychaetes
Skjælholmene
Herring gull
Steilene
Blue mussels
Midtmeie
Cod, krill, herring and prawns
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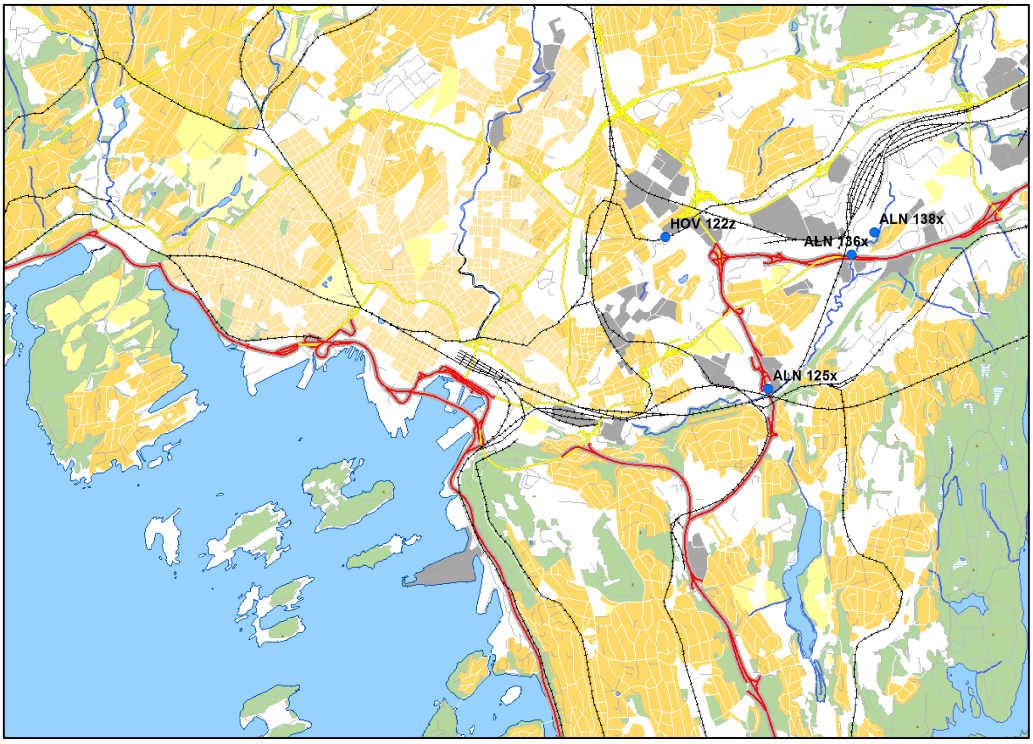


C.

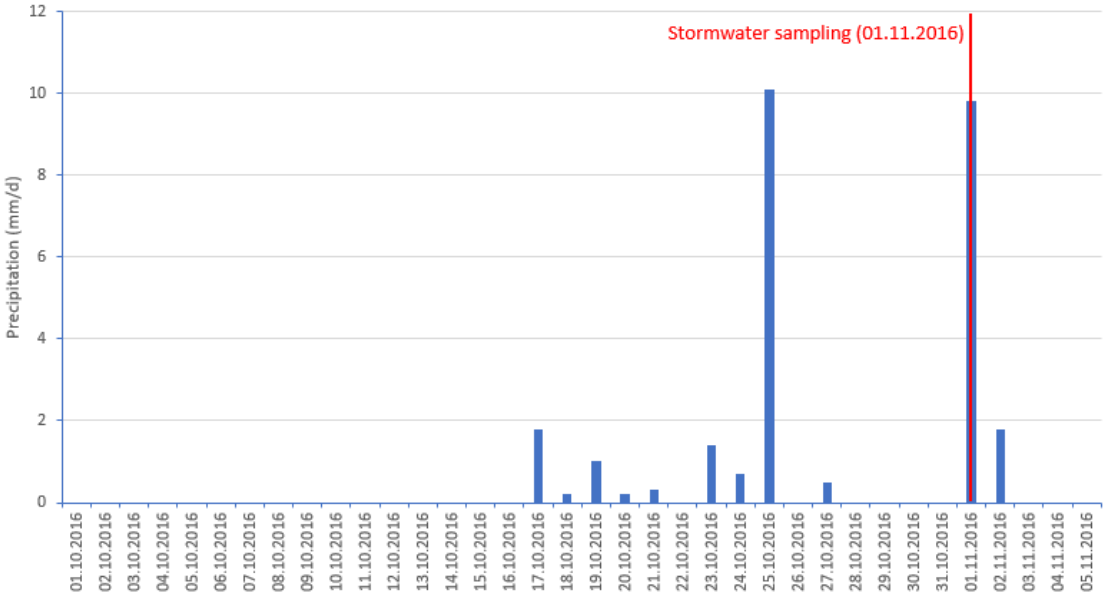


Figure 1. A.: (previous page) Map depicting stations for collection of sediment and polychaetes (Brown dot), blue mussel (blue dot), and krill, prawns, herring and cod (pink dot) in the Inner Oslofjord, as well as collection of herring gull eggs and blood (grey dot). B.: Map depicting sites for collection 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

Tables 3-5 provide a detailed overview of the compounds/parameters analysed in the different samples. 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 6). These were analysed at NIVA, except for gonad pathology, which was assessed at IRIS.

Table 3.
Overview: analyses in different matrices from the different localities (original programme).

Species/matrix	Locality	Analytes
Sediment	Cm21 (Inner Oslofjord)	Metals, PCB, PFAS, Triclosan, Triclocarban, bisphenols DBDPE, TBBPA, octylphenol, nonylphenol, chloroparafins, UV-chemicals, siloxanes, PFR
Polychaetes	Cm21 (Inner Oslofjord)	Metals, PCB, PFAS, Triclosan, Triclocarban, bisphenols DBDPE, TBBPA, octylphenol, nonylphenol, chloroparafins, UV-chemicals, siloxanes, PFR
Zooplankton	Midtmeie	Metals, PCB, PFAS, Triclosan, Triclocarban, bisphenols DBDPE, TBBPA, octylphenol, nonylphenol, chloroparafins, UV-chemicals, siloxanes, PFR
Prawns	Midtmeie	Metals, PCB, PFAS, Triclosan, Triclocarban, bisphenols DBDPE, TBBPA, octylphenol, nonylphenol, chloroparafins, UV-chemicals, siloxanes, PFR
Blue mussel	Steilene	Metals, PCB, PFAS, Triclosan, Triclocarban, bisphenols DBDPE, TBBPA, octylphenol, nonylphenol, chloroparafins, UV-chemicals, siloxanes, PFR
Herring	Midtmeie	Metals, PCB, PFAS, Triclosan, Triclocarban, bisphenols DBDPE, TBBPA, octylphenol, nonylphenol, chloroparafins, UV-chemicals, siloxanes, PFR
Cod	Midtmeie	Metals, PCB, PFAS, Triclosan, Triclocarban, bisphenols DBDPE, TBBPA, octylphenol, nonylphenol, chloroparafins, UV-chemicals, siloxanes, PFR
Herring gull (blood)	Søndre skjælholmen	Metals [1], PCB, PFAS, Triclosan, Triclocarban, bisphenols DBDPE, TBBPA, octylphenol, nonylphenol, chloroparafins, UV-chemicals, siloxanes, PFR
Herring gull (eggs)	Søndre skjælholmen	Metals, PCB, PFAS, Triclosan, Triclocarban, bisphenols DBDPE, TBBPA, octylphenol, nonylphenol, chloroparafins, UV-chemicals, DDT, siloxanes, PFR
Inputs storm water [2]	See Figure 1	Metals, PCB, PFAS, Triclosan, Triclocarban, bisphenols DBDPE, TBBPA, chloroparafins, UV-chemicals, PFR

[1] Not sufficient material to analyse metals. Instead DDT-compounds (and HCH-isomers) were analysed in the extracts for PCB-analysis.

[2] Dissolved and particulate fractions.

Table 4.
Analytes included in the programme. (See the 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 (plus 4:2 FTS, PFDS, PFDoS, N-EtFOSE, N-MeFOSE, N-EtFOSA, N-MeFOSA, N-MeFOSAA, N-EtFOSAA) Perfluorinated carboxylic acids (6-14 C-atoms): PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnA, PFDoA, PFTrA, PFTeA, PFPeA (plus PFBA, PFPA)
Triclosan and Triclocarban	3380-34-5 and 101-20-2
Brominated flameretardants	Decabromodiphenyl ethane (DBDPE), Tetrabromobisphenol A (TBBPA) (plus 23 polybrominated diphenyl ethers, PBDEs).
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)
ΣDDT	p,p'-DDT, p,p'-DDE, p,p'-DDD (plus o,p'-DDT, o,p'-DDE, o,p'-DDD og α-, ß- and γ-HCH)
Siloxanes	Octamethylcyclotetrasiloxane (D4), decamethylcyclopentasiloxane (D5), dodecamethylcyclohexasiloxane (D6)
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)

Table 5.
Supportparameters included in the programme

Parameter	Specific single parameters	Comment
Stable isotopes	$\delta^{15}N$ and $\delta^{13}C$ (and $\delta^{34}S$ in herring gull)	In biological matrices
Eggshell thickness	Eggshell thickness	In egg
Lipid content (%) in biota		In biological matrices
Weight and length		Fish
Age		Cod
Grain size distribution	Fraction <63 µm	Sediment
TOC		Sediment

Table 6.
Biological effect parameters (in cod)

Parameter	Indicator of
Gonad histopathology	Effects on gonads
Vitellogenin (VTG)	Compounds with oestrogenic (or anti-oestrogenic) effect
Micronucleii	Chromosome break/genotoxicity
Acetylcholin esterase (AChE)	Inhibition by contaminants such as organophosphates
Other relevant physiological parameters: **Liversomatic index** **Gonadosomatic index**	

2.2.1 Analysis of metals

Metal analyses were performed by NILU.

Sample Preparation

Sediment- 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) and arsenic (As) 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.

2.2.2 Analysis of PCBs, DDT, S/MCCP and DBDPE

Polychlorinated biphenyls (PCBs), DDT, short- and medium chained chloroparaffins (S/MCCP) and decabromodiphenyl ethane (DBDPE) were analysed by NILU. The analysis was extended to include additional PCB- DDT- hexachlorocyclohexane- (HCH) and polybrominated diphenylether- (PBDE) compounds (Table 4).

Extraction

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

The water-, 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).

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 and DDT compounds. For the other compounds, the same quality assurance procedures (as for the accredited compounds) were applied.

2.2.3 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 and biota samples were extracted twice with acetonitrile and the extracts were cleaned using active coal if needed. Water samples were concentrated and cleaned up using an SPE column.

Analysis

PFAS compounds were analysed using LC/QToF (ESI negative mode).

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. NIVA has previously participated in intercalibrations, e.g. organized by UNEP-coordinated Global Inter Laboratory Assessment, with good results (z-score<2 for PFOS, PFOSA, PFHxs and PFDS).

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.

2.2.4 Analysis of alkylphenols and bisphenols

Alkylphenols and bisphenols (octylphenol, nonylphenol, bisphenol A, bisphenol S, bisphenol F and tetrabromobisphenol A, TBBPA) were analysed by NILU. The analysis was extended to include additional phenolic compounds (Table 4).

Extraction

Prior to extraction, the samples were added a mixture of isotope labelled bisphenols and alkylphenols for quantification purposes.

The sediment samples were extracted with accelerated solvent extraction (ASE) and to remove interferences further cleaned with SPE column. Biota-samples were extracted with organic solvents and concentrated under nitrogen flow. Then they were further cleaned with liquid-liquid extraction and an SPE column to remove lipids and other interferences prior to analysis. In addition, prior to the extraction and clean-up procedure for biota, liver 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).

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. Due to the lack of internal standards relevant to additional bisphenols included in Table 4, the results are semi-quantitative.

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.

2.2.5 Analysis of UV-chemicals and anti-bacterial compounds

UV-chemicals (octocrylene, benzophenone and ethylhexylmethoxycinnamate) and anti-bacterial compounds (Triclosan and Triclocarban) were analysed by NIVA

Extraction of UV-chemicals and Triclosan
Blood and egg samples were extracted first with acetonitrile and then with hexane. The rest of the biota samples were extracted with a mix of isopropanol and cyclohexane. All samples except blood samples were cleaned up using gel permeation chromatography (GPC), before analysis. Some of the samples were also purified using PSA (silica) and/or SPE (Fluorisil). Sediment samples were extracted twice with dichloromethane and the water samples were extracted with SPE (HLB).

Analysis of UV-chemicals and Triclosan
UV-chemicals and triclosan were analysed using GC-HRMS (Waters GCT Premier) or GC-MSD EI, SIM mode (Agilent 6890N, 5973N MSD).

Extraction of triclocarban
Prior to extraction, the samples were added a deuterated internal standard, for quantification purposes. Sediment and biota samples were extracted twice with acetonitrile and the extracts were cleaned using active coal if needed. Water samples were concentrated and cleaned up using an SPE column.
Sediment samples were extracted twice with dichloromethane and the water samples were extracted with SPE (HLB).

Analysis of triclocarban
Triclocarban was analysed using LC/QToF (ESI negative mode).

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
Samples were analysed in groups with at least one additive standard sample and a blank control.

2.2.6 Analysis of siloxanes

Siloxanes, i.e. octamethylcyclotetrasiloxane (D4), decamethylcyclopentasiloxane (D5), and dodecamethylcyclohexasiloxane (D6) were analysed by NILU – Norwegian Institute for Air Research.

Extraction
Sediment and biota tissues were extracted using sold-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 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 programs 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 sent 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 7.

Table 7.
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)
Reference blank 1	9.8	2.0	2.0
Reference blank 2	9.8	2.0	1.0
Reference blank 3	9.8	2.0	1.0
Reference blank 4	9.8	2.0	1.0
Mean (reference blanks)	**9.8**	**2.0**	**1.25**
Standard deviation (reference blanks)	**0**	**0**	**0.5**
Field blank 1 (Polychaetes)	16.6	2.2	1.3
Field blank 2 (Cod)	19.0	3.8	3.1
Field blank 3 (Herring gull egg)	12.6	1.5	0.7
Field blank 4 (Herring gull blood)	17.5	1.7	1.0
Field blank 5 (Blue mussel)	20.9	3.4	2.6

2.2.7 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- 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.

2.2.8 Support parameters

Stable isotopes of nitrogen, carbon and sulphur 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). Analysis of sulphur isotopes was done by combustion in an element analyser with V_2O_5 to increase the amount of available oxygen reduction of SOx to SO_2, separation of SO_2 from other products of combustion on a GC-column, and determination of $\delta^{34}S$ at IRMS.

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 the 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:

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

Eggshell thickness (herring gull eggs) was determined according to procedures described by Nygård (1983).

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.

2.2.9 Biological effect parameters (cod)

Gonad histopathology
Gonad histopathology was performed by IRIS. Gonads were dissected, put in histocassettes and placed into histological fixative (3.7% formaldehyde) for wax sections. Tissue samples were no thicker than 1 cm to ensure proper fixation. Samples were then stored at 4˚C until embedding. Histological sections (3 µm) were prepared at Stavanger University Hospital (SUS). The tissues were examined for health parameters related to physiological conditions, inflammatory and non-specific pathologies and those associated with pathogen and parasite infections. Gonad abnormalities were scored using the criteria suggested by Benly et al. (2008) and Sensini et al. (2008). Each alteration was scored according to its severity and frequency (0 = absence of alteration, 1 = ≤ 10 % of the histological section showed the alteration, 2 = between 10% and 50% of the histological section showed the alteration, 3 = between 50% and 100% of the histological section showed the alteration). The presence of parasites and non-specific inflammation were scored as absent (0) or present (1). All micrographs were captured using an AxioCam MRc5 (Zeiss) digital camera mounted on a *Zeiss Axioplan 2* light microscope (Göttingen, Germany). The slides were analysed blind. The stage of the gonads was also evaluated.

Vitellogenin in blood plasma
Vitellogenin (VTG) was measured in blood plasma of cod using an enzyme–linked immunosorbent assay (ELISA). Anti-VTG in a polyclonal serum was bound to dissolved VTG in competition with a known amount of VTG bound to the wells (primary antibody). An enzyme conjugated antibody bound to the primary antibody (high affinity) transformed the substrate to a coloured product that was detected spectrophotometrically.

Micronucleii
Blood samples of cod were smeared on microscope slides. The samples were dyed and monted in glycerol before micronuclei were counted under fluorescence microscope (1000× magnification). Initially, a minimum of 4000 cells per sample were counted for four individuals. If more than 2 micronucleii were encountered, more individuals would be assessed. According to ICES (2011), The background assessment criteria for micronucleii in cod erythrocytes is 0.4 per 1000 cells.

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 the above mentioned effect parameters, 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:

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

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

2.2.10 Analysis of contaminants and DNA damage (comet assay) in herring gulls from Hornøya

A description of the analysis of contaminats and DNA damage (comet assay) in the herring gulls sampled at Hornøya is given by Keilen (2016).

2.3 Data treatment

Statistical analysis (linear regressions; general linear models) was 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-programme; Ruus et al. 2016; The Norwegian Environment Agency M-601). 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).

When exploring correlations between contaminant concentrations and trophic position, as well as other predictors (such as length), concentrations of the following contaminants were expressed on a wet weight basis: Metals, PFASs, PFRs and phenolic compounds, while the concentrations of following contaminants were expressed on a lipid weight basis: PCBs and other organochlorine compounds, chlorinated paraffins, brominated flame retardants, siloxanes, anti-bacterial compounds and UV-filters. When exploring correlations between contaminant concentrations and biochemical response parameters (such as vitellogenin and AChE activity), all concentrations were expressed on a wet weight basis.

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

2.3.1 Mixture toxicity / cumulative risk

Based on knowledge on combined effects of chemicals from laboratory and field studies, a conceptual framework for environmental risk assessment of chemical mixtures has been proposed based on an approximation to concentration addition (CA) (Backhaus and Faust, 2012). In the proposed framework, the environmental risk of chemical mixtures is assessed through a tiered approach using available effect data (NOEC and EC50 values) and predicted or measured exposure concentrations (PEC or MEC). In the first tier a risk quotient (RQ) is calculated by summing up the ratios between exposure concentrations (MEC or PEC) and predicted no effect concentrations (PNEC) for all chemicals in the mixture. Backhaus and Faust (2012) showed that summation of PEC/PNEC ratios can serve as a justifiable, conservative, first-tier approach to CA. If the resulting RQ is ≥ 1, there is a potential environmental risk and the next tier should be performed. In tier 2, the environmental risk of the chemical mixture is assessed for each species group (e.g. algae, crustaceans, fish) by summing up the toxic units (TU = MEC/EC50) for all chemicals in the mixture. The RQ is obtained by application of an appropriate assessment factor on the sumSTU, and a value ≥ 1 is indicative of an environmental risk. Concentration Addition as well as Independent Action can be applied to external (aqueous) or internal (in-biota) concentrations, as long as exposure as well as hazard estimates relate to the same compartment.

This or similar approaches has been used in several studies to assess the environmental risk of chemical mixtures detected in the aquatic environment (Backhaus and Karlsson, 2014; Bundschuh et al. 2014; Finizio et al. 2005; Moschet et al. 2014; Petersen et al. 2013), and in biota (Herzke et al. 2014, 2015; The Norwegian Environment Agency M-261 and M-354).

In order to assess whether the mixture of contaminants measured in the organisms pose a risk to their predators, measured concentrations (MEC) in blue mussels, polychaetes and herring and available predicted no effect concentrations for secondary poisoning ($PNEC_{pred}$, $PNEC_{oral}$, or $(E)QS_{biota,\ secpois}$) or human health ($(E)QS_{biota,\ hh}$) were used to calculate the sum of $MEC/PNEC_{pred}$ ratios. The average of three measured concentrations was used as MEC for blue mussels, polychaetes and herring. It should be noted that $(E)QS_{biota,hh}$ values are calculated in a different way than the values for secondary poisoning as the tolerable daily intake (TDI) or acceptable daily intake (ADI) for humans are used instead of PNEC values, potentially making this value lower and thus more conservative than the $PNEC_{pred}$, $PNEC_{oral}$ and $EQS_{biota,\ sec.pois.}$values. $PNEC_{pred}$, $PNEC_{oral}$ and $(E)QS_{biota,\ secpois}$ values also have different protection goals than the $(E)QS_{biota,\ hh}$. The $(E)QS_{biota,\ hh}$ values are set to protect humans from adverse effects resulting from the consumption of chemical-contaminated food (fish, molluscs, crustaceans, etc), whereas the protection goal of $QS_{biota,\ secpois}$ is to protect top predators, such as birds and mammals, from risks of secondary poisoning brought about by consuming toxic chemicals in their prey. Therefore, $PNEC_{pred,}$ $PNEC_{oral}$ and $(E)QS_{biota,\ secpois}$ values were used as far as possible to avoid overestimation of the risk and $(E)QS_{biota,\ hh}$ values were only used for substances or substance groups where no other values were found. In cases where several PNECs for secondary poisoning were found, the lowest one was used. Only the compounds listed in Table 13 (see Chapter 3.7) could be included in the cumulative risk assessment for secondary poisoning. The $MEC/PNEC_{pred}$ ratios were summed and a potential risk was identified by a sum ≥ 1.

The potential risk of effects on gulls brought about by the level of measured contaminants in gull eggs were assessed. Available effect data for exposure in eggs compiled and assessed by Andersen et al. (2014) were used in the assessment. The median value of 15 egg concentrations was used as MEC. The sum of MEC/effect data for all possible compounds was calculated and a sum ≥1 was indicative of a potential risk to the birds.

As $PNEC_{pred}$ values and effect data were only available for a few of the tested compounds, the mixture risk assessment performed in this study is not considered complete but is thought to give an indication of which food source pose the highest risk for predators and potential risk drivers.

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 are given in Appendix (Tables A2-A5).

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.

Stable isotopes of sulphur may also be applied to increase the knowledge of how and to what extent different food items contribute to the bioaccumulation of a compound. It has previously been shown that $\delta^{34}S$ may be used to indicate if a bird forages in the marine environment or in the terrestrial environment, since $\delta^{34}S$ in marine sulphate is generally higher than $\delta^{34}S$ in terrestrial systems (Lott et al. 2003). Furthermore, it is suggested that birds foraging in/near urbanized centres display lower $\delta^{34}S$ ratios (Eulaers et al. 2014).

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, as organisms

(here cod and herring gull) grow, they may feed on larger prey organisms, thus an increase in trophic level is likely to occur, which is then quantified. For compounds with bioaccumulative potential, a consequence may be higher tissue concentrations. Thirdly, 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; The Norwegian Environment Agency M-205, M-375 and M-601) 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; Ruus et al. 2016; The Norwegian Environment Agency M-601).

Since the individual herring gulls (or eggs) display a range of $\delta^{15}N$ values, implicating different feeding behaviour placing individuals in different trophic positions, the bioaccumulative properties of contaminants are also evaluated by analysing relationships between trophic level and contaminant concentrations in herring gull (in isolation; see Chapter 3.2.4). Similar analyses are performed for cod (of which 15 individuals are analysed; see Chapter 3.2.3).

As previously mentioned, after the first programme period (2013 and 2014) of the "Urban fjord" monitoring programme, changes have been made to the programme, to sample a more representative food web, and the sampling programme in 2016 was identical to that in 2015. The results of the stable isotope analysis (Figure 2) suggest that the species sampled in 2015 and 2016 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 (~2.9) trophic levels with blue mussel defined at trophic level 2 (see Chapter 2.2.8), polychaetes and zooplankton (krill) at trophic level 3.0 and 3.1, respectively, prawns and herring at trophic level 3.6 and 3.5, respectively, and cod at trophic level 4.6 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 (Ruus et al. 2016; The Norwegian Environment Agency M-601), although with one blue mussel sample with higher $\delta^{13}C$ ratio (for unknown reasons).

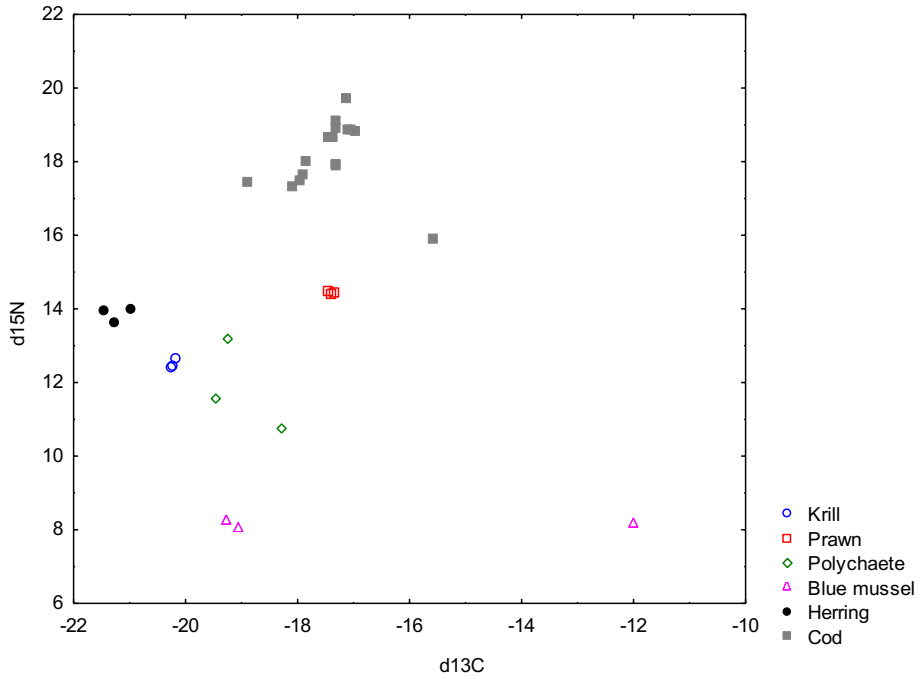


Figure 2. $\delta^{13}C$ plotted against $\delta^{15}N$ in organisms from the inner Oslofjord marine food web.

The isotopic signatures of the herring gulls showed the same patterns as in 2015 (Ruus et al. 2016; The Norwegian Environment Agency M-601). When herring gull matrices (blood and eggs) are evaluated (Figure 3), it can be seen that the matrices show similar $\delta^{15}N$. Herring gull would therefore be placed on approximately the same average trophic level regardless of matrix. The $\delta^{13}C$ ratio is, however, higher in blood than in eggs possibly 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 A2-A3) and a C:N ratio of >3.5 implies the presence of lipids, which may somewhat confound $\delta^{13}C$ 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 A2-A5). Keilen (2017) suggested that some herring gull individuals may have a higher proportion of food items of marine origin in their diet, based on the $\delta^{13}C$ (enveloped in stapled lines in Figure 3). Some differences in contaminant concentrations were found between these individuals and those with lower $\delta^{13}C$ (See Keilen, 2017, for details).

There was a good correlation between $\delta^{34}S$ and $\delta^{13}C$ in the bird matrices (R^2=0.30; p=0.0363 for egg; R^2=0.74; p=0.00004 for blood), which could suggest that a higher importance of terrestrial carbon (lower $\delta^{13}C$) is equivalent with a stronger urban signal (lower $\delta^{34}S$). $\delta^{15}N$ also correlated well with both $\delta^{13}C$ (R^2=0.86; p=0.00000 for egg; R^2=0.82; p=0.00000 for blood) and $\delta^{34}S$ (R^2=0.30; p=0.0351 for egg; R^2=0.80; p=0.00001 for blood).

Obviously, the co-linearity between variables (such as $\delta^{13}C$, $\delta^{15}N$ and $\delta^{34}S$ in herring gull) makes it difficult to conclude on likely causality with regard to correlations with contaminant concentrations. For instance, it is difficult to relate concentrations to foraging on more marine/less urban food items (suggested by $\delta^{34}S$ signature; Lott et al. 2003; Eulaers et al. 2014), when evidence also indicate foraging on higher trophic level, as known to be reflected in higher $\delta^{15}N$ (Layman et al. 2012; Post 2002).

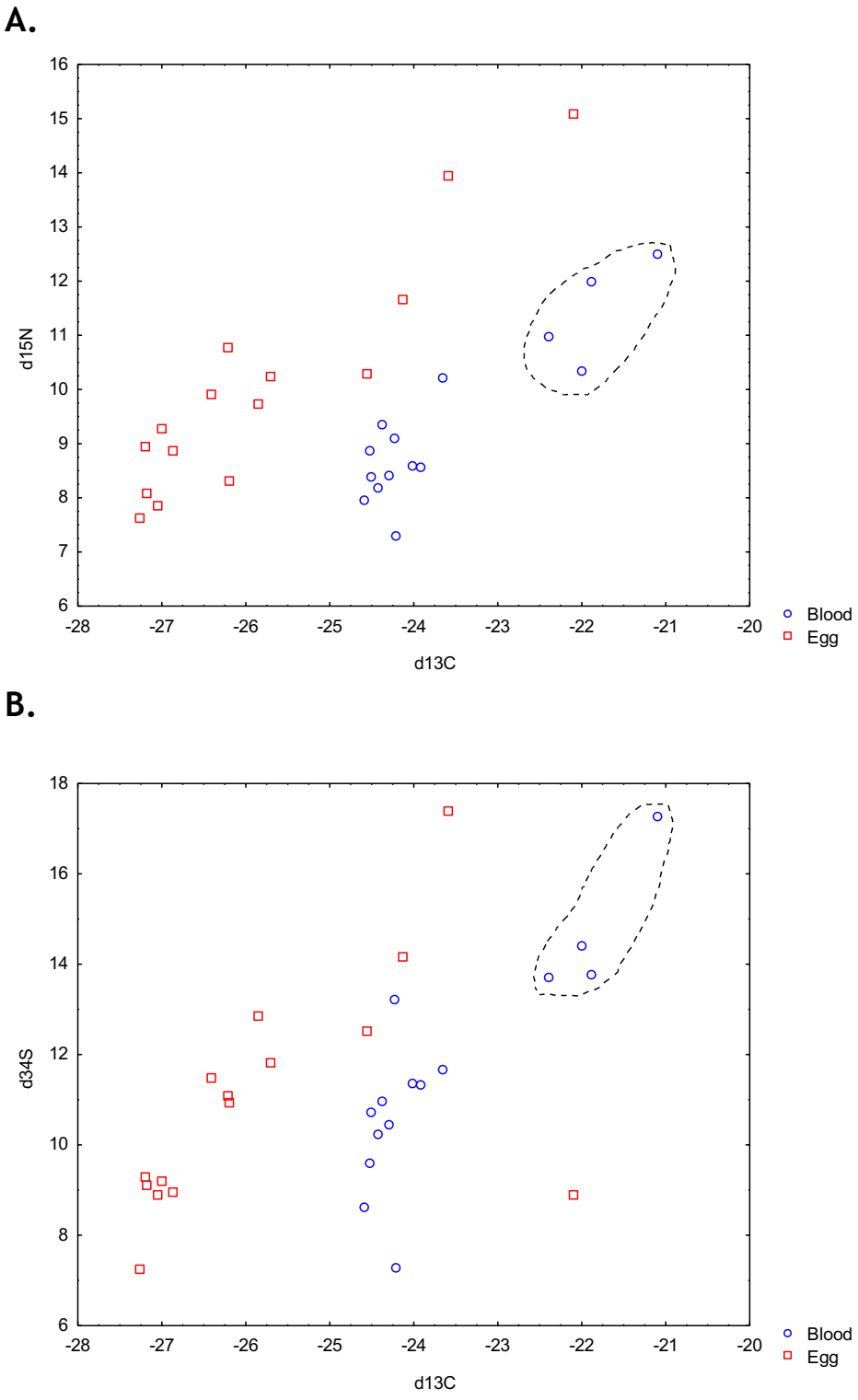
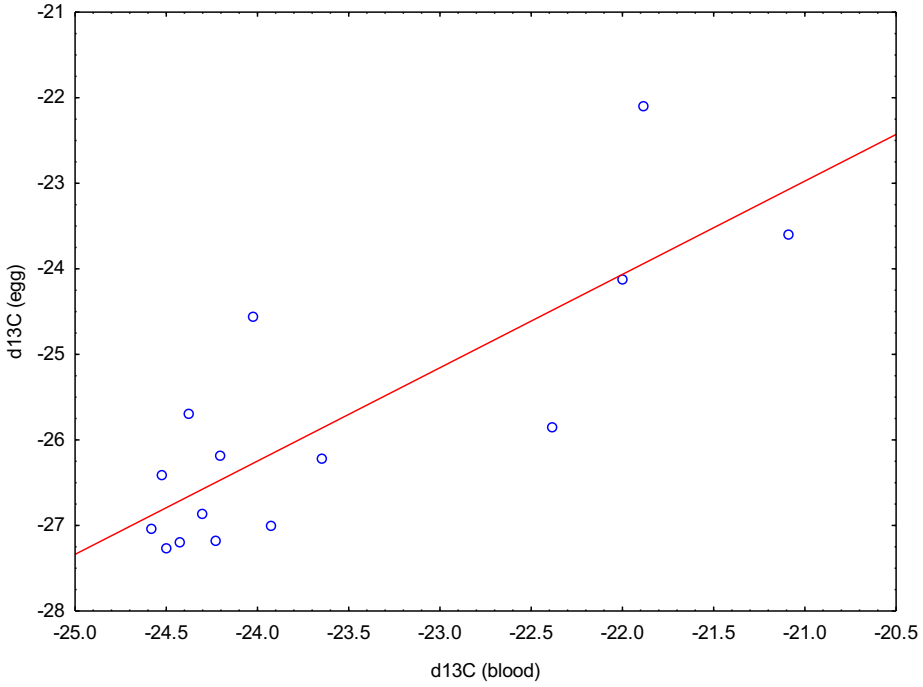


Figure 3. $\delta^{13}C$ plotted against $\delta^{15}N$ (A.) and $\delta^{34}S$ (B.) in Herring gull blood and eggs from the Inner Oslofjord area. Gull individuals enveloped in stapled line are suggested by Keilen (2017) to have a higher proportion of food items of marine origin in their diet.

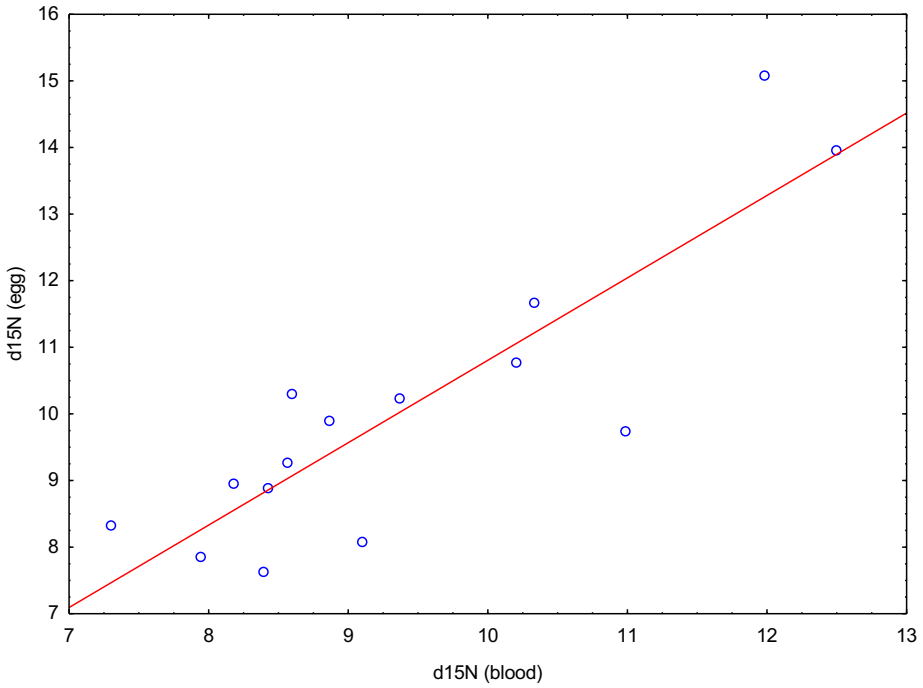
Regarding herring gulls, adult female and egg was sampled from the same nest (i.e. mother and future offspring). This is reflected in the isotopic signatures, as significant relationships

were found between egg and blood ($\delta^{13}C$: R^2=0.66; p=0.0002; $\delta^{15}N$: R^2=0.76; p=0.00002; $\delta^{34}S$: R^2=0.36; p=0.0181; Figure 4).

A.



B.



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C.

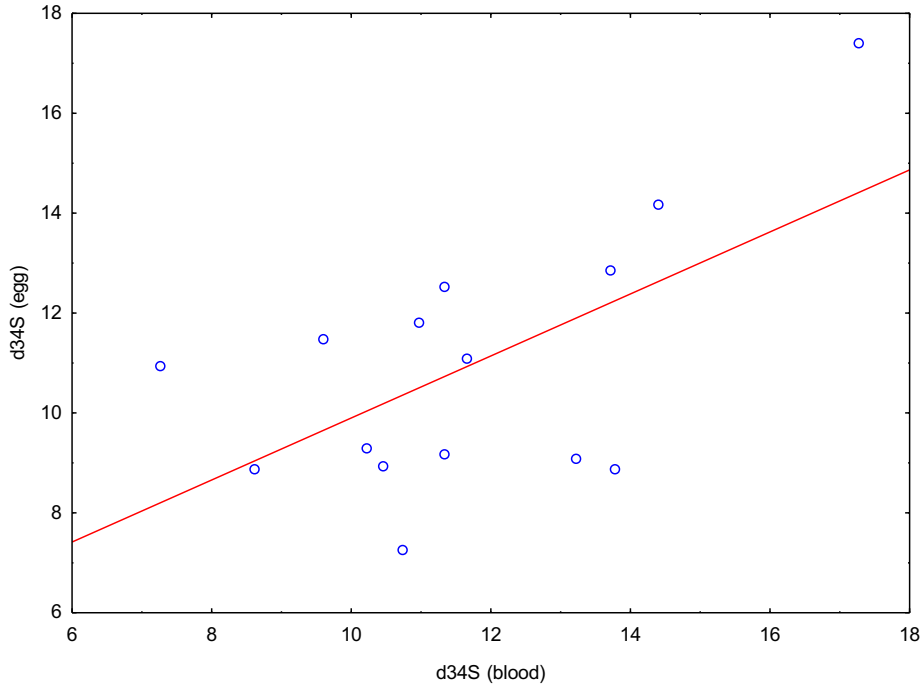


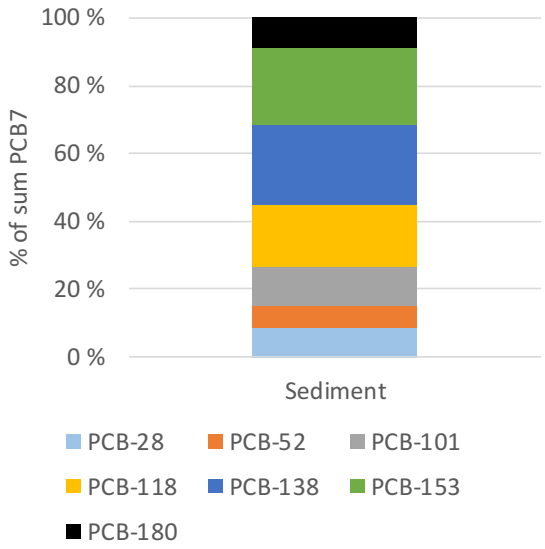
Figure 4. Isotopic ratios of carbon ($\delta^{13}C$, A.), nitrogen ($\delta^{15}N$, B.) and sulphur ($\delta^{34}S$, C.) in herring gull blood plotted against isotopic ratios inn eggs sampled at the same nest.

3.2 Environmental contaminants

3.2.1 Sediment

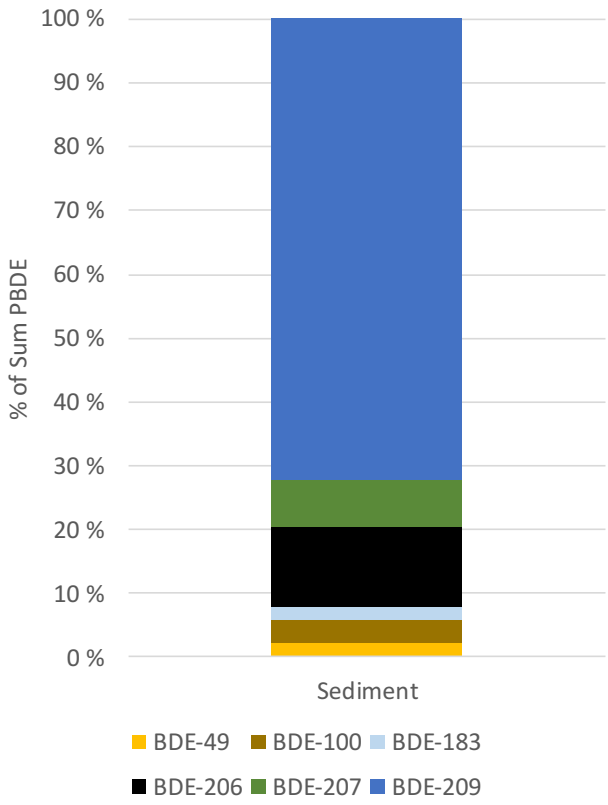
The sediments of the inner Oslofjord is a potential source of environmental contaminants to sediment dwelling organisms and the contaminants may thus enter the food chain. Several of the target compounds of this study were detected in the sediment sample. Inputs to the fjord via storm water (see Chapter 3.2.5) for several of the compounds is also shown.

The relative contribution (%) of PCB-congeners to the sum of PCB7 is presented in Figure 5. PCB-138 and -153 constituted the highest percentages. The relative contribution (%) of BDE-congeners to the sum of PBDE is presented in Figure 6. BDE-209 constituted the highest percentage. The relative contribution (%) of PFR compounds to the sum of PFR is presented in Figure 7. TPP constituted the highest percentage. Of the PFAS compounds, only PFOS and PFUdA were detected in sediments.



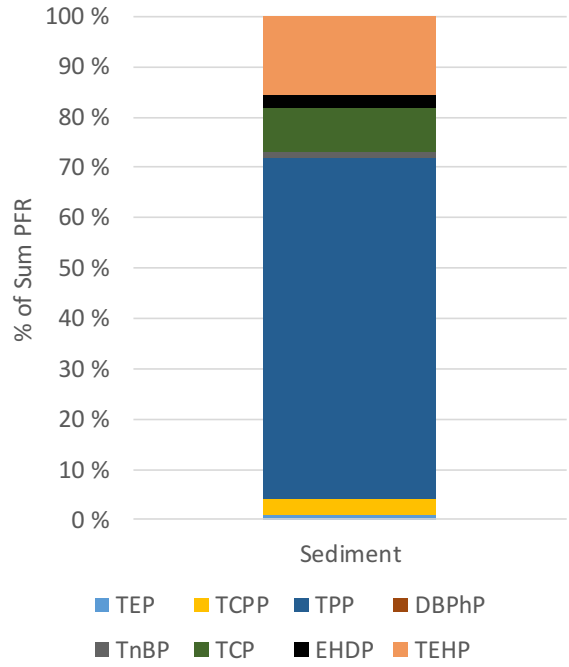
	PCB-28	PCB-52	PCB-101	PCB-118	PCB-138	PCB-153	PCB-180
ng/g (dry wt.)	1.080	0.820	1.473	2.269	2.954	2.861	1.123

Figure 5. 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.



	BDE-49	BDE-100	BDE-183	BDE-206	BDE-207	BDE-209
ng/g (dry wt.)	0.035	0.054	0.031	0.184	0.113	1.080

Figure 6. Relative contribution (%) of BDE-congeners to the sum of (detected) PBDE in sediment from the Inner Oslofjord (station Cm21). Concentrations (ng/g dry wt.) of detected components are given in the associated table.



	TEP	TCPP	TPP	DBPhP	TnBP	TCP	EHDP	TEHP
ng/g (dry wt.)	0.820	2.40	52.3	0.087	0.828	6.889	2.068	11.79

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

For several compounds, environmental quality standards 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 (The Norwegian Environment Agency M-608). For the target compounds of this study of which quality standards exist, the sediment concentrations and quality standards are compared in Table 8. D5, PCB7, Zn, As, Ni, Hg and PFOS exceeded the quality standards. Regarding inputs to the fjord (apart from the above mentioned storm water; Chapter 3.2.5), according to Skarbøvik et al. (2016; The Norwegian Environment Agency M-634), River Alna brought 32.5 g/yr PCB7, 12-14 g/yr ΣPBDE (excl. BDE-28), 1.1 kg/yr SCCPs, 0.61 kg/yr MCCPs, 442 g/yr bisphenol A, 0.7-2.7 g/yr TBBPA and 1.6 g/yr PFOS in 2015. Furthermore, the annual mean concentration of Pb, Zn and Cu in the river water was 2.4 µg/L 5.1 µg/L and 20.8 µg/L, respectively.

The last annual report from VEAS sewage treatment plant (STP) is from 2015 and they reported a discharge of 49 kg As, 82 kg Pb, 5.8 kg Cd, 785 kg Cu, 78 kg Cr, 0.37 kg Hg, 306 kg Ni and 2324 kg Zn that year (VEAS 2016). BEVAS STP at Bekkelaget reported a discharge of 18,12 kg As, 579 kg Cu, 1206 kg Zn, 0.94 kg Cd, 7.74 kg Cr, 139 kg Ni, 6.28 kg Pb, 0.097 kg Hg, 0.685 kg TBBPA, 0.268 kg PCB (sum) and 0.268 kg nonylphenol in 2016(BEVAS 2017). As such, there are currently several known fluxes of these contaminants to the Inner Oslofjord.

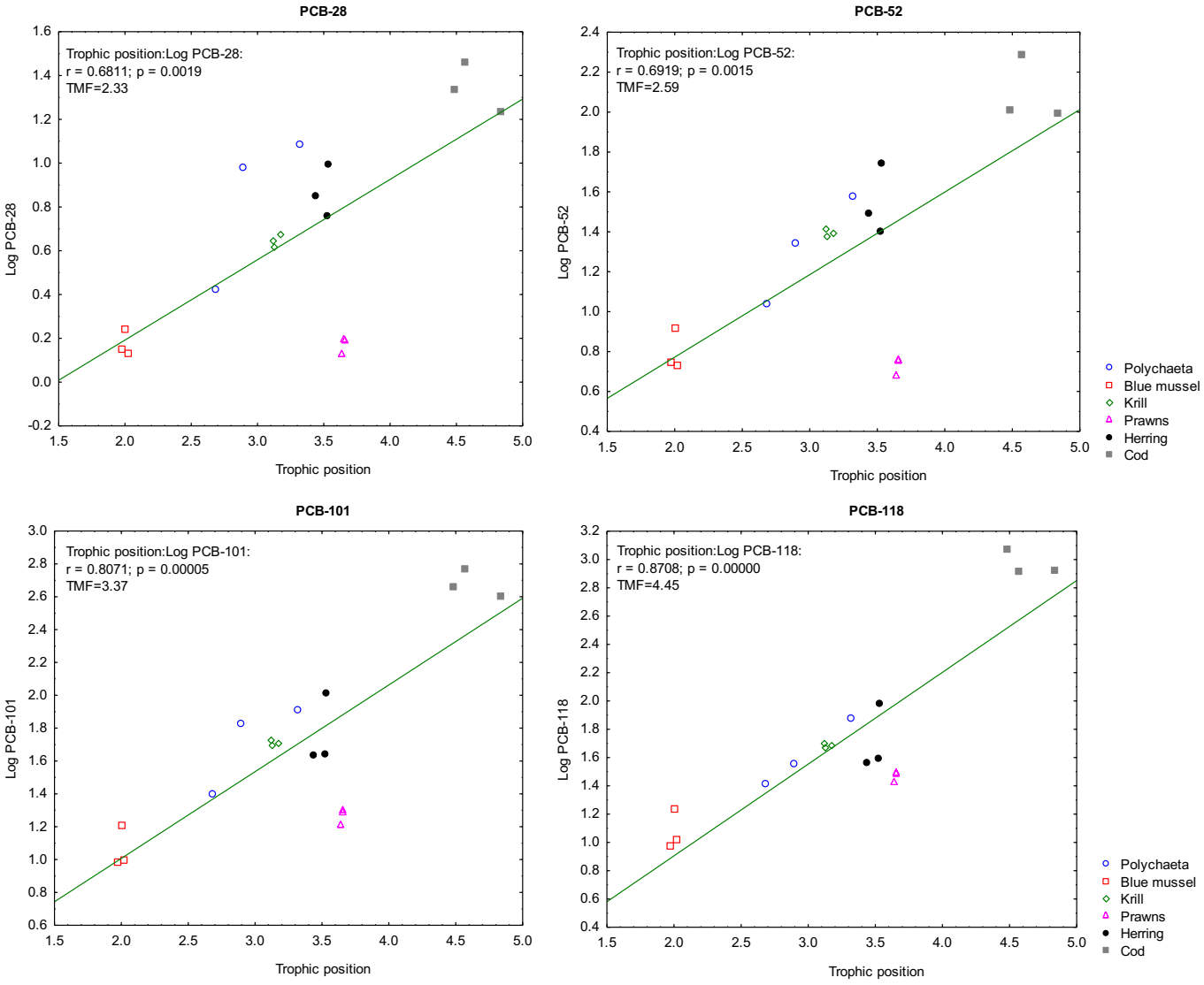
Table 8.
Concentrations of contaminants (mg/kg dry wt) of which Norwegian quality standards (from the Norwegian Environment Agency; M-608) exist in sediment from the inner Oslofjord. Red numbers indicate excess of the quality standard.

River basin specific compounds	EQS (mg/kg dry wt.)	Sediment conc. (mg/kg dry wt.)
Bisphenol A	0.0011	<0.015 ***
Decamethylcyclopentasiloxane (D5)	0.044	0.091
Medium chained chloroparafins (MCCPs)	4.6	0.002
Copper (Cu)	84	57.84
PCB7	0.0041	0.0126
PFOA	0.071	<0.0005
Zinc (Zn)	139	255
TBBPA	0.108	<0.0008
TCEP	0.0716	<0.0012
Triclosan	0.009	<0.003
Arsenic (As)	18	60.6
Chromium (Cr)	660	84.7
EU priority substances		
Cadmium (Cd)	2.5	0.15
Lead (Pb)	150	87.5
Nickel (Ni)	42	43.4
Mercury (Hg)	0.52	0.93
Brominated diphenyl ethers *	0.062	<0.0009
Hexachlorobenzene	0.017	0.0003
C10-13 chloroalkanes **	0.8	0.2
Pentachlorobenzene	0.4	0.0003
Nonylphenol (4-)	0.016	<0.00004
Oktylphenol (4-*tert*-)	0.0003	<0.170 ***
PFOS	0.00023	0.00048

* 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, 27 showed significant biomagnification, including the seven constituting PCB7 (Figure 8). These findings correspond well with the findings from last year of the "Urban fjord" programme (Ruus et al. 2016; The Norwegian Environment Agency M-601), 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").



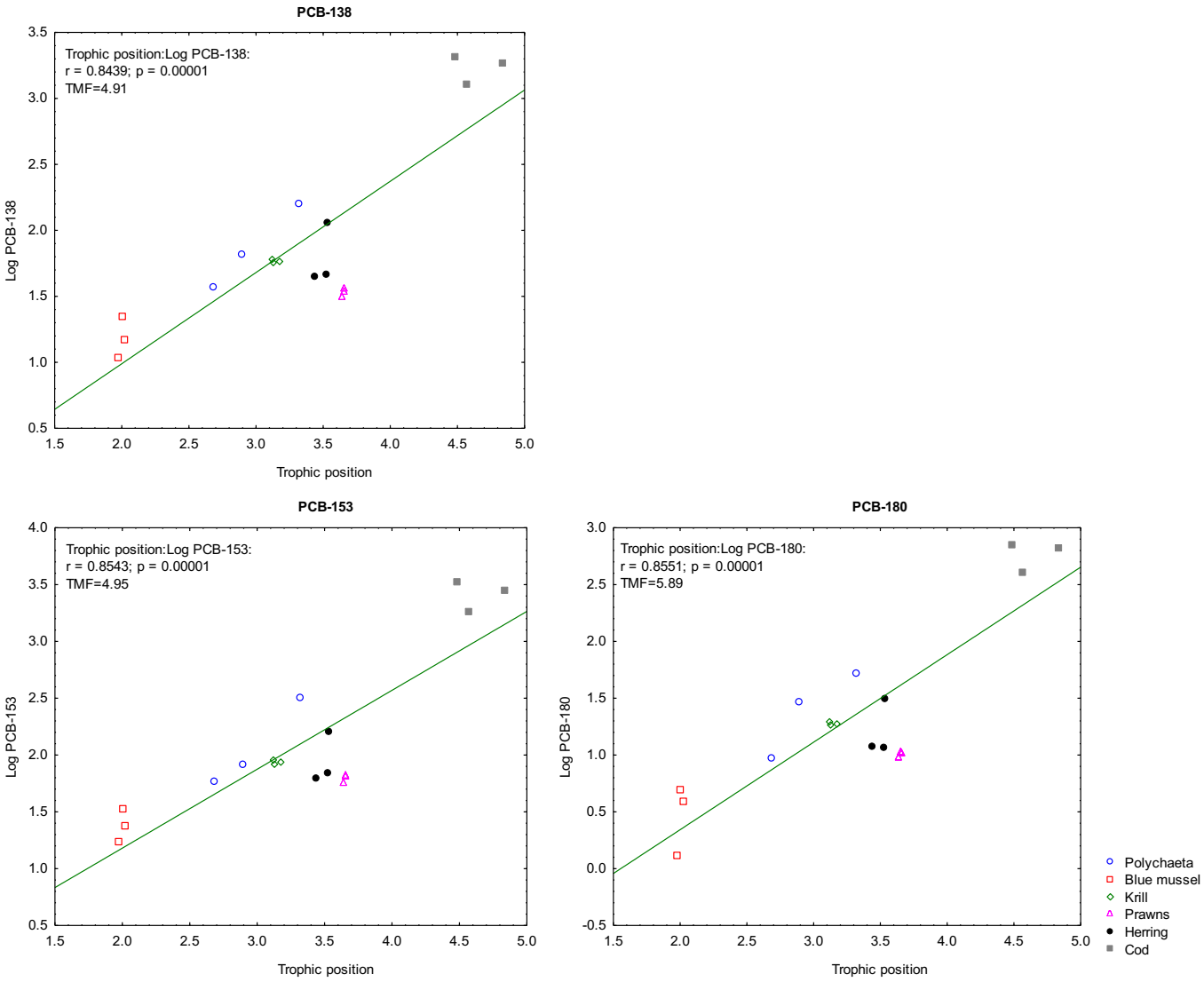
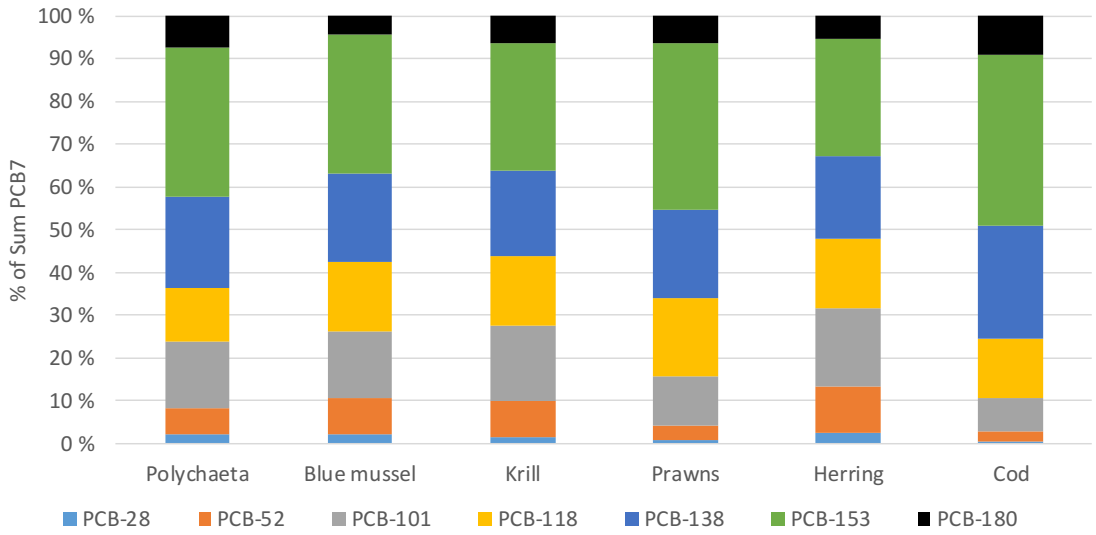


Figure 8. Trophic position against concentrations (ng/g lipid wt.; log-transformed) of PCB-28, PCB-52, PCB-101, PCB-118, PCB-138, PCB-153 and PCB-180 in the studied Inner Oslofjord food web. Note different scales on axes.

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 9).

Hexachlorobenzene (HCB) was another organochlorine compound that showed statistically significant biomagnification (TMF= 2.17) in the present study, as was observed in the "Urban fjord" programme in 2015 (Ruus et al. 2016; The Norwegian Environment Agency M-601), and in previous studies (e.g. Hallanger et al. 2011).



	PCB-28	PCB-52	PCB-101	PCB-118	PCB-138	PCB-153	PCB-180
Polychaeta	0.178	0.508	1.264	0.970	1.856	3.177	0.649
Blue mussel	0.033	0.141	0.264	0.274	0.353	0.551	0.075
Krill	0.142	0.799	1.657	1.553	1.897	2.820	0.612
Prawns	0.031	0.114	0.393	0.624	0.718	1.330	0.216
Herring	0.493	2.397	4.053	3.657	4.363	6.203	1.165
Cod	10.8	66.2	227.3	403.7	716.6	1080.1	240.0

Figure 9. 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.

Among the brominated compounds TBA showed statistically significant trophic dilution (TMF=0.41), as observed in 2015 (Ruus et al. 2016; The Norwegian Environment Agency M-601). The following polybrominated diphenyl ethers showed statistically significant biomagnification: BDE-17 (TMF=1.45), BDE-28 (TMF=3.26), BDE-47 (TMF=4.36; Figure 10), BDE-49 (TMF=5.12), BDE-100 (TMF=4.64; Figure 10) and BDE-154 (TMF=3.81; Figure 10). Biomagnification of BDE-28, -47, -49, -100 and -154 was also found in the 2015 “Urban fjord” programme (Ruus et al. 2016; The Norwegian Environment Agency M-601). Furthermore, biomagnification of PBDEs has previously been shown in marine systems (e.g. Hallanger et al. 2011).

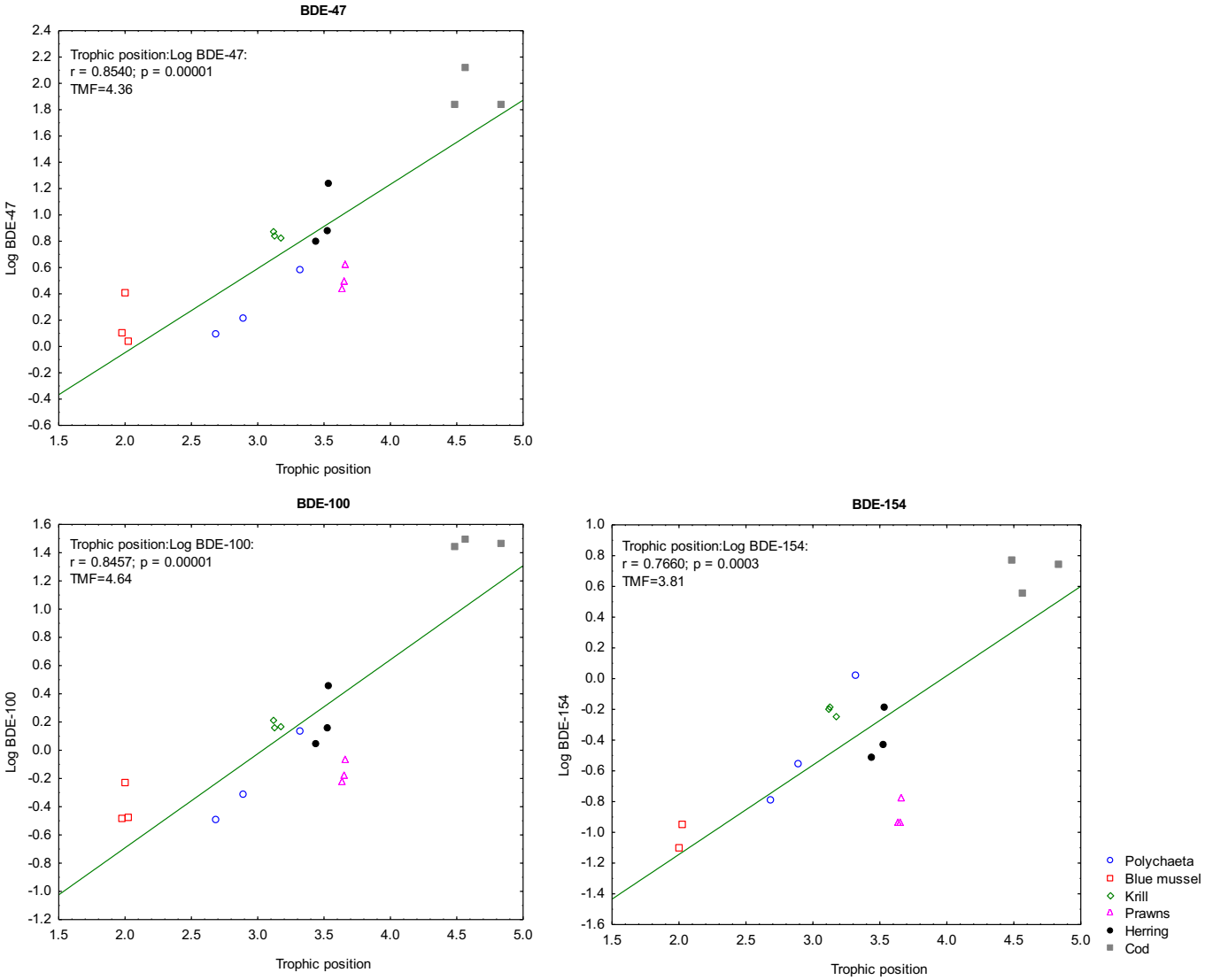
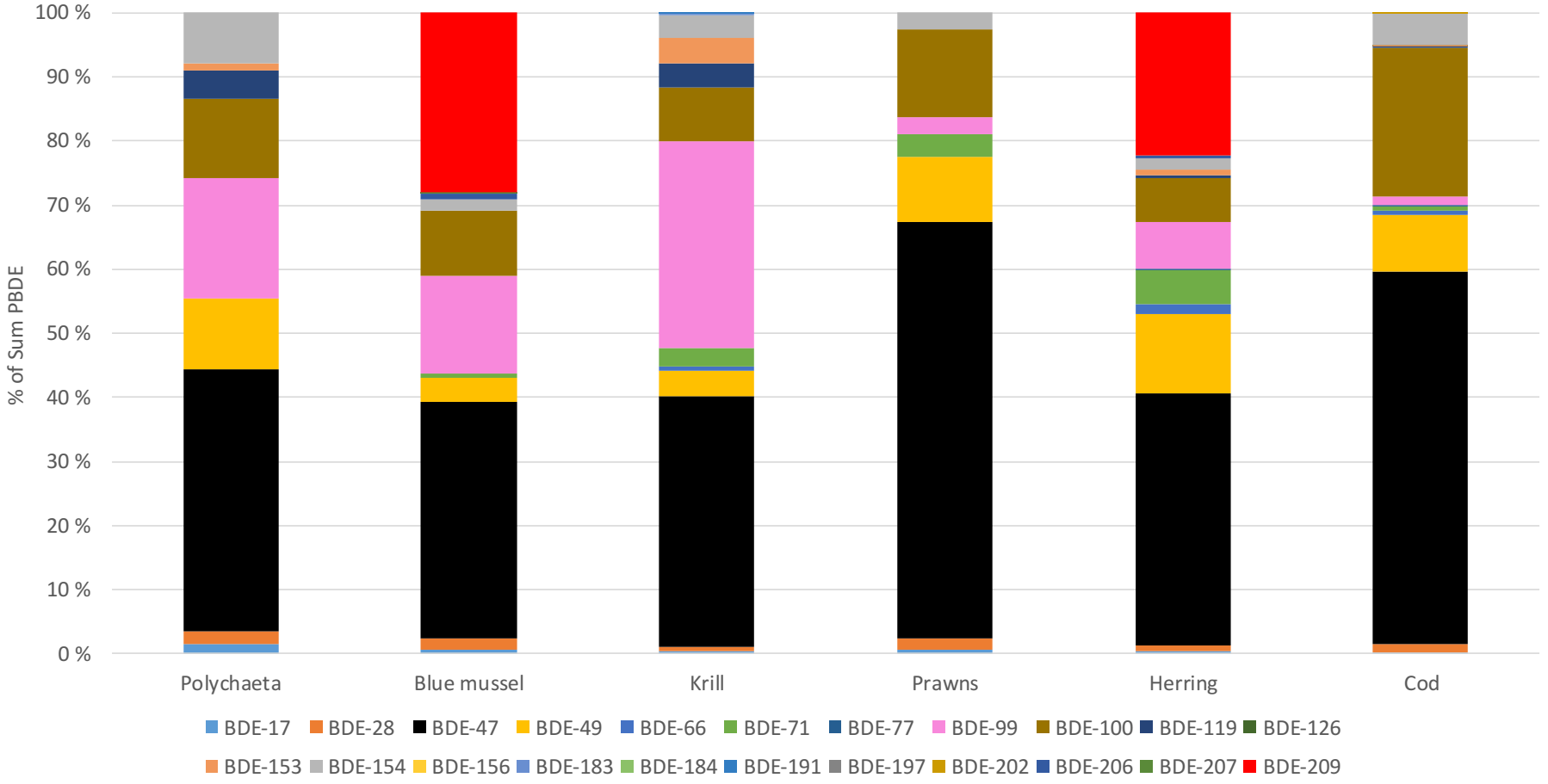


Figure 10. Trophic position against concentrations (ng/g lipid wt.; log-transformed) of BDE-47, -100 and -154 in the studied Inner Oslofjord food web. Note different scales on axes.

The relative contribution (%) of BDE-congeners to the sum of PBDEs appeared somewhat different among the species of the Inner Oslofjord food web (Figure 11). BDE-47 constituted the highest percentage in all species (Figure 11). BDE-209 was only detected in blue mussel and herring, where it appeared to be a major constituent (>20%; Figure 11), as in the sediments. BDE-99 was detected in all species and constituted ~15 to ~30% in the lower end of the food web (Polychaeta, blue mussel and krill; Figure 11).

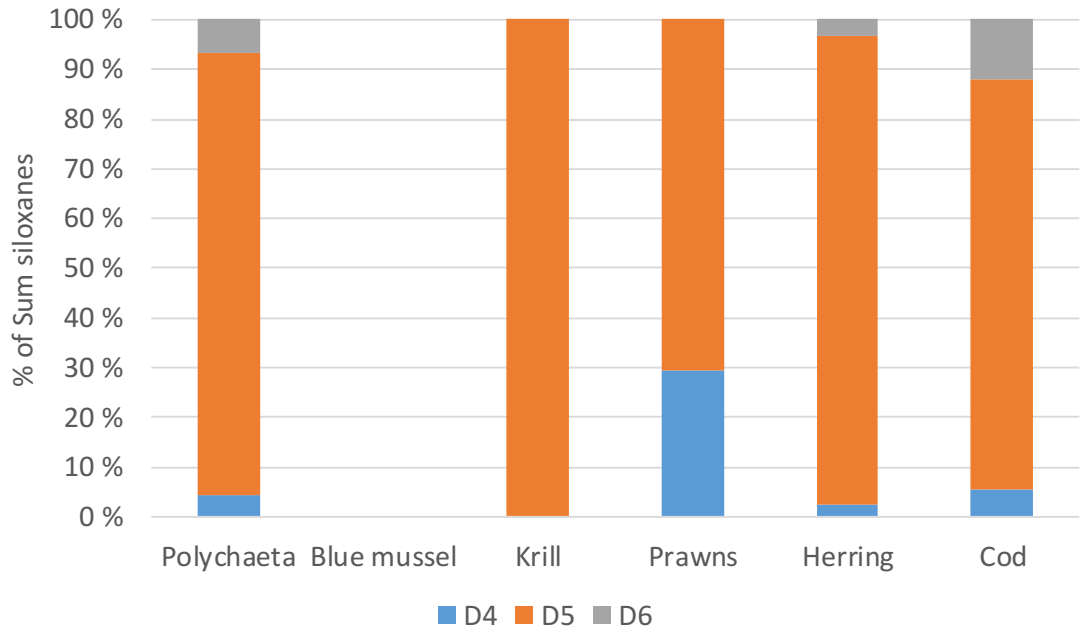

100 %
90 %
80 %
70 %
60 %
50 %
40 %
30 %
20 %
10 %
0 %
% of Sum PBDE
Polychaeta
Blue mussel
Krill
Prawns
Herring
Cod
BDE-17
BDE-28
BDE-47
BDE-49
BDE-66
BDE-71
BDE-77
BDE-99
BDE-100
BDE-119
BDE-126
BDE-153
BDE-154
BDE-156
BDE-183
BDE-184
BDE-191
BDE-197
BDE-202
BDE-206
BDE-207
BDE-209

	Polychaeta	Blue mussel	Krill	Prawns	Herring	Cod
BDE-17	0.0012	0.0003	0.0017	0.0006	0.0052	0.0765
BDE-28	0.0021	0.0015	0.0048	0.0019	0.0175	0.9696
BDE-47	0.0472	0.0365	0.2257	0.0707	0.6617	45.4047
BDE-49	0.0129	0.0019	0.0242	0.0111	0.2097	8.1387
BDE-66	n.d.	n.d.	0.0031	n.d.	0.0231	0.4187
BDE-71	n.d.	0.0040	0.0169	0.0037	0.1157	0.1518
BDE-77	n.d.	n.d.	n.d.	n.d.	0.0018	0.0258
BDE-99	0.0201	0.0110	0.1863	0.0029	0.1217	0.8622
BDE-100	0.0151	0.0092	0.0491	0.0149	0.1161	13.3100
BDE-119	0.0052	n.d.	0.0211	n.d.	0.0067	0.1664
BDE-126	n.d.	n.d.	n.d.	n.d.	n.d.	0.0159
BDE-153	0.0022	n.d.	0.0235	n.d.	0.0133	0.1235
BDE-154	0.0103	0.0014	0.0200	0.0028	0.0285	2.0495
BDE-156	n.d.	n.d.	n.d.	n.d.	n.d.	0.0023
BDE-183	n.d.	n.d.	0.0014	n.d.	n.d.	0.0078
BDE-184	n.d.	n.d.	n.d.	n.d.	n.d.	0.0127
BDE-191	n.d.	n.d.	0.0009	n.d.	n.d.	n.d.
BDE-197	n.d.	n.d.	n.d.	n.d.	n.d.	0.0031
BDE-202	n.d.	n.d.	n.d.	n.d.	n.d.	0.0763
BDE-206	n.d.	0.0068	n.d.	n.d.	0.0068	n.d.
BDE-207	n.d.	0.0025	n.d.	n.d.	n.d.	n.d.
BDE-209	n.d.	0.2227	n.d.	n.d.	0.3440	n.d.

Figure 11. Relative contribution (%) of BDE-congeners to the sum of (detected) PBDEs in the species of the Inner Oslofjord food web (previous page). 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.

The concentrations of siloxanes (D4, D5 and D6) displayed no significant relationship with trophic position. This was also the case for the PFRs (of which there were many non-detects for several compounds). 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 form the period 2010-2015, Fjeld et al. 2016; The Norwegian Environment Agency M-548) demonstrated biomagnification of D5 in the lakes Mjøsa and Randsfjorden with a common TMF of 2.28, and biomagnification of D6 with a common TMF of 2.29. The siloxane compound that appeared in the highest concentrations was D5 (Fjeld et al. 2016; The Norwegian Environment Agency M-548).

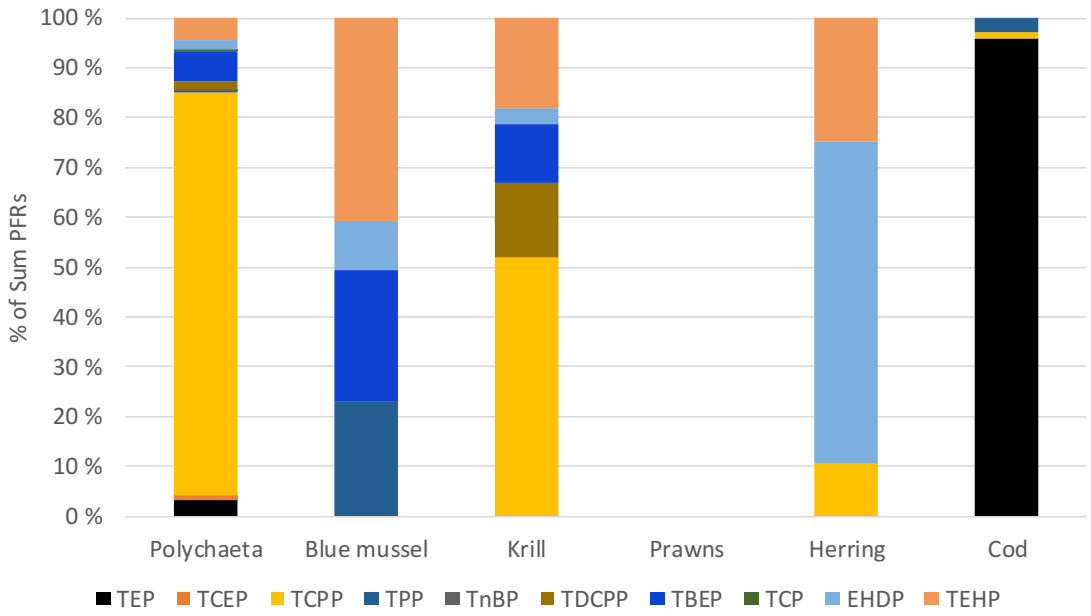
Of the siloxanes analysed in the present study, D5 also appeared in the highest concentrations in all species of the food web (Figure 12; siloxanes not detected in blue mussel). In cod, the mean concentration of D5 was apparently twice as high as observed in 2015 (Ruus et al. 2016; The Norwegian Environment Agency M-601). However, there was large variability in the concentrations in 2016 and the apparent difference was not statistically significant ($p = 0.77$; Mann-Whitney U).



	D4	D5	D6
Polychaeta	6.07	118.09	8.30
Blue mussel	n.d.	n.d.	n.d.
Krill	n.d.	268.26	n.d.
Prawns	5.48	13.09	n.d.
Herring	3.67	150.63	4.98
Cod	62.85	2065.07	135.94

Figure 12. 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.

Of the PFRs, TCCP constituted the highest percentage (of sum PFRs) in polychaetes and krill (Figure 13). TEP constituted the highest percentage in cod and EHDP constituted the highest percentage in herring (Figure 13). No PFCs were detected in Prawns.



	Polychaeta	Blue mussel	Krill	Prawns	Herring	Cod
TEP	0.06	n.d.	n.d.	n.d.	n.d.	20.37
TCEP	0.20	n.d.	n.d.	n.d.	n.d.	n.d.
TCPP	6.69	n.d.	0.46	n.d.	0.23	0.51
TPP	0.08	0.20	n.d.	n.d.	n.d.	0.36
TnBP	0.07	n.d.	n.d.	n.d.	n.d.	n.d.
TDCPP	0.33	n.d.	0.15	n.d.	n.d.	n.d.
TBEP	0.48	0.66	0.14	n.d.	n.d.	n.d.
TCP	0.06	n.d.	n.d.	n.d.	n.d.	n.d.
EHDP	0.13	0.08	0.04	n.d.	0.76	n.d.
TEHP	0.36	0.35	0.16	n.d.	0.36	n.d.

Figure 13. Relative contribution (%) of PFR compounds-to the sum of (detected) PFRs 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.

Mercury displayed statistically significant biomagnification (TMF=2.80; Figure 14), as observed in the 2015 “Urban fjord” programme. The biomagnifying properties of mercury (Hg) are well known (e.g. Jaeger et al. 2009; Ruus et al. 2015). Furthermore, also the elements As (TMF=2.42; Figure 15) and Ag (TMF=8.41; Figure 16) again displayed statistically significant positive relationships between (log) concentrations and trophic position (as in 2015). It should be mentioned that in this study (as in 2015), 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. Both As and Ag were detected in Sediments from the Inner Oslofjord, as well as in storm water entering the fjord (see electronic Appendix). 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 ($AgNO_3$).

Regarding PFAS compounds, there were many non-detects for most compounds. PFOS and PFOSA, however, were detected in all samples, and both displayed a significant positive relationship between (log) concentrations and trophic position (TMFs=4.38 and 2.07, respectively; Figure 17). Biomagnification of PFAS and PFOSA 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.

PFOSA constituted the highest percentage (of sum PFAS) in blue mussel, krill, herring and cod (Figure 18). PFOS was also an important constituent in Herring and cod (constituting ~40% of Sum PFAS; Figure 18).

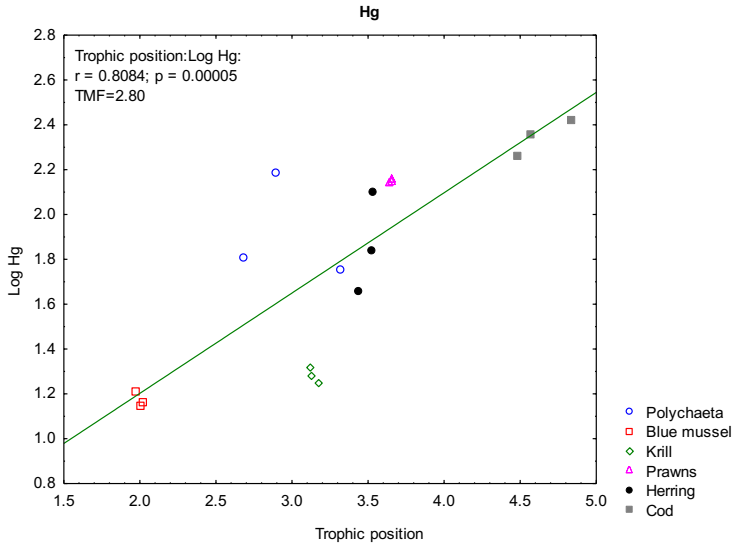


Figure 14. Trophic position against concentrations (ng/g wet wt.; log-transformed) of mercury (Hg) in the studied Inner Oslofjord food web.

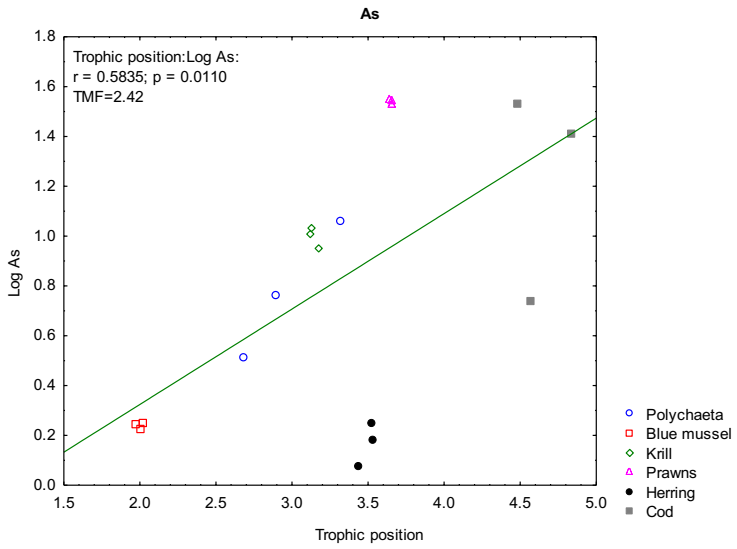


Figure 15. Trophic position against concentrations (µg/g wet wt.; log-transformed) of arsenic (As) in the studied Inner Oslofjord food web.

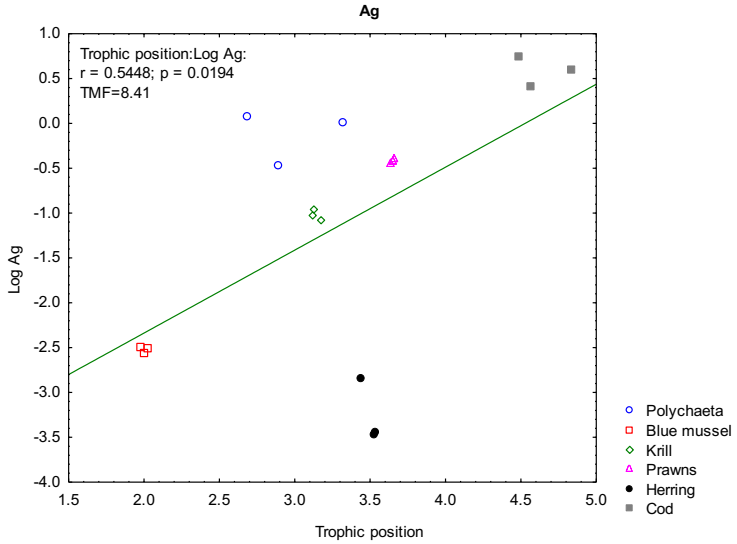


Figure 16. Trophic position against concentrations (µg/g wet wt.; log-transformed) of silver (Ag) in the studied Inner Oslofjord food web.

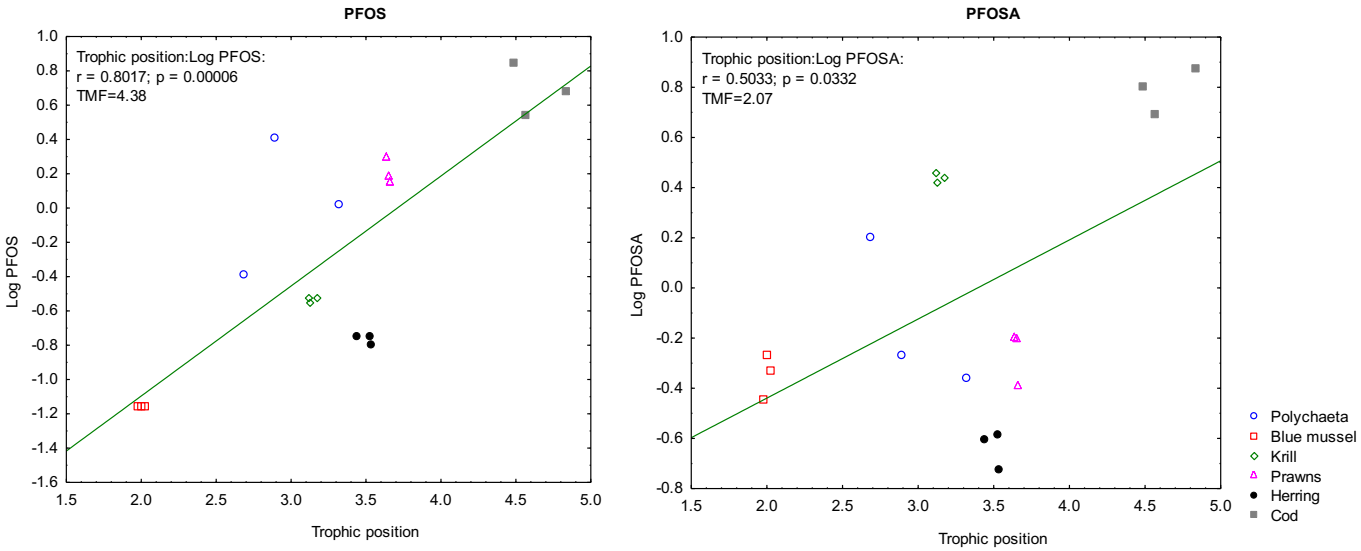
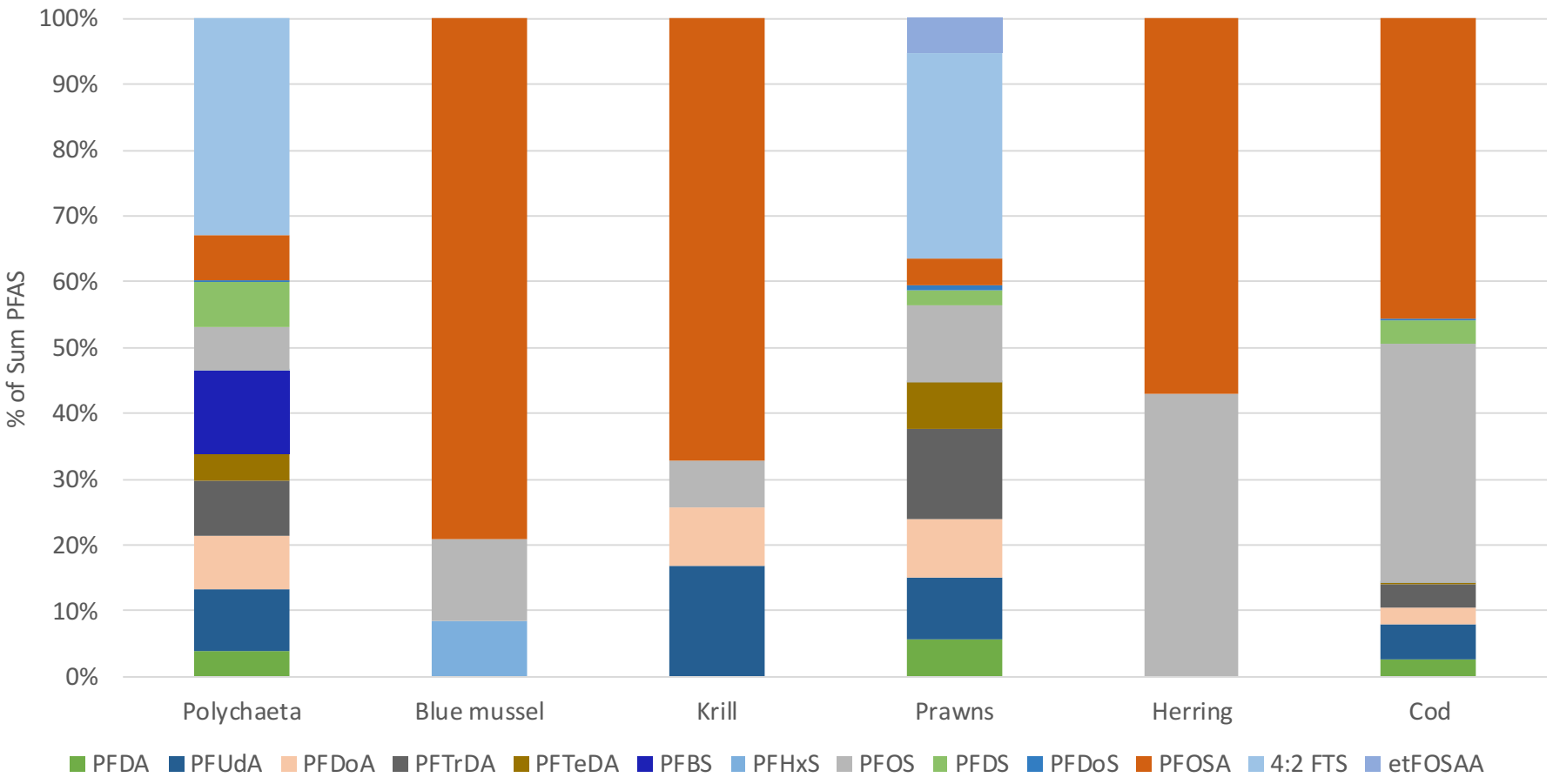


Figure 17. Trophic position against concentrations (ng/g wet wt.; log-transformed) of PFOS and PFOSA in the studied Inner Oslofjord food web. Note different scales on axes.


100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
% of Sum PFAS
Polychaeta
Blue mussel
Krill
Prawns
Herring
Cod
PFDA
PFUdA
PFDoA
PFTrDA
PFTeDA
PFBS
PFHxS
PFOS
PFDS
PFDoS
PFOSA
4:2 FTS
etFOSAA

	Polychaeta	Blue mussel	Krill	Prawns	Herring	Cod
PFDA	0.69	n.d.	n.d.	0.82	n.d.	0.43
PFUdA	1.56	n.d.	0.69	1.35	n.d.	1.08
PFDoA	1.28	n.d.	0.36	1.28	n.d.	0.49
PFTrDA	1.28	n.d.	n.d.	2.00	n.d.	0.72
PFTeDA	0.64	n.d.	n.d.	1.05	n.d.	0.08
PFBS	1.16	n.d.	n.d.	n.d.	n.d.	n.d.
PFHxS	0.04	0.05	n.d.	0.03	n.d.	0.01
PFOS	1.35	0.07	0.29	1.66	0.17	5.12
PFDS	1.12	n.d.	n.d.	0.36	n.d.	0.49
PFDoS	0.07	n.d.	n.d.	0.11	n.d.	0.05
PFOSA	0.86	0.46	2.76	0.56	0.23	6.25
4:2 FTS	76.18	n.d.	n.d.	4.49	n.d.	n.d.
etFOSAA	n.d.	n.d.	n.d.	0.78	n.d.	n.d.

Figure 18. Relative contribution (%) of PFAS compounds-to the sum of (detected) PFASs in the species of the Inner Oslofjord food web (previous page). 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.

Triclosan, triclocarban and UV chemicals were not detected in any biota samples of the Inner Oslofjord marine food web (except for EHMC that was detected in one cod sample; see electronic Appendix).

No phenolic compounds were detected in more than three samples of the Inner Oslofjord food web. The limit of detection was high for some of the compounds, due to blank issues.

3.2.3 Cod

As mentioned, environmental contaminants were analysed in 15 cod individuals (although 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 are presented Table 9, as well as in Appendix.

Table 9.
Lipid content (%) and concentrations of the different analytes 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 (minimum and maximum) are presented (n=15). In calculations of mean, non-detected components were assigned a value of zero (0).

Analyte	Mean	Min.	Max.	Detected in no. of samples
Lipid content (%), liver	44.4	6.44	78.7	15
PeCB	0.7	0.1	1.8	15
HCB	8.6	1.0	21.5	15
PCBs (PCB7)	**Mean**	**Min.**	**Max.**	**Detected in no. of samples**
PCB-28	10.8	0.9	32.6	15
PCB-52	66.2	4.1	247.0	15
PCB-101	227.2	38.2	956.0	15
PCB-118	403.7	143.0	1270.0	15
PCB-138	716.6	203.0	1880.0	15
PCB-153	1080.1	272.0	2810.0	15
PCB-180	240.0	48.9	607.0	15
Sum-PCB_7	2744.7	891.3	7802.6	15
TBA, PBDEs and DBDPE	**Mean**	**Min.**	**Max.**	**Detected in no. of samples**
TBA	0.037	<0.01	0.124	14
BDE-17	0.076	<0.003	0.322	12
BDE-28	0.970	0.051	5.500	15
BDE-47	45.405	2.520	270.000	15
BDE-49	8.139	0.132	47.100	15
BDE-66	0.419	<0.026	1.070	13
BDE-71	0.152	<0.003	1.330	2
BDE-77	0.026	<0.002	0.084	8
BDE-85	n.d.	<0.005	<0.061	0
BDE-99	0.862	<0.016	2.740	13
BDE-100	13.310	2.270	65.600	15
BDE-119	0.166	<0.004	0.700	14
BDE-126	0.016	<0.003	0.075	5
BDE-138	n.d.	<0.011	<0.011	0
BDE-153	0.124	<0.009	0.317	13

BDE-154	2.049	0.496	5.380	15
BDE-156	0.002	<0.017	0.035	1
BDE-183	0.008	<0.007	0.019	8
BDE-184	0.013	<0.005	0.042	9
BDE-191	n.d.	<0.011	<0.011	0
BDE-196	n.d.	<0.019	<0.019	0
BDE-197	0.003	<0.015	0.047	1
BDE-202	0.076	<0.019	0.254	14
BDE-206	n.d.	<0.043	<0.043	0
BDE-207	n.d.	<0.026	<0.026	0
BDE-209	n.d.	<0.574	<0.574	0
DBDPE	20.047	1.770	34.383	15
Chloroparaffins	**Mean**	**Min.**	**Max.**	**Detected in no. of samples**
SCCP	56.0	<1.1	242.0	13
MCCP	1.6	<0.2	5.6	14
Siloxanes	**Mean**	**Min.**	**Max.**	**Detected in no. of samples**
D4	62.8	10.3	155.6	15
D5	2065.1	106.0	6391.9	15
D6	135.9	18.6	468.3	15
Phosphorus flame retardants (PFRs)	**Mean**	**Min.**	**Max.**	**Detected in no. of samples**
TEP	20.371	0.900	65.539	15
TCEP	n.d.	<0.2	<0.2	0
TPrP	n.d.	<0.02	<0.02	0
TCPP	0.510	<0.5	1.560	7
TiBP	n.d.	<1.2	<1.2	0
BdPhP	n.d.	<0.01	<0.01	0
TPP	0.359	<0.2	1.698	5
DBPhP	n.d.	<0.01	<0.01	0
TnBP	n.d.	<0.2	<0.2	0
TDCPP	n.d.	<1	<1	0
TBEP	n.d.	<0.9	<0.9	0
TCP	n.d.	<0.01	<0.01	0

EHDP	n.d.	<0.3	<0.3	0
TEHP	n.d.	<0.1	<0.1	0
Phenolic compounds	**Mean**	**Min.**	**Max.**	**Detected in no. of samples**
Bisphenol A	18.5	<338	240	1
Tetrabromobisphenol A	n.d.	<19	<19	0
4,4-bisphenol F	-	-	-	-
2,2-bisphenol F	n.d.	<6	<6	0
Hexafluorobisphenol A	n.d.	<4	<4	0
Bisphenol BP	n.d.	<22	<22	0
Bisphenol S	n.d.	<11	<11	0
4-nonylphenol	-	-	-	-
4-octylphenol	-	-	-	-
4-tert-octylphenol	-	-	-	-
Bisphenol B	n.d.	<42	<42	0
Bisphenol Z	n.d.	<72	<72	0
Bisphenol AP	n.d.	<12	<12	0
Bisphenol E	n.d.	<267	<267	0
Bisphenol FL	n.d.	<13	<13	0
Bisphenol P	n.d.	<23	<23	0
Bisphenol M	n.d.	<11	<11	0
Bisphenol G	n.d.	<25	<25	0
Bisphenol TMC	n.d.	<55	<55	0
Bisphenol 2,4' -S	n.d.	<19	<19	0
2,4-Bisphenol F	28.2	<142	423	1
Bisphenol 2,4'- A	n.d.	<29	<29	0
Metals	**Mean**	**Min.**	**Max.**	**Detected in no. of samples**
Ni	0.085	0.028	0.202	15
Cu	6.608	2.638	12.155	15
Ag	4.067	0.414	13.533	15
Cd	0.102	0.008	0.321	15
Hg	225.032	116.150	367.432	15
Pb	0.065	0.003	0.257	15

Cr	0.038	<0.119	0.219	10
Fe	26.871	8.994	86.330	15
Zn	22.943	16.040	34.909	15
As	21.749	2.488	45.569	15
Sb	0.075	0.001	0.321	15
PFAS compounds	**Mean**	**Min.**	**Max.**	**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	0.000	<0.5	0.550	1
PFNA	n.d.	<0.5	<0.5	0
PFDA	0.429	<0.5	1.470	8
PFUdA	1.079	<0.4	6.390	11
PFDoA	0.493	<0.4	2.170	8
PFTrDA	0.721	<0.4	3.550	9
PFTeDA	0.084	<0.4	1.260	1
PFBS	n.d.	<0.2	<0.2	0
PFPS	0.009	<0.1	0.130	0
PFHxS	n.d.	<0.2	<0.2	0
PFOS	5.122	1.620	10.380	15
8Cl-PFOS	n.d.	<0.2	<0.2	0
PFNS	n.d.	<0.2	<0.2	0
PFDS	0.493	0.160	1.360	15
PFDoS	0.051	<0.2	0.260	4
PFOSA	6.254	2.270	11.040	15
me-PFOSA	n.d.	<0.3	<0.3	0
et-PFOSA	n.d.	<0.3	<0.3	0
me-PFOSE	n.d.	<5	<5	0
et-PFOSE	n.d.	<5	<5	0
me-FOSAA	n.d.	<0.3	<0.3	0
et-FOSAA	n.d.	<0.3	<0.3	0
4:2 FTS	0.000	<0.3	0.400	1

6:2 FTS	n.d.	<0.3	<0.3	0
8:2 FTS	n.d.	<0.3	<0.3	0
Triclosan and triclocarban	**Mean**	**Min.**	**Max.**	**Detected in no. of samples**
TCC	n.d.	<1	<1	0
Triclosan	n.d.	<3	<6	0
UV-chemicals	**Mean**	**Min.**	**Max.**	**Detected in no. of samples**
BP3	n.d.	<5	<20	0
EHMC	n.d.	<5	<20	1
OC	n.d.	<5	<30	0

Of the substances analysed for which (biota) quality standards exist (for EU priority substances or Norwegian river basin specific substances; The Norwegian Environment Agency; M-608), mean concentrations of Hg, PBDEs and PCB7 exceeded the quality standards. 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.

As mentioned, the mean concentration of D5 in cod liver was apparently twice as high as observed in 2015 (Ruus et al. 2016; The Norwegian Environment Agency M-601). However, there was large variability in the concentrations in 2016 and the apparent difference was not statistically significant ($p = 0.77$; Mann-Whitney U). Furthermore, no individual D5 concentration exceeded the quality standard of 15217 ng/g (The Norwegian Environment Agency; M-608). The mean D5 concentration in the cod liver on a lipid weight basis (3518 ng/g ± 2901 standard deviation) was comparable to that in trout from Lake Mjøsa in 2015 (2800 ± 2800; Fjeld et al. 2016; The Norwegian Environment Agency M-548).

Mercury in cod showed a statistically significant positive relationship with the length of cod (Figure 19). The 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). Furthermore, Jones et al. (2013) argued that detecting the influence of changes in Hg exposure will depend on how well fish biotmetrics (length, age and growth rates) are considered.

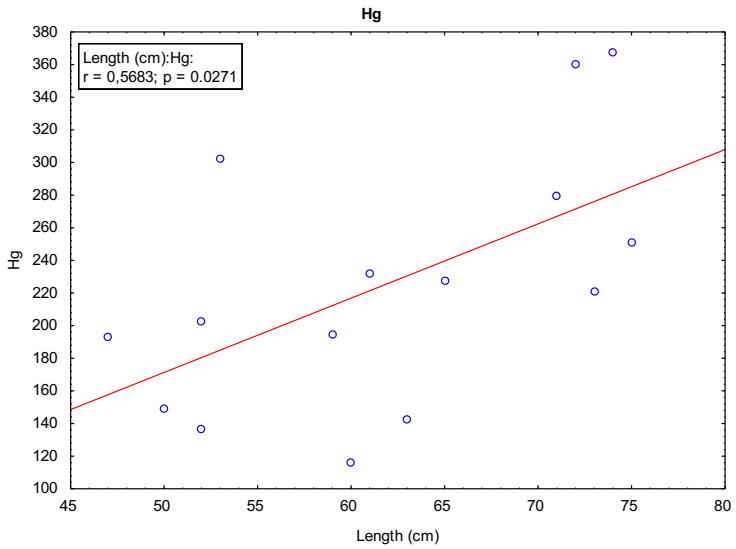


Figure 19. Concentrations (ng/g wet wt.) of mercury (Hg) against length (cm) in cod from the Inner Oslofjord.

Triclosan, triclocarban and UV chemicals were not detected in any cod liver samples, except for EHMC which was detected in one cod sample; see electronic Appendix.

Phenolic compounds were hardly detected in any cod samples. The limit of detection was high for some of the compounds, due to blank issues.

3.2.4 Herring gull

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 10. The number of samples in which the substance was detected is also shown in Table 10.

Table 10.
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 Min.	Blood Max.	Egg Mean	Egg Min.	Egg Max.	Det. no.
Lipid content (%)	2.23	0.40	14.80	9.02	5.80	13.50	15/15
PeCB	0.003	<0.034	0.038	0.1810	0.066	0.428	1/15
HCB	0.269	<0.106	1.180	4.370	1.360	18.600	12/15
PCBs (PCB7)	**Blood Mean**	**Blood Min.**	**Blood Max.**	**Egg Mean**	**Egg Min.**	**Egg Max.**	**Det. no.**
PCB-28	0.054	<0.024	0.629	1.275	0.213	4.690	3/15
PCB-52	0.065	<0.030	0.382	4.100	0.074	16.600	4/15
PCB-101	0.223	<0.059	1.620	9.927	0.353	38.700	4/15
PCB-118	3.546	0.167	26.700	42.893	6.230	123.000	15/15
PCB-138	5.743	0.513	38.100	73.200	14.700	190.000	15/15
PCB-153	7.223	1.010	41.500	105.673	22.000	266.000	15/15
PCB-180	1.409	0.200	7.910	26.891	5.750	73.200	15/15
Sum-PCB_7	18.262	1.890	116.307	263.958	50.946	699.090	15/15
TBA, PBDEs and DBDPE	**Blood Mean**	**Blood Min.**	**Blood Max.**	**Egg Mean**	**Egg Min.**	**Egg Max.**	**Det. no.**
TBA	n.d.	<0.005	<0.026	0.006	<0.003	0.014	0/12
BDE-17	0.000	<0.002	0.003	0.002	<0.001	0.010	0/7
BDE-28	0.001	<0.003	0.013	0.021	0.002	0.097	2/15
BDE-47	0.324	<0.033	2.050	4.129	1.300	13.500	13/15
BDE-49	0.002	<0.004	0.021	0.047	0.005	0.186	2/15
BDE-66	0.001	<0.016	0.020	0.059	0.010	0.179	1/15
BDE-71	n.d.	<0.002	<0.008	0.001	<0.001	0.014	0/1
BDE-77	0.000	<0.001	0.002	0.005	<0.001	0.018	1/8
BDE-85	0.001	<0.002	0.013	0.040	0.009	0.114	2/15
BDE-99	0.123	<0.011	0.369	1.872	0.761	3.390	14/15
BDE-100	0.075	<0.009	0.430	1.121	0.396	2.870	13/15

BDE-119	0.004	<0.003	0.040	0.025	<0.002	0.069	2/12
BDE-126	n.d.	<0.002	<0.008	0.005	<0.002	0.029	0/6
BDE-138	n.d.	<0.005	<0.018	0.030	<0.007	0.059	0/13
BDE-153	0.026	<0.007	0.069	0.438	0.138	0.879	13/15
BDE-154	0.013	<0.006	0.055	0.247	0.102	0.463	9/15
BDE-156	n.d.	<0.009	<0.043	n.d.	<0.004	<0.012	0/0
BDE-183	0.008	<0.005	0.022	0.134	0.043	0.309	9/15
BDE-184	n.d.	<0.003	<0.013	0.034	<0.002	0.078	0/9
BDE-191	n.d.	<0.006	<0.028	n.d.	<0.004	<0.013	0/0
BDE-196	0.003	<0.014	0.029	0.092	0.025	0.210	2/15
BDE-197	0.009	<0.011	0.040	0.169	0.044	0.421	4/15
BDE-202	n.d.	<0.009	<0.047	0.040	0.023	0.061	0/15
BDE-206	0.025	<0.022	0.196	0.119	<0.012	0.445	3/12
BDE-207	0.075	<0.019	0.260	0.655	0.079	2.220	11/15
BDE-209	0.981	<0.287	4.180	4.260	<0.252	13.900	7/11
DBDPE	35.225	16.635	101.880	0.744	0.412	1.5596	15/15
DDT-compounds	**Blood Mean**	**Blood Min.**	**Blood Max.**	**Egg Mean**	**Egg Min.**	**Egg Max.**	**Det. no.**
o,p'-DDE	n.d.	<0.014	<0.072	0.032	<0.007	0.253	0/8
p,p'-DDE	2.047	<1.140	14.800	45.081	9.210	171.000	6/15
o,p'-DDD	n.d.	<0.010	<0.039	0.020	<0.004	0.078	0/10
p,p'-DDD	0.006	<0.019	0.090	0.784	0.029	3.880	1/15
o,p'-DDT	n.d.	<0.030	<0.105	0.015	<0.010	0.040	0/8
p,p'-DDT	n.d.	<0.054	<0.272	0.742	0.065	3.120	0/15
Chloroparaffins	**Blood Mean**	**Blood Min.**	**Blood Max.**	**Egg Mean**	**Egg Min.**	**Egg Max.**	**Det. no.**
SCCP	24.20	11.00	56.00	3.99	<0.60	9.90	15/9
MCCP	0.43	<0.10	2.00	0.05	<0.10	0.80	6/1
Siloxanes	**Blood Mean**	**Blood Min.**	**Blood Max.**	**Egg Mean**	**Egg Min.**	**Egg Max.**	**Det. no.**
D4	1.33	<2.00	3.04	4.74	<2.60	13.52	7/11
D5	2.72	<1.30	10.11	205.43	12.50	1174.09	12/15

D6	0.189	<1.1	2.45	13.61	<9.10	33.75	1/12
Phosphorus flame retardants (PFRs)	**Blood Mean**	**Blood Min.**	**Blood Max.**	**Egg Mean**	**Egg Min.**	**Egg Max.**	**Det. no.**
TEP	n.d.	<0.30	<0.30	n.d.	<0.06	<0.20	0/0
TCEP	n.d.	<0.20	<0.20	n.d.	<0.20	<0.20	0/0
TPrP	n.d.	<0.02	<0.02	n.d.	<0.02	<0.02	0/0
TCPP	n.d.	<0.50	<0.50	0.19	<0.70	2.81	0/1
TiBP	0.64	<1.20	4.81	n.d.	<0.70	<0.70	3/0
BdPhP	n.d.	<0.01	<0.01	n.d.	<0.01	<0.01	0/0
TPP	n.d.	<0.20	<0.20	n.d.	<0.06	<0.10	0/0
DBPhP	n.d.	<0.01	<0.01	n.d.	<0.01	<0.01	0/0
TnBP	n.d.	<0.20	<0.20	n.d.	<0.01	<0.12	0/0
TDCPP	n.d.	<1.00	<1.00	n.d.	<0.20	<0.40	0/0
TBEP	n.d.	<0.90	<0.90	1.56	<0.30	21.74	0/2
TCP	n.d.	<0.01	<0.01	n.d.	<0.01	<0.01	0/0
EHDP	n.d.	<0.30	<0.30	0.07	<0.05	0.77	0/2
TEHP	0.09	<0.10	0.26	n.d.	<0.03	<0.05	6/0
Phenolic compounds	**Blood Mean**	**Blood Min.**	**Blood Max.**	**Egg Mean**	**Egg Min.**	**Egg Max.**	**Det. no.**
Bisphenol A	1.608	<20	24.126	n.d.	<10	<10	1/0
Tetrabromobisph. A	n.d.	<2.6	<2.6	n.d.	<1.4	<1.4	0/0
4,4-bisphenol F	n.d.	<8.7	<8.7	n.d.	<5.4	<5.4	0/0
2,2-bisphenol F	n.d.	<1.5	<1.5	n.d.	<1.1	<1.1	0/0
Hexafluorobisph. A	n.d.	<0.8	<0.8	n.d.	<0.3	<0.3	0/0
Bisphenol BP	n.d.	<1.2	<1.2	n.d.	<0.7	<0.7	0/0
Bisphenol S	n.d.	<0.7	<0.7	0.058	<0.5	0.872	0/0
4-nonylphenol	n.d.	<0.04	<0.04	n.d.	<0.02	<0.02	0/0
4-octylphenol				0.368	<0.3	5.524	-/1
4-tert-octylphenol				n.d.	<616	<616	-/0
Bisphenol B	2.196	<2.8	19.789	n.d.	<1.2	<1.2	3/0
Bisphenol Z	n.d.	<3.9	<3.9	n.d.	<1.9	<1.9	0/0
Bisphenol AP	n.d.	<0.7	<0.7	n.d.	<0.3	<0.3	0/0

Bisphenol E	n.d.	<8.4	<8.4	n.d.	<3.4	<3.4	0/0
Bisphenol FL	n.d.	<1	<1	n.d.	<0.5	<0.5	0/0
Bisphenol P	0.178	<0.7	1.663	0.103	<0.3	1.022	2/2
Bisphenol M	0.267	<0.4	1.085	n.d.	<0.2	<0.2	6/0
Bisphenol G	n.d.	<6.6	<6.6	n.d.	<0.9	<0.9	0/0
Bisphenol TMC	n.d.	<1.8	<1.8	n.d.	<1	<1	0/0
Bisphenol 2,4' -S	n.d.	<1.7	<1.7	n.d.	<0.4	<0.4	0/0
2,4-Bisphenol F	n.d.	<10	<10	n.d.	<6	<6	0/0
Bisphenol 2,4'- A	0.930	<1.6	13.952	n.d.	<0.5	<0.5	1/0
Metals	**Blood Mean**	**Blood Min.**	**Blood Max.**	**Egg Mean**	**Egg Min.**	**Egg Max.**	**Det. no.**
Ni	-	-	-	0.458	0.029	2.479	-/15
Cu	-	-	-	0.708	0.471	1.055	-/15
Ag	-	-	-	0.001	0.000	0.003	-/15
Cd	-	-	-	0.000	<0.001	0.001	-/1
Hg	-	-	-	78.555	21.592	297.792	-/15
Pb	-	-	-	0.007	<0.004	0.027	-/8
Cr	-	-	-	0.766	0.027	4.424	-/15
Fe	-	-	-	34.539	22.676	49.217	-/15
Zn	-	-	-	14.238	9.186	21.890	-/15
As	-	-	-	0.052	0.002	0.132	-/15
Sb	-	-	-	0.000	<0.0002	0.0001	-/2
PFAS compounds	**Blood Mean**	**Blood Min.**	**Blood Max.**	**Egg Mean**	**Egg Min.**	**Egg Max.**	**Det. no.**
PFPA	n.d.	<0.50	<0.50	n.d.	<0.50	<0.50	0/0
PFHxA	n.d.	<0.50	<0.50	n.d.	<0.50	<0.50	0/0
PFHpA	n.d.	<0.50	<0.50	n.d.	<0.50	<0.50	0/0
PFOA	0.31	<0.50	2.40	n.d.	<0.50	<0.50	2/0
PFNA	0.54	<0.50	1.60	0.09	<0.50	0.70	9/1
PFDA	0.23	<0.50	1.50	0.59	<0.50	1.80	4/10
PFUdA	0.37	<0.40	2.30	1.09	<0.40	3.40	5/14
PFDoA	0.21	<0.40	1.00	1.07	0.40	2.70	5/15

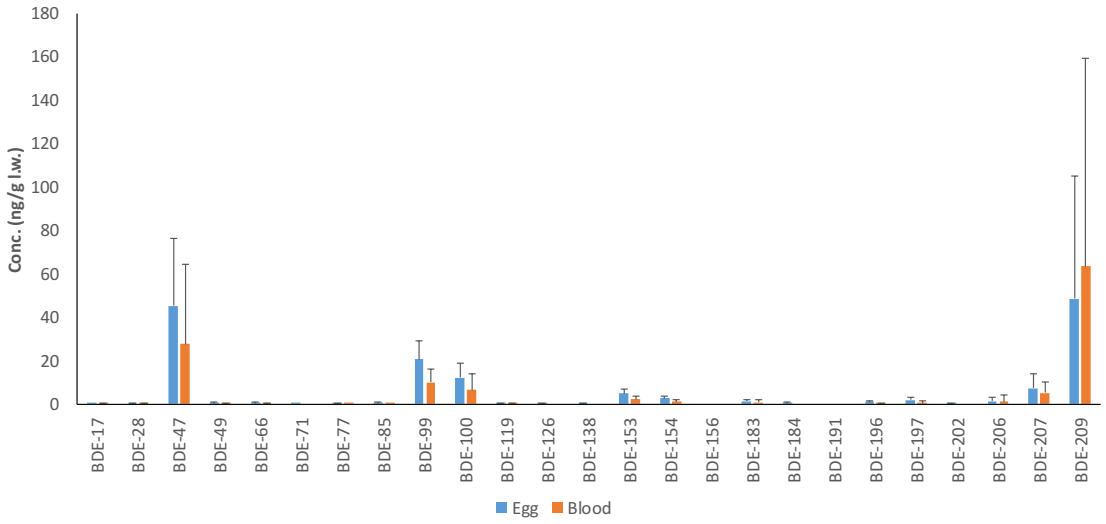
PFTrA	0.19	<0.40	1.00	1.17	0.50	2.40	5/15
PFTeA	0.07	<0.40	0.40	0.84	0.35	1.30	3/15
PFBS	n.d.	<0.10	<0.10	n.d.	<0.10	<0.10	0/0
PFPS	n.d.	<0.20	<0.20	n.d.	<0.20	<0.20	0/0
PFHxS	0.35	0.10	0.70	0.19	0.10	0.30	15/15
PFHpS	0.01	<0.20	0.20	0.09	<0.20	0.20	1/7
PFOS	11.52	1.47	55.10	19.49	5.70	53.00	15/15
8Cl-PFOS	n.d.	<0.20	<0.20	n.d.	<0.20	<0.20	0/0
PFNS	n.d.	<0.20	<0.20	0.01	<0.20	0.20	0/1
PFDS	0.07	<0.20	0.50	0.35	<0.20	0.90	3/14
PFDoS	n.d.	<0.20	<0.20	n.d.	<0.20	<0.20	0/0
PFOSA	0.03	<0.10	0.30	0.08	<0.10	0.60	2/3
me-PFOSA	n.d.	<0.30	<0.30	n.d.	<0.30	<0.30	0/0
et-PFOSA	n.d.	<0.30	<0.30	n.d.	<0.30	<0.30	0/0
me-PFOSE	n.d.	<5.00	<5.00	n.d.	<5.00	<5.00	0/0
et-PFOSE	n.d.	<5.00	<5.00	n.d.	<5.00	<5.00	0/0
me-FOSAA	n.d.	<0.30	<0.30	n.d.	<0.30	<0.30	0/0
et-FOSAA	n.d.	<0.30	<0.30	n.d.	<0.30	<0.30	0/0
4:2 FTS	n.d.	<0.30	<0.30	n.d.	<0.30	<0.30	0/0
6:2 FTS	n.d.	<0.30	<0.30	n.d.	<0.30	<0.30	0/0
8:2 FTS	n.d.	<0.30	<0.30	n.d.	<0.30	<0.30	0/0
Triclosan and triclocarban	**Blood Mean**	**Blood Min.**	**Blood Max.**	**Egg Mean**	**Egg Min.**	**Egg Max.**	**Det. no.**
TCC	n.d.	<1.00	<1.00	n.d.	<1.00	<1.00	0/0
Triclosan	n.d.	<3.00	<3.00	n.d.	<3.00	<3.00	0/0
UV-chemicals	**Blood Mean**	**Blood Min.**	**Blood Max.**	**Egg Mean**	**Egg Min.**	**Egg Max.**	**Det. no.**
BP3	n.d.	<3.00	<3.00	n.d.	<6.00	<6.00	0/0
EHMC	n.d.	<3.00	<3.00	0.60	<6.00	9.00	0/1
OC	1.59	<5.00	11.00	1.53	<6.00	23.00	3/1

Concentrations of selected contaminants, specifically PBDEs (lipid wt. basis), siloxanes (lipid wt. basis) and PFAS compounds (wet wt. basis) in herring gull (blood and egg) are also

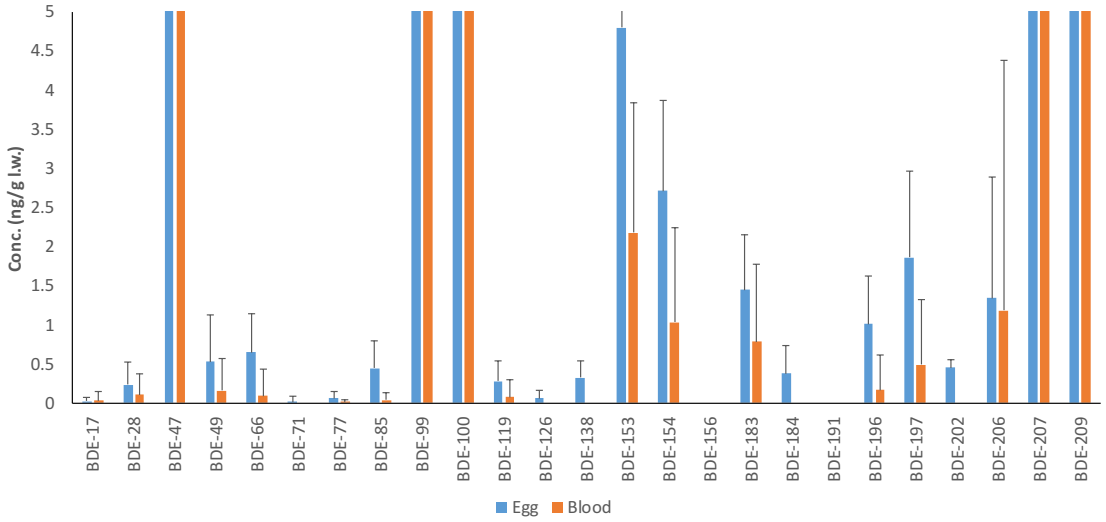
presented in Figure 20 to Figure 22. The figures include tables with concentrations (on relevant basis: wet wt. or lipid wt.).

The PBDE congeners displaying the highest concentrations in herring gull (both blood and eggs) were BDE-209, -47 and -99, although variability was high (Figure 20). This corresponds with previous observations from the Urban fjord programme (Ruus et al. 2016; Ruus et al. 2015; Ruus et al. 2014; The Norwegian Environment Agency M-601, M-375 and M-205). In blood, concentrations of DBDPE were even higher than the above mentioned PBDE congeners (Table 10), and as this compound is a substitute for BDE-209, future monitoring will indicate potential temporal trends. As observed/mentioned earlier (Ruus et al. 2015; Ruus et al. 2016; The Norwegian Environment Agency M-375 and M-601), 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. 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 (Herzke et al. 2017; The Norwegian Environment Agency M-752). Otherwise, concentrations of PBDEs appeared higher in the sparrow hawk eggs, than in the herring gull eggs (Herzke et al. 2017; The Norwegian Environment Agency M-752).

A.



B.



C.

Analyte	Blood Mean	Blood Min.	Blood Max.	Egg Mean	Egg Min.	Egg Max.	Det. no.
Lipid content (%)	2.23	0.40	14.80	9.02	5.80	13.50	15/15
PBDEs							
BDE-17	0.031	n.d.	0.470	0.026	n.d.	0.144	0/7
BDE-28	0.102	n.d.	0.893	0.231	0.028	0.946	2/15
BDE-47	27.8	n.d.	137	45.2	14.1	132	13/15
BDE-49	0.156	n.d.	1.373	0.524	0.055	2.033	2/15

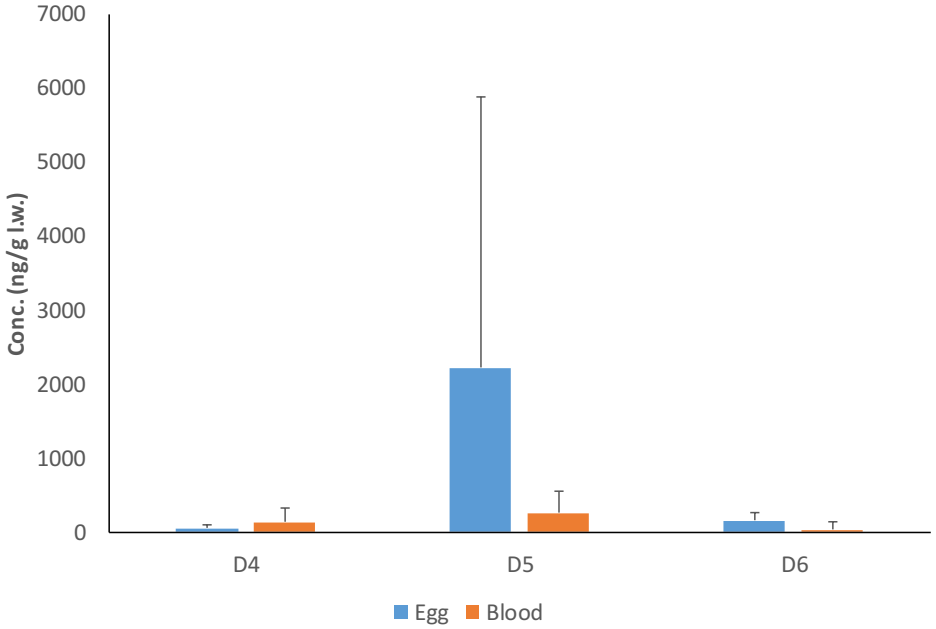
BDE-66	0.088	n.d.	1.313	0.650	0.118	1.755	1/15
BDE-71	n.d.	n.d.	n.d.	0.017	n.d.	0.248	0/1
BDE-77	0.008	n.d.	0.117	0.060	n.d.	0.307	1/8
BDE-85	0.036	n.d.	0.314	0.447	0.095	1.326	2/15
BDE-99	9.913	n.d.	24.6	20.5	11.0	36.5	14/15
BDE-100	6.487	n.d.	28.7	12.3	5.739	28.1	13/15
BDE-119	0.074	n.d.	0.840	0.282	n.d.	0.779	2/12
BDE-126	n.d.	n.d.	n.d.	0.058	n.d.	0.334	0/6
BDE-138	n.d.	n.d.	n.d.	0.325	n.d.	0.692	0/13
BDE-153	2.177	n.d.	5.525	4.802	1.689	9.452	13/15
BDE-154	1.033	n.d.	3.687	2.715	1.172	4.721	9/15
BDE-156	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0/0
BDE-183	0.786	n.d.	3.300	1.444	0.617	2.522	9/15
BDE-184	n.d.	n.d.	n.d.	0.381	n.d.	0.856	0/9
BDE-191	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0/0
BDE-196	0.166	n.d.	1.419	1.013	0.280	2.471	2/15
BDE-197	0.486	n.d.	2.800	1.859	0.488	4.953	4/15
BDE-202	n.d.	n.d.	n.d.	0.450	0.252	0.657	0/15
BDE-206	1.180	n.d.	12.3	1.344	n.d.	5.494	3/12
BDE-207	5.164	n.d.	16.3	7.375	0.877	26.1	11/15
BDE-209	63.4	n.d.	240	48.7	n.d.	172	7/11

Figure 20. A. Concentrations of PBDEs (ng/g lipid wt.) in herring gull (eggs and blood) 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).

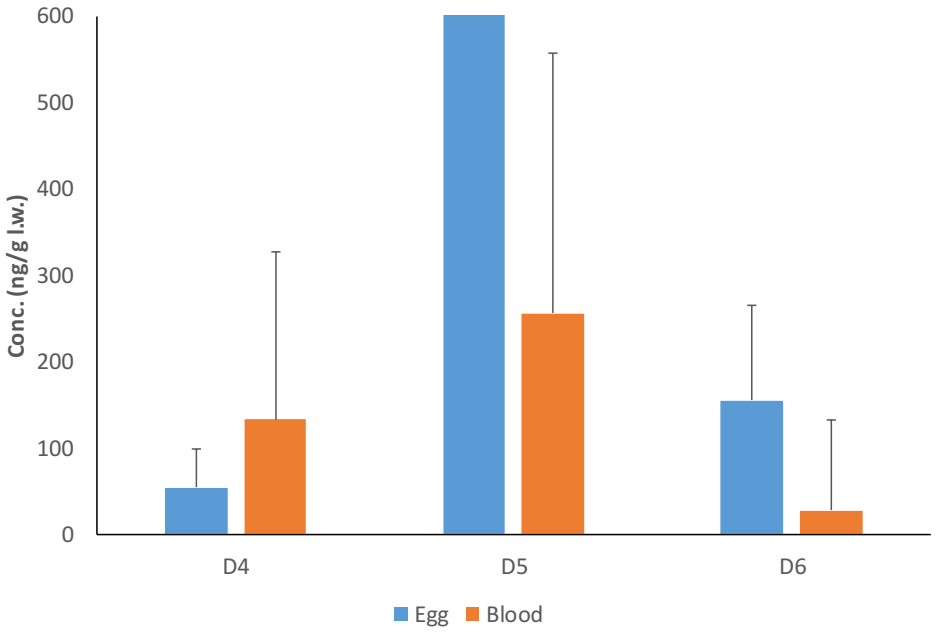
Siloxanes were detected in eggs and blood of herring gull (Figure 21). Decamethylcyclo-pentasiloxane (D5) displayed the highest concentrations but the variability was high. This corresponds with previous observations from the Urban fjord programme (Ruus et al. 2016; Ruus et al. 2015; Ruus et al. 2014; The Norwegian Environment Agency M-601, M-375 nad M-205). Mean D5 concentration in eggs from the Oslofjord area (present study) was a factor of ~140 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. The mean concentration of siloxanes in the herring gull eggs form the Oslofjord area also appeared higher than in eggs of sparrow hawk from the Oslo area (Herzke et al. 2017; The Norwegian Environment Agency M-752). This may also reflect that while the sparrow hawk feeds mostly on birds, the herring gull might feed on human waste and leftovers.

Concentrations of “legacy” contaminants, such as PCB-153 and p,p′-DDE 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. It must be mentioned, however, that the concentrations of PCBs in the sparrow hawk eggs from the Oslo area (Herzke et al. 2017; The Norwegian Environment Agency M-752) appeared higher than in the herring gull eggs from the Oslofjord area (Table 10).

A.


7000
6000
5000
4000
3000
2000
1000
0
Conc. (ng/g l.w.)
D4
D5
D6
Egg
Blood

B.


600
500
400
300
200
100
0
Conc. (ng/g l.w.)
D4
D5
D6
Egg
Blood

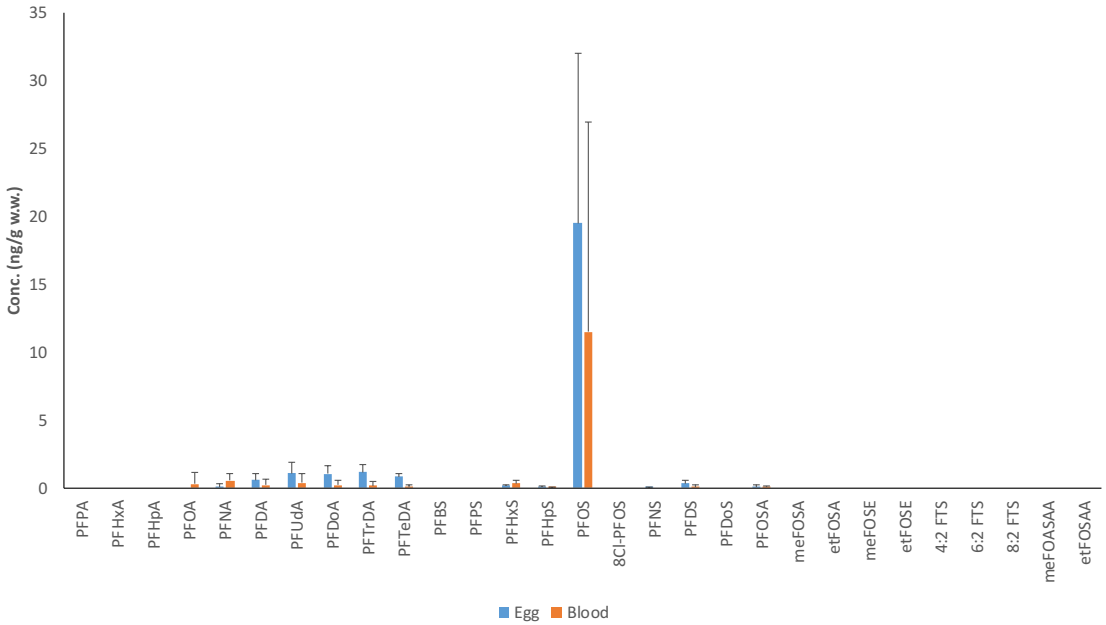
C.

Analyte	Blood Mean	Blood Min.	Blood Max.	Egg Mean	Egg Min.	Egg Max.	Det. no.
Lipid content (%)	2.23	0.40	14.80	9.02	5.80	13.50	15/15
Siloxanes							
D4	133	n.d.	701	54.5	n.d	148	7/11
D5	256	n.d.	1123	2222	145	12832	12/15
D6	27.3	n.d.	409	155	n.d.	369	1/12

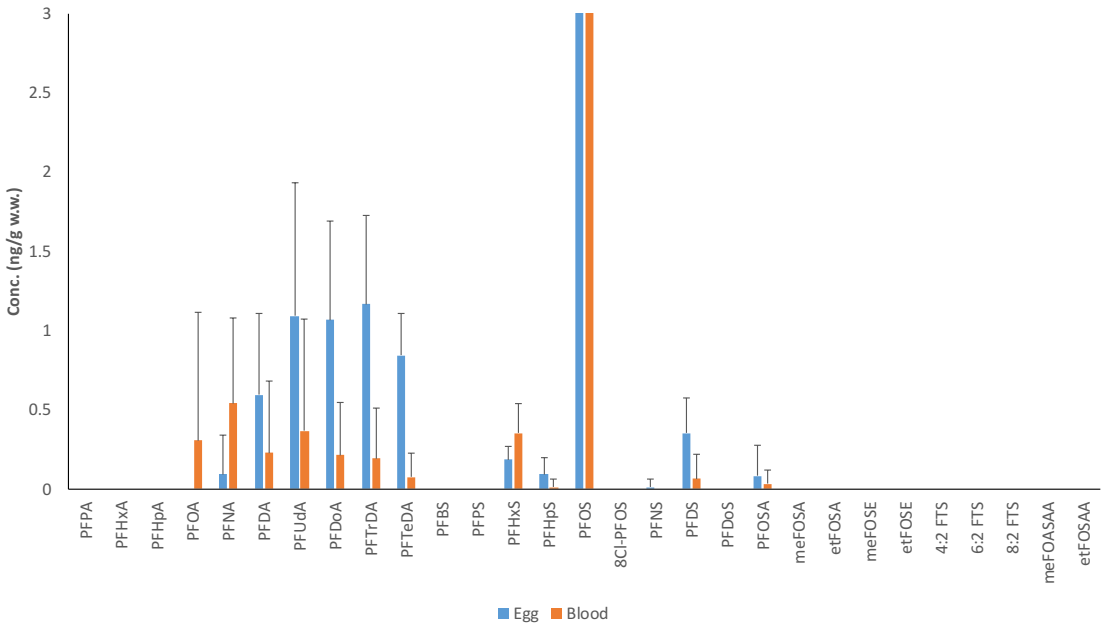
Figure 21. A. Concentrations of cyclic volatile methylsiloxanes (ng/g lipid wt.) in herring gull (eggs and blood) from the Inner Oslofjord (mean and standard deviation; n=15; non-detects are assigned values of zero). B. Magnification of the lower part (0-600) of the concentration axis in A. C. Lipid 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 (Figure 22). PFOS constituted, by far, the highest concentrations in both matrices. The variability was high. This corresponds with previous observations from the Urban fjord programme (Ruus et al. 2016; Ruus et al. 2015; Ruus et al. 2014; The Norwegian Environment Agency M-601, M-375 and M-205). PFOS was also the dominating PFAS compound in sparrow hawk eggs from the Oslo area (Herzke et al. 2017; The Norwegian Environment Agency M-752), and the PFOS concentrations appeared higher than in the herring gull eggs (Table 10)

A.


Conc. (ng/g w.w.)
35
30
25
20
15
10
5
0
PFPA
PFHxA
PFHpA
PFOA
PFNA
PFDA
PFUdA
PFDoA
PFTrDA
PFTeDA
PFBS
PFPS
PFHxS
PFHpS
PFOS
8Cl-PFOS
PFNS
PFDS
PFDoS
PFOSA
meFOSA
etFOSA
meFOSE
etFOSE
4:2 FTS
6:2 FTS
8:2 FTS
meFOASAA
etFOSAA
Egg
Blood

B.


Conc. (ng/g w.w.)
3
2.5
2
1.5
1
0.5
0
PFPA
PFHxA
PFHpA
PFOA
PFNA
PFDA
PFUdA
PFDoA
PFTrDA
PFTeDA
PFBS
PFPS
PFHxS
PFHpS
PFOS
8Cl-PFOS
PFNS
PFDS
PFDoS
PFOSA
meFOSA
etFOSA
meFOSE
etFOSE
4:2 FTS
6:2 FTS
8:2 FTS
meFOASAA
etFOSAA
Egg
Blood

C.

Analyte	Blood Mean	Blood Min.	Blood Max.	Egg Mean	Egg Min.	Egg Max.	Det. no.
Lipid content (%)	2.23	0.40	14.80	9.02	5.80	13.50	15/15
PFAS compounds							
PFPA	n.d.	<0.50	<0.50	n.d.	<0.50	<0.50	0/0
PFHxA	n.d.	<0.50	<0.50	n.d.	<0.50	<0.50	0/0
PFHpA	n.d.	<0.50	<0.50	n.d.	<0.50	<0.50	0/0
PFOA	0.31	<0.50	2.40	n.d.	<0.50	<0.50	2/0
PFNA	0.54	<0.50	1.60	0.09	<0.50	0.70	9/1
PFDA	0.23	<0.50	1.50	0.59	<0.50	1.80	4/10
PFUdA	0.37	<0.40	2.30	1.09	<0.40	3.40	5/14
PFDoA	0.21	<0.40	1.00	1.07	0.40	2.70	5/15
PFTrA	0.19	<0.40	1.00	1.17	0.50	2.40	5/15
PFTeA	0.07	<0.40	0.40	0.84	0.35	1.30	3/15
PFBS	n.d.	<0.10	<0.10	n.d.	<0.10	<0.10	0/0
PFPS	n.d.	<0.20	<0.20	n.d.	<0.20	<0.20	0/0
PFHxS	0.35	0.10	0.70	0.19	0.10	0.30	15/15
PFHpS	0.01	<0.20	0.20	0.09	<0.20	0.20	1/7
PFOS	11.52	1.47	55.10	19.49	5.70	53.00	15/15
8Cl-PFOS	n.d.	<0.20	<0.20	n.d.	<0.20	<0.20	0/0
PFNS	n.d.	<0.20	<0.20	0.01	<0.20	0.20	0/1
PFDS	0.07	<0.20	0.50	0.35	<0.20	0.90	3/14
PFDoS	n.d.	<0.20	<0.20	n.d.	<0.20	<0.20	0/0
PFOSA	0.03	<0.10	0.30	0.08	<0.10	0.60	2/3
me-PFOSA	n.d.	<0.30	<0.30	n.d.	<0.30	<0.30	0/0
et-PFOSA	n.d.	<0.30	<0.30	n.d.	<0.30	<0.30	0/0
me-PFOSE	n.d.	<5.00	<5.00	n.d.	<5.00	<5.00	0/0
et-PFOSE	n.d.	<5.00	<5.00	n.d.	<5.00	<5.00	0/0
me-FOSAA	n.d.	<0.30	<0.30	n.d.	<0.30	<0.30	0/0
et-FOSAA	n.d.	<0.30	<0.30	n.d.	<0.30	<0.30	0/0

4:2 FTS	n.d.	<0.30	<0.30	n.d.	<0.30	<0.30	0/0
6:2 FTS	n.d.	<0.30	<0.30	n.d.	<0.30	<0.30	0/0
8:2 FTS	n.d.	<0.30	<0.30	n.d.	<0.30	<0.30	0/0

Figure 22. A. Concentrations (ng/g wet wt.) of PFAS in herring gull (eggs and blood) 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).

As mentioned, in 2016 there was an addition to the programme, as a student conducted her MSc-thesis measuring DNA-damage (Comet-assay) in the herring gulls of the Oslofjord, in addition to measuring DNA-damage and selected contaminants in herring gulls of a remote colony (Hornøya, Northern Norway). The results from this study are dealt with in Keilen (2017), but data are presented in Appendix. In short, the study showed that concentrations of siloxanes were apparently higher in blood of herring gulls from the Inner Oslofjord, compared to the rural colony at Hornøya, likely reflecting urban influence. Keilen (2017) points out, however, that caution should be taken interpreting the results, because of some methodological issues. On the other hand, concentrations of HCB and PCBs were higher in the gulls from the rural Hornøya colony. The findings seem to corroborate the above comparison of herring gull eggs from the Oslofjord with eggs from more remote marine colonies at Sklinna and Røst. Interestingly, DNA-damage was significantly higher in the herring gulls from the Inner Oslofjord, compared to the rural colony at Hornøya (Keilen, 2017). This suggest higher stress associated with urban influence, although it is difficult to relate this to contaminants, specifically.

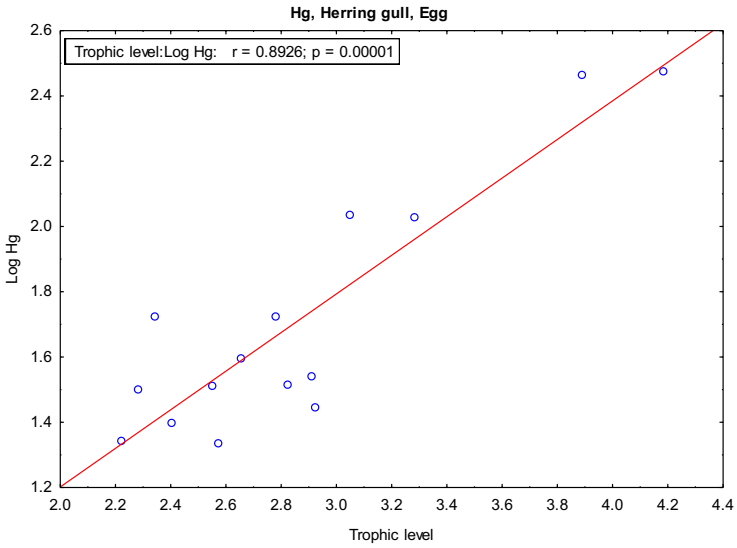
The consistent herring gull results between years in the “Urban fjord” programme, suggest the suitability of this species to study urban influence. In this regard, it is important to acknowledge that with the opportunistic feeding habits of herring gull, urbanisation implies a shift towards less marine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

Egg

Several of the compounds that displayed significant biomagnification in the Inner Oslofjord food web (chapter 3.2.2), also showed a significant relationship between (log) concentrations and trophic position of herring gull eggs. This included As and Hg (Figure 23), and several of the PCBs (e.g. PCB-28, -52, -101, -118, -138 and -153 of the PCB7; PCB-28 shown in Figure 24). Of the PBDEs displaying significant biomagnification in the Inner Oslofjord food web, BDE-28, -47, -49, -100 and -154 also showed a significant relationship between (log) concentrations and trophic position of herring gull eggs (BDE-47 shown in Figure 25). Furthermore, several PFAS compounds displayed a significant relationship between (log) concentrations and trophic position of herring gull eggs, including PFOS (Figure 26). These relationships could serve as useful information in terms of assessing bioaccumulative potential in a weight of evidence approach.

Although siloxanes did not display biomagnification in the Inner Oslofjord food web (chapter 3.2.2), both D4 and D5 (Figure 27) showed a statistically significant relationship between (log) concentrations and trophic position of herring gull eggs.

A.



B.

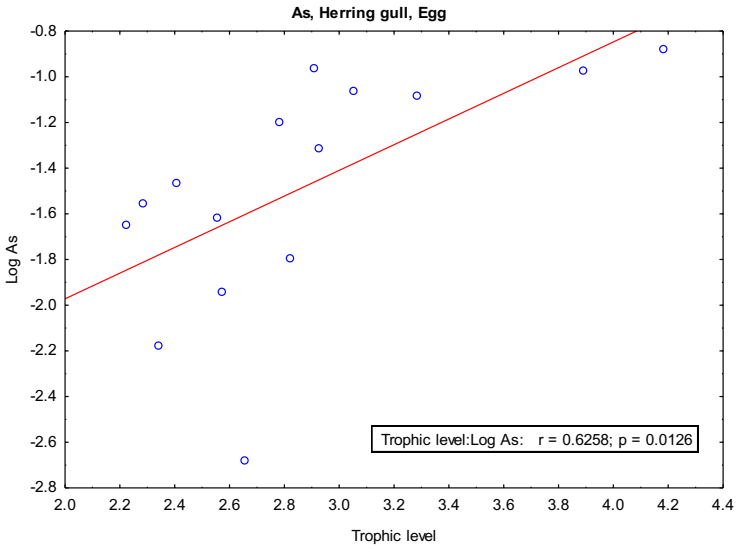


Figure 23. Trophic position against concentrations of mercury (Hg; ng/g wet wt.; log-transformed; A.) and arsenic (As; µg/g wet wt.; log-transformed; B.) in Herring gull eggs.

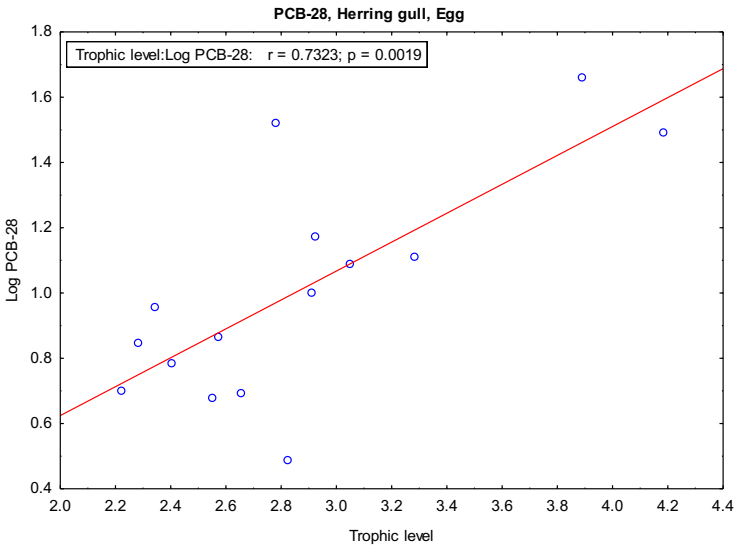


Figure 24. Trophic position against concentrations (ng/g lipd wt.; log-transformed) of PCB-28 in Herring gull eggs.

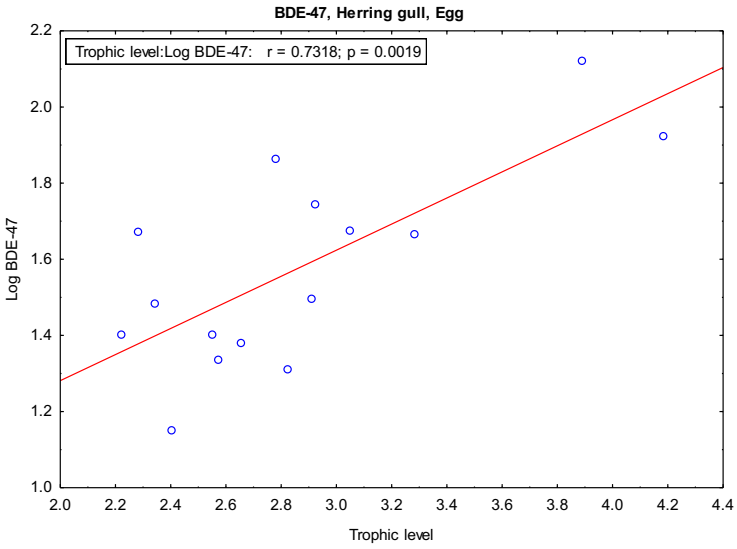


Figure 25. Trophic position against concentrations (ng/g lipid wt.; log-transformed) of BDE-47 in Herring gull eggs.

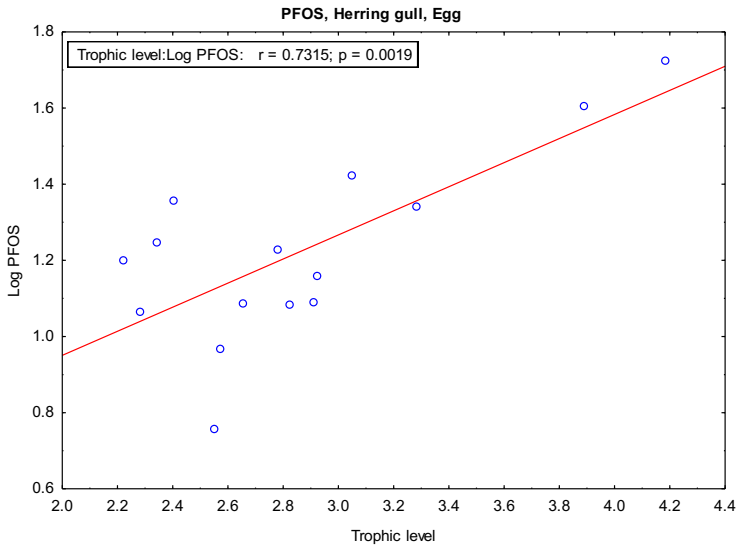
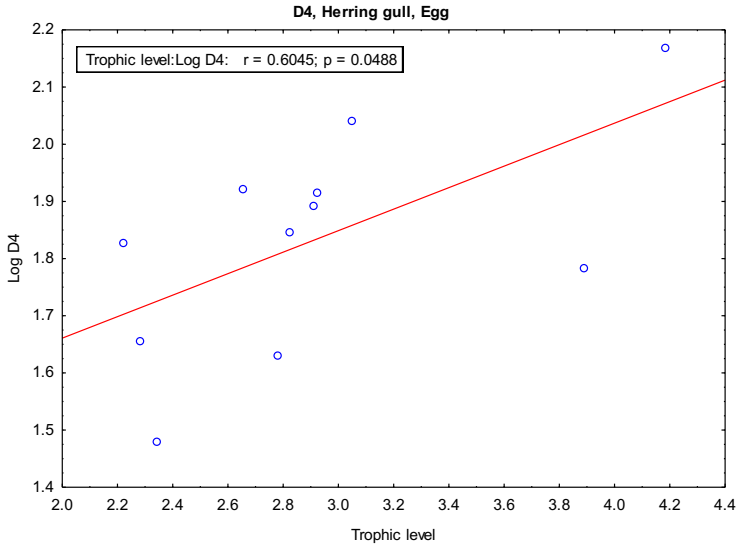


Figure 26. Trophic position against concentrations (ng/g wet wt.; log-transformed) of PFOS in Herring gull eggs.

A.



B.

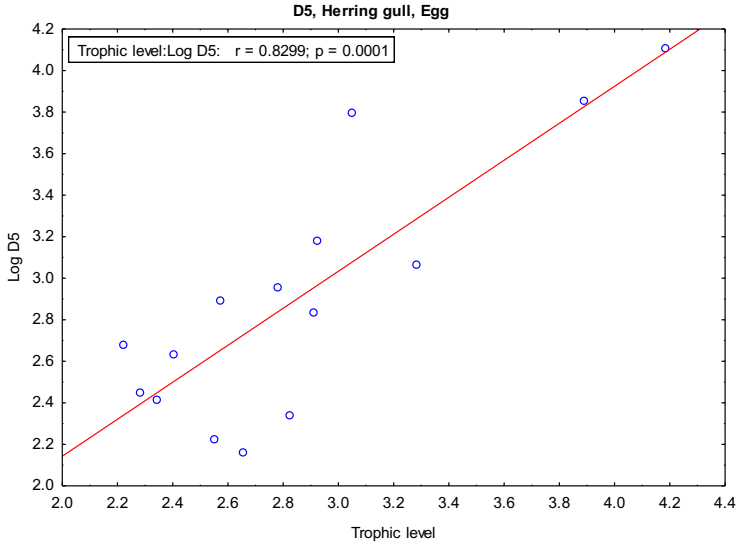


Figure 27. Trophic position against concentrations (ng/g lipid wt.; log-transformed) of octamethylcyclotetrasiloxane (D4; A.) and decamethylcyclopentasiloxane (D5; B.) in Herring gull eggs.

Blood

As for herring gull eggs, several of the compounds that displayed significant biomagnification in the Inner Oslofjord food web (chapter 3.2.2), also showed a significant relationship between (log) concentrations and trophic position of herring gull blood. This included several of the PCBs (such as -118 and -138 of the PCB7), as well as BDE-47, -100 and -154. Furthermore, some PFAS compounds displayed a significant relationship between (log) concentrations and trophic position of herring gulls (blood), including PFOS (Figure 28).

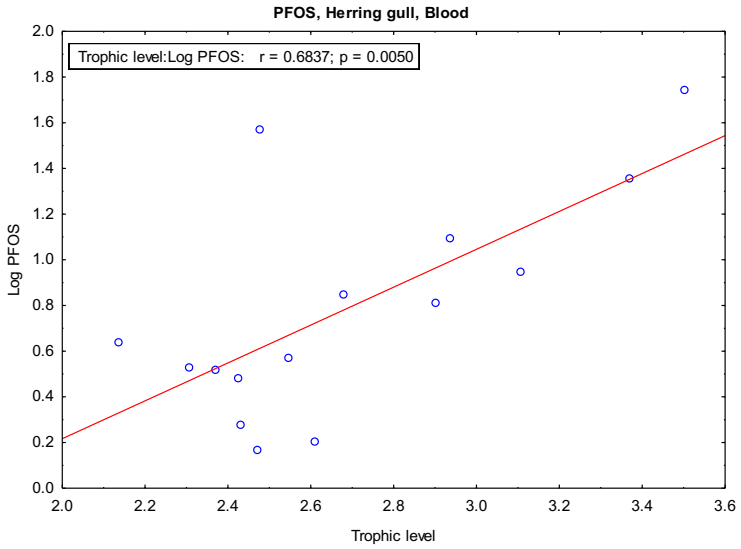


Figure 28. Trophic position against concentrations (ng/g wet wt.; log-transformed) of PFOS in Herring gull blood.

Egg versus blood

Adult female gulls and eggs were sampled from the same nest (i.e. mother and future offspring). Statistically significant relationships between the stable isotope ratios ($\delta^{13}C$, $\delta^{15}N$ and $\delta^{34}S$) in the blood and in the egg were observed (see chapter 3.1). Furthermore, statistically significant positive (log-log) relationships between egg and blood concentrations could be shown for several compounds, such as PCB-118, -138, -153 (Figure 29) and -180 of the PCB7, BDE-47 (Figure 30) and -100, PFOS (Figure 31) and decamethylcyclopentasiloxane (D5; Figure 32).

Verboven et al. (2009) found that Glaucous gull (*Larus hyperboreus*) eggs reflect maternal contaminant patterns (as far as proportions of major contaminant classes are concerned), but emphasized that extrapolation of the POP concentrations in eggs to a value for female body burden should be performed with caution, taking into account contaminant-related differences in egg size and lipid content.

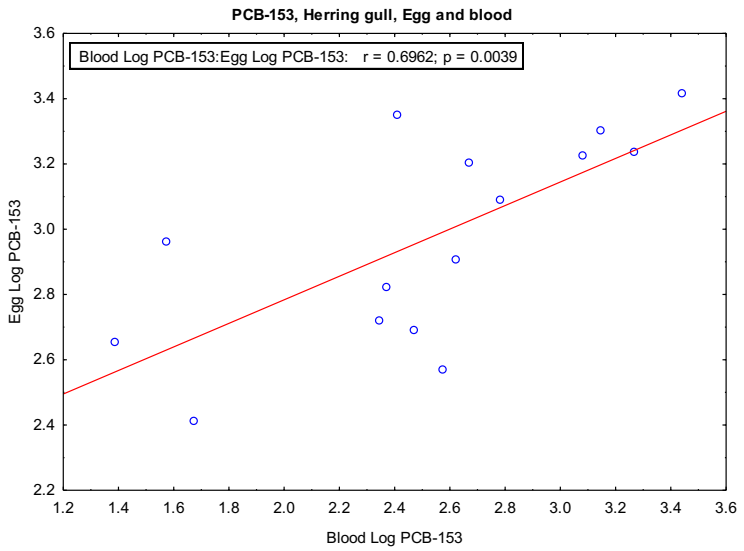


Figure 29. Concentrations (ng/g lipid wt; log-transfromed) of PCB-153 in Blood versus egg of herring gull.

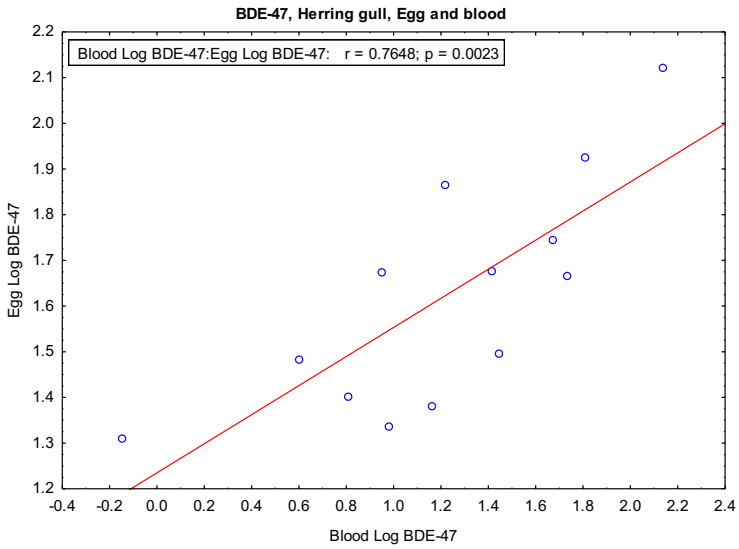


Figure 30. Concentrations (ng/g lipid wt; log-transfromed) of BDE-47 in Blood versus egg of herring gull.

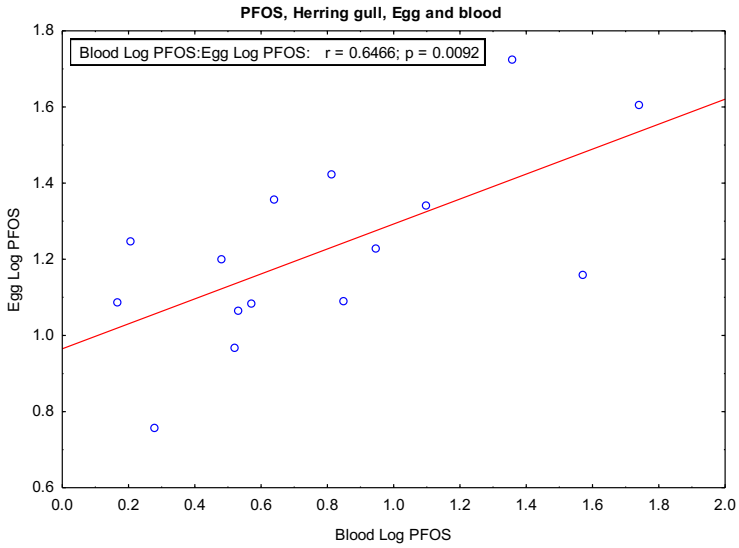


Figure 31. Concentrations (ng/g wet wt; log-transfromed) of PFOS in Blood versus egg of herring gull.

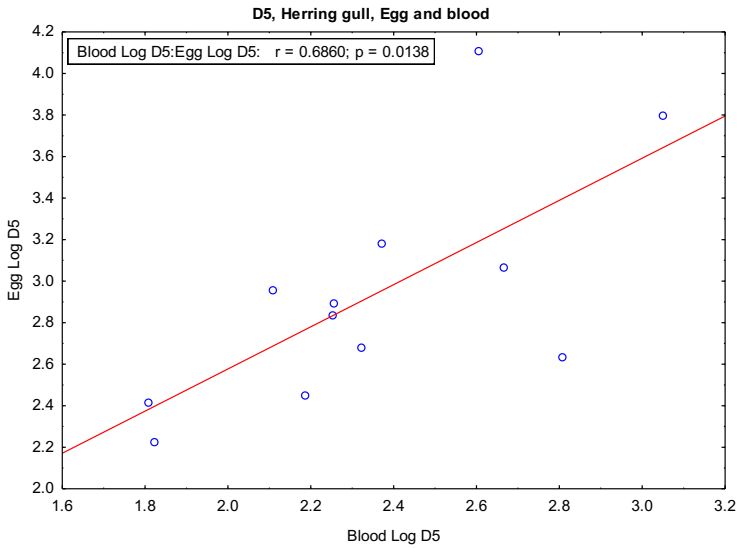
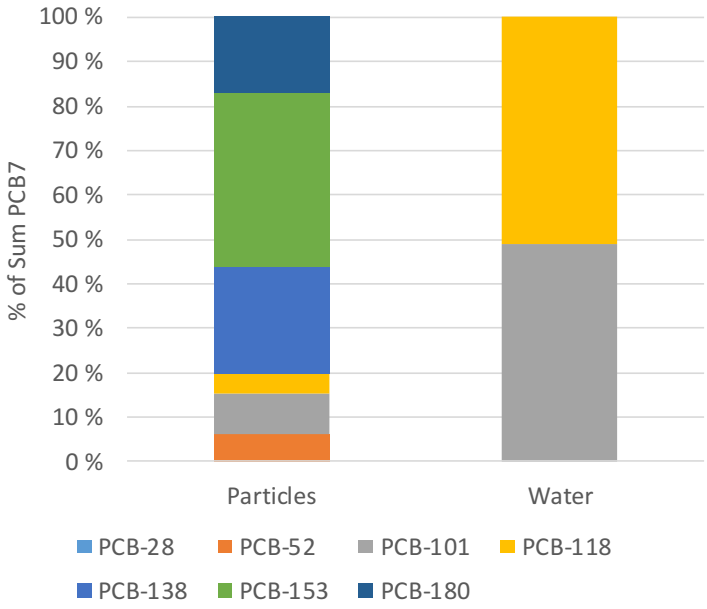


Figure 32. Concentrations (ng/g lipid wt; log-transfromed) of decamethylcyclopentasiloxane (D5) in Blood versus egg of herring gull.

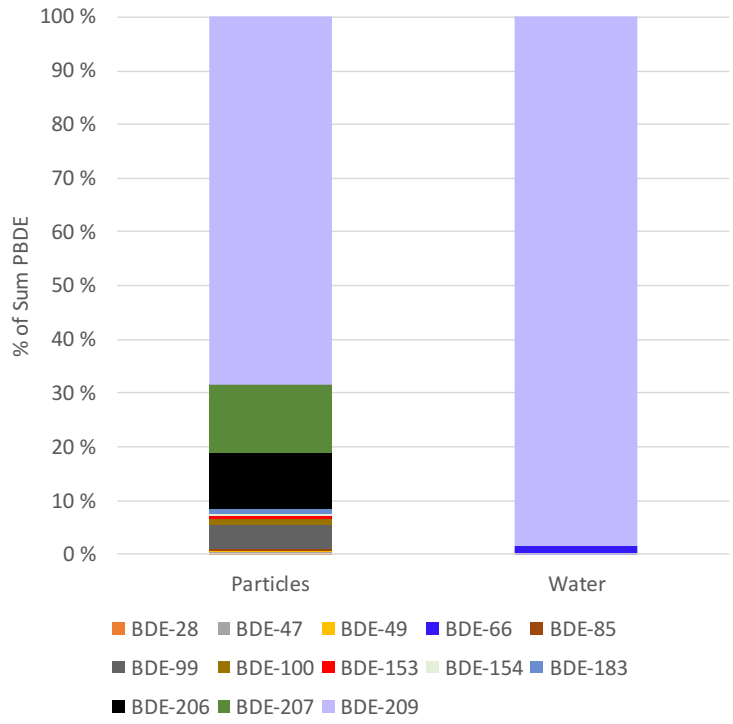
3.2.5 Storm water

The results of the chemical analysis of storm water can be found in the electronic Appendix. PCB-concentrations were, as expected, apparently generally higher in the particulate fraction, than in the dissolved fraction. Given the hydrophobic nature of these compounds, they have a high affinity for the particulate phase and are usually associated with particles. A larger number of congeners were also detected in the particulate fraction (Figure 33). As for the PCBs, BDE-concentrations were generally higher in the particulate fraction, than in the dissolved fraction. A larger number of congeners were also detected in the particulate fraction (Figure 34). BDE-209 constituted the highest percentage in both fractions (Figure 34), as in the sediments (see chapter 3.2.1).



	PCB-28	PCB-52	PCB-101	PCB-118	PCB-138	PCB-153	PCB-180
Particles	n.d.	0.23	0.32	0.15	0.40	0.68	0.31
Water	n.d.	n.d.	0.33	0.16	n.d.	n.d.	n.d.

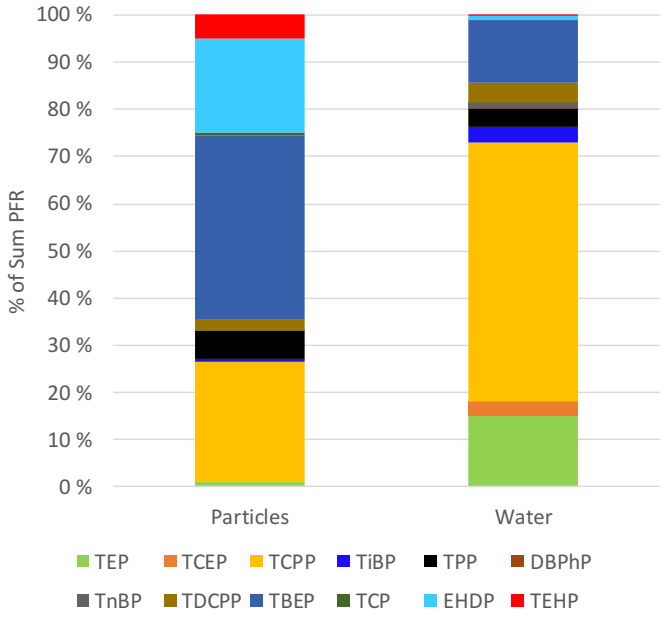
Figure 33. Relative contribution (%) of PCB-congeners to the sum of PCB7 in the particulate and dissolved fraction of storm water (mean of 4 samples. Non-detected components were assigned values of zero). Concentrations (ng/L; mean; non-detected components were assigned a value of zero) are given in 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-28	0.015	n.d.
BDE-47	0.166	n.d.
BDE-49	0.019	n.d.
BDE-66	0.018	0.009
BDE-85	0.006	n.d.
BDE-99	0.347	n.d.
BDE-100	0.063	n.d.
BDE-153	0.053	n.d.
BDE-154	0.033	n.d.
BDE-183	0.075	n.d.
BDE-206	1.073	n.d.
BDE-207	1.177	n.d.
BDE-209	16.400	0.559

Figure 34. Relative contribution (%) of BDE-congeners to the sum of (detected) PBDEs in the particulate and dissolved fraction of storm water (mean of 4 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.

PFR compounds were present in both the particulate fraction and the dissolved fraction of storm water. Most compounds were detected in the highest concentrations in the dissolved fraction (see electronic Appendix). TCPP and TBEP were the compounds that constituted large fractions of sum PFRs in both fractions (the latter especially in the particulate fraction; Figure 35).



	Particles	Water
TEP	5.40	333.98
TCEP	n.d.	57.73
TCPP	76.86	2528.87
TiBP	1.83	213.34
TPP	64.21	72.69
DBPhP	0.04	3.50
TnBP	n.d.	59.85
TDCPP	22.58	120.07
TBEP	673.11	456.13
TCP	5.34	1.08
EHDP	290.43	22.04
TEHP	2.89	3.08

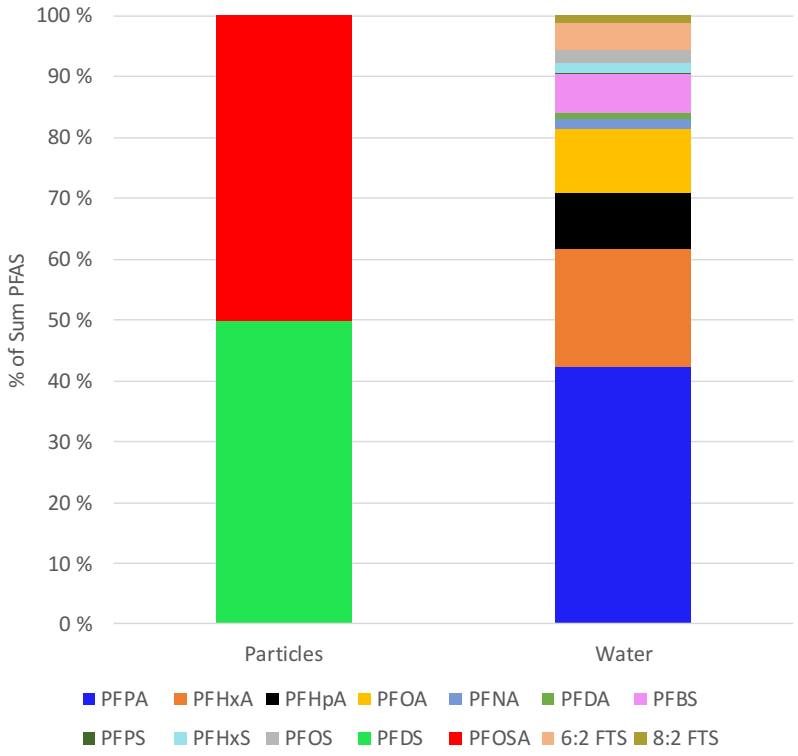
Figure 35. Relative contribution (%) of PFR compounds to the sum of (detected) PFRs in the particulate and dissolved fraction of storm water (mean of 4 samples. Non-detected components were assigned values of zero). Concentrations (ng/L; mean; non-detected components were assigned a value of zero) of 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.

PFAS compounds were mostly detected in the dissolved fraction of storm water. Only PFDS and PFOSA were detected in the particulate fraction (and each in just one of four samples; Figure 36).

As such, inputs of several of the target compounds to the fjord via storm water are found.

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 (The Norwegian Environment Agency M-608). For the target compounds of this study of which quality standards exist, the water concentrations (dissolved fraction) and quality standards are compared in Table 11 (quality standards for coastal water used, to elucidate the potential of surface water as source of contaminants to parts of the fjord).

Concentrations of bisphenol A, copper, zinc, arsenic, chromium, lead 4-*tert*-octylphenol and PFOS exceeded the quality standards, reflecting runoff from the surrounding (urban) area. It should be mentioned that the proposed quality standard for arsenic is low (based on an EC10/NOEC for *Strongylocentrotus purpuratus* of 6 µg/L and an assessment factor of 10; i.e. 0.6 µg/L; Arp et al. 2014; The Norwegian Environment Agency M-241). According to Donat and Bruland (1995) common concentrations in sea water lies between 1.5 and 1.8 µg/L (20 – 24 µM). Zinc, arsenic and PFOS also exceeded the quality standards for sediment out at station Cm21 (see chapter 3.2.1).



	Particles	Water
PFPA	n.d.	13.57
PFHxA	n.d.	5.42
PFHpA	n.d.	2.88
PFOA	n.d.	2.99
PFNA	n.d.	0.36
PFDA	n.d.	0.15
PFBS	n.d.	2.20
PFPS	n.d.	0.07
PFHxS	n.d.	0.67
PFOS	n.d.	0.71
PFDS	0.08	n.d.
PFOSA	0.03	n.d.
6:2 FTS	n.d.	1.45
8:2 FTS	n.d.	0.40

Figure 36. Relative contribution (%) of PFAS compounds to the sum of (detected) PFASs in the particulate and dissolved fraction of storm water (mean of 4 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 11.
Concentrations of contaminants (µg/L) of which Norwegian quality standards (from the Norwegian Environment Agency; M-608) exist in coastal water in Stormwater (dissolved fraction). Red numbers indicate excess of the quality standard.

River basin specific compounds	EQS (µg/L)	Stormwater conc. (dissolved; µg/L)
Bisphenol A	0.15	0.2561
Decamethylcyclopentasiloxane (D5)	0.17	n.a.
Medium chained chloroparafins (MCCPs)	0.05	0.0077
Copper (Cu)	2.6	49.5
PFOA	9.1	0.003
Zinc (Zn)	3.38	113.4
TBBPA	0.254	<0.0024
TCEP	6.5	0.0577
Triclosan	0.1	n.a.
Arsenic (As)	0.6	2.7
Chromium (Cr)	3.4	5.3
EU priority substances		
Cadmium (Cd)	0.2	0.2
Lead (Pb)	1.3	3.7
Nickel (Ni)	8.6	5.9
Mercury (Hg)	0.07 ***	0.0007
Brominated diphenyl ethers *	0.014 ***	n.a.
Hexachlorobenzene	0.05 ***	n.a.
C10-13 chloroalkanes **	0.4	0.1375
Pentachlorobenzene	0.0007	n.a.
Nonylphenol (4-)	0.3	<0.00004
Oktylphenol (4-*tert*-)	0.01	0.047
PFOS	0.00013	0.0007

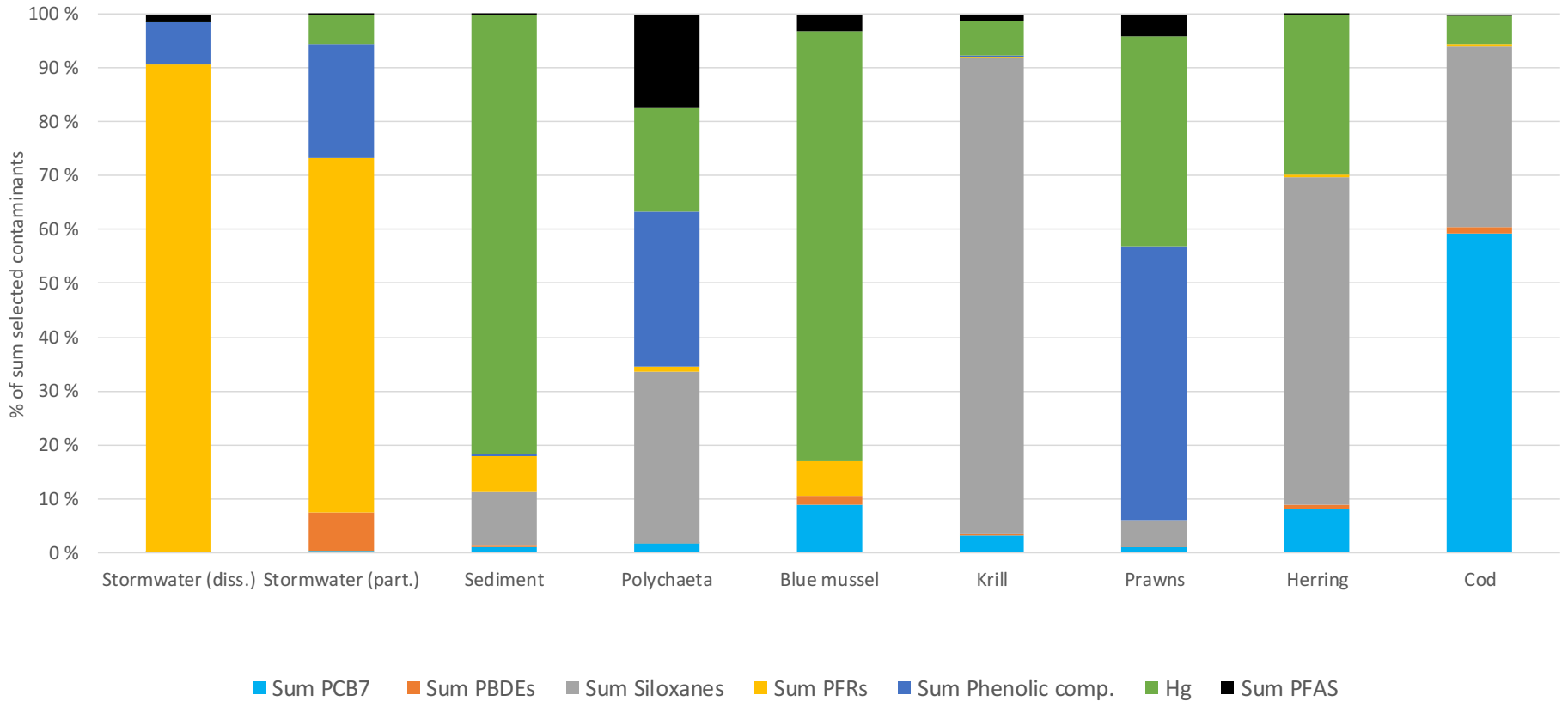
* Sum of BDE-28, -47, -99, -100, -153 and -154.
** Short chained chloroparaffins (SCCPs)
*** No AA-EQS for these substances, thus this is the MAC-EQS (M-608)

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. The selected contaminants were Sum PCB7, Sum PBDEs, Sum Siloxanes, Sum PFRs, Sum Phenolic compounds, Hg and Sum PFAS (See Table 4 for specifics regarding the constituents of the sums of contaminant groups).

PFRs apparently constitute a major proportion of the contaminants in storm water, and were also found in sediment and mussels to some degree. These chemicals are not major constituents of the sum of contaminants in the organisms in the Inner Oslofjord. Mercury is a major constituent of the sum of contaminants in sediments and constitutes different proportions of the sum of contaminants in the organisms of the Inner Oslofjord. In blue mussel Hg constitutes the largest proportion of the sum of contaminants (as in sediment). Note that mercury was analysed in cod liver in 2016 (not muscle, where concentrations are likely somewhat higher). PCBs constituted the largest proportion of the sum of contaminants in the lipid rich cod livers. Siloxanes (not analysed in storm water) were major constituents of the sum of contaminants in sediment, polychaetes, krill, herring and cod (liver).

A.


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

B.

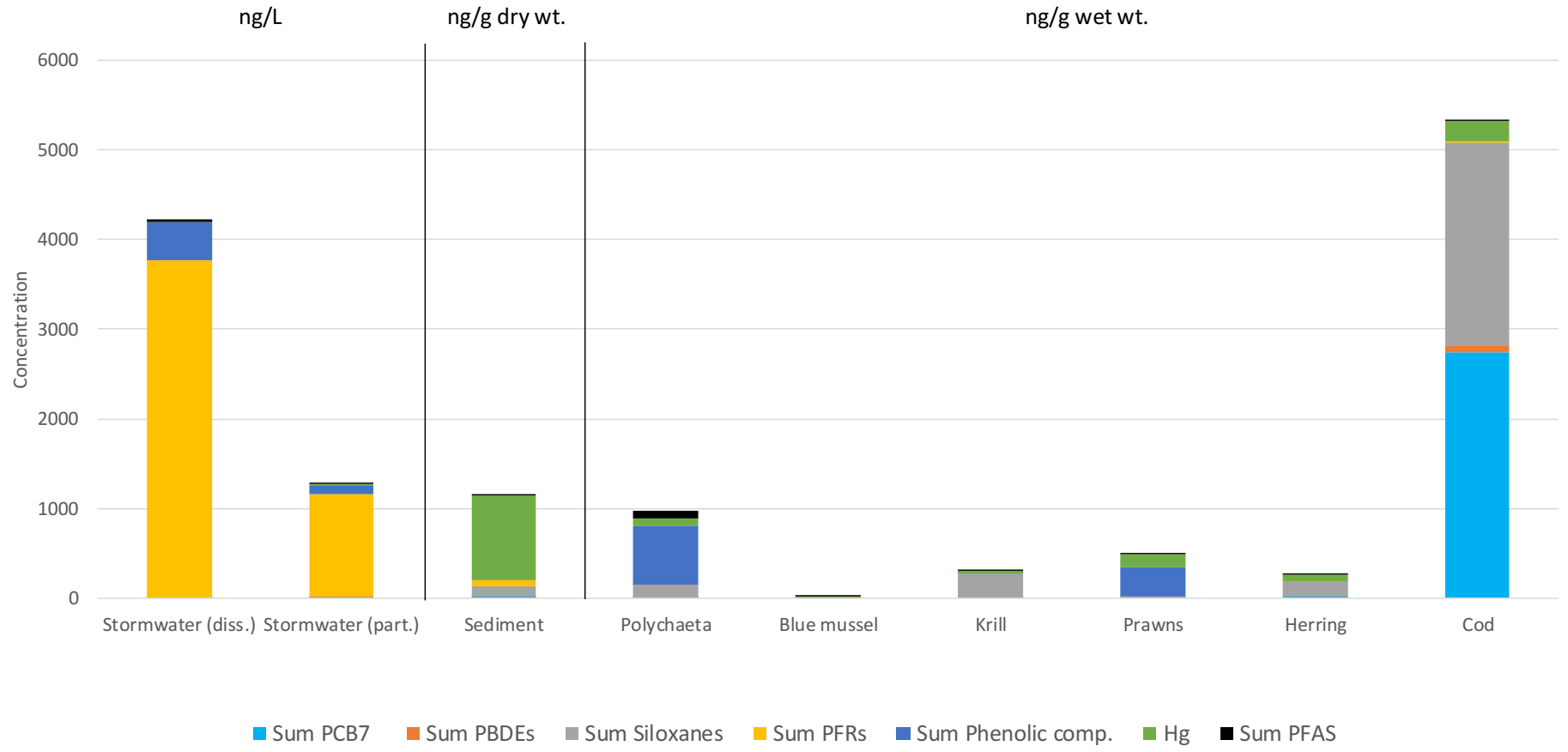


Figure 37. Relative contribution of selected contaminants/groups of contaminants to the sum of these contaminants/groups of contaminants (A.), as well as concentrations (B.), in stormwater (dissolved and particulate fractions) entering the Oslofjord, sediments of the Inner Oslofjord, and polychaetes, blue mussel, krill, prawns, herring and cod (liver) from the Inner Oslofjord Note that siloxanes were not analysed in stormwater.

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, $\delta^{34}S$, $\delta^{13}C$, $\delta^{15}N$, C:N (W%), trophic position (deduced from $\delta^{15}N$,) weight of egg (g) and eggshell thickness (mm) for herring gull eggs, $\delta^{34}S$, $\delta^{13}C$, $\delta^{15}N$, C:N (W%), trophic position (deduced from $\delta^{15}N$), wing length (mm), head length (mm) and body mass (g) for herring gull (blood), $\delta^{13}C$, $\delta^{15}N$, 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, 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. Some of these were included in different statistical analyses referred to above. The measurements of these support parameters are presented in Tables A1-A5 in the Appendix. The lipid content of all biological samples is given in the electronic Appendix.

3.5 Biological effect parameters

The following biological effect parameters were measured in cod: Gonad histopathology, vitellogenin (VTG) in blood plasma, micronucleii (in blood cells), acetylcholinesterase (AChE) activity in muscle (microsomal fraction), as well as the physiological parameters liversomatic index (LSI) and gonadosomatic index (GSI).

The purpose of the gonad histopathology was to assess the histological status of gonads, including histopathological conditions. Histological parameters are commonly used as markers of health status in various fish species. The identification of pathologies and diseases are increasingly being used as indicators of environmental stress since they provide a definite and ecologically-relevant end-point for chronic/sub-chronic contaminant exposure. Histopathological alterations illustrate a definitive endpoint of historical exposure, intermediate between initial biochemical changes and reproductive capability and growth.

Vitellogenin is a parameter of which the response is well characterized and limited to substances with estrogenic (or anti estrogenic) activity. Synthesis of VTG is regulated by the hormone estradiol. High levels of estradiol mean high production of VTG in the liver and thus higher levels in blood plasma.

Micronucleus formation (MN) is one of the most widely used methods to investigate chromosomal aberrations resulting in the formation of satellite DNA. Micronucleus formation can be used as a measure of chemical induced genotoxicity.

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. Acetylcholinesterase (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).

Gonad histopathology was performed by IRIS and the results are reported in the Appendix. Some quantitative measures from the histopathology are also presented in Table 12, together with results from the other effect parameter analyses. It was concluded that there were only 3 individuals with pathological changes in gonads. These were females with granulomatous inflammation together with fibrosis appearing during normal spawning process as utilization of aretic hydrated oocytes (AHO). It is difficult to relate this to any contaminant concentrations.

Vitellogenin was measured in blood plasma of cod using an enzyme-linked immunosorbent assay (ELISA). As expected, concentrations were apparently higher in females (n=12), than in males (n=3), and variation was high (Figure 38; No statistics performed as the number of males was low). The individual female with the markedly highest VTG concentrations was also the one with the highest gonadosomatic index (GSI; Table 12), and there was a statistically significant positive relationship (log-log) between GSI and VTG in females (R^2=0.42; p=0.0229). There were some statistically significant relationships (log-log) between the concentrations of contaminants and VTG in females. The following compounds showed a positive relationship with VTG: PCB-31 and -167, TBA, BDE-99 and MCCP. There were also several PCBs, PFAS compounds and metals (As, Ag, Sb and Pb) that showed a negative relationship with VTG. However, any possible causality between VTG and contaminant concentrations is difficult to establish. Co-variability between parameters is an issue of concern, and for instance PCBs have been shown to have both oestrogenic and anti-oestrogenic effects in fish (Calò et al. 2010).

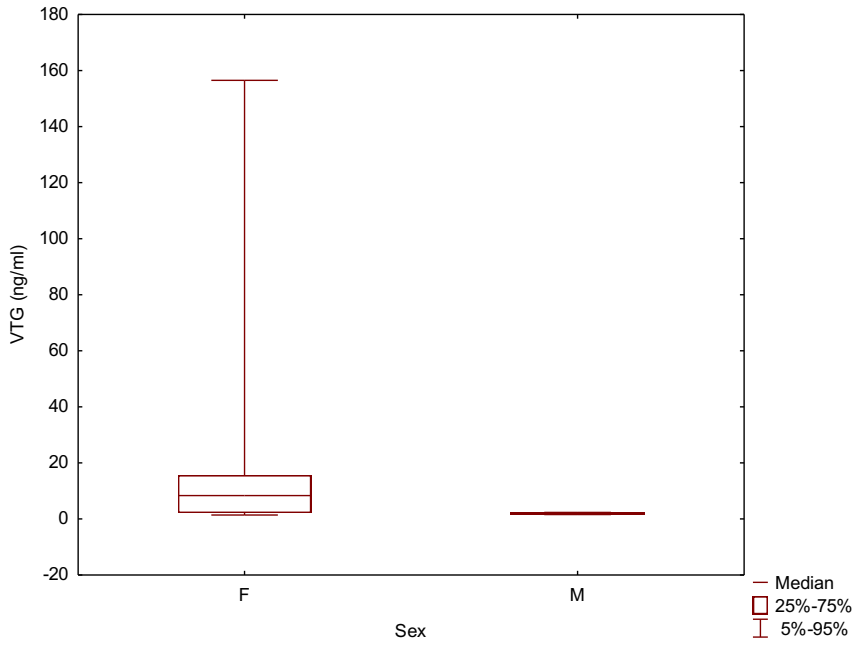


Figure 38. Box plot (median and percentiles) of vitellogenin concentrations (ng/ml) in blood plasma of cod (female, n=12, and male, n=3, respectively) from the Inner Oslofjord.

Table 12.
Biological effect parameters measured for Cod from the Inner Oslofjord.

							Histological analysis, Gonads (see full report in Appendix)		
Sample no.	Sex	VTG *	AChE **	MN ***	GSI	LSI	Stage	Increased vascular or interstitial proteinaceous fluid	Granulomatous inflammation	Atretic follicles
1	F	21.26	9.43		1.08	4.58	5			
2	F	8.85	8.93		0.87	5.68	5			
3	F	7.85	11.77		1.47	3.31	2			
4	M	2.35	11.15		0.51	4.90	6			
5	F	156.50	5.75		4.09	12.92	3			
6	F	9.71	10.76		0.79	4.30	5			
7	M	1.57	13.32		0.41	1.90	3			
8	F	7.86	19.35		0.77	7.04	5	1		
9	F	1.42	17.56		0.91	1.64	5			
10	F				1.17	1.42	6			2
11	F	24.28	11.85		0.81	6.53	5			1
12	F	2.08	13.20		0.55	2.44	5			
13	F	1.92	10.89	0.25	0.47	2.73	5		0.25	
14	F	2.22	14.59	0.00	0.62	2.02	5		0.00	
15	F	9.98	11.84	0.25	0.27	3.77	4		0.25	2

*Vitellogenin (ng/ml); **Acetylcholin esterase activity (nmol ATC/min/mg protein); ***Micronucleii (MN/1000 cells).

Table 12 cont.
Effect parameters measured for Cod from the Inner Oslofjord (extra specimens of which some effect parameters were measured).

							Histological analysis, Gonads			
Sample no. (fish no.)	**Sex**	**VTG ***	**AChE ****	**MN *****	**GSI**	**LSI**	**Stage**	**Increased vascular or interstitial proteinaceous fluid**	**Granulomatous inflammation**	**Atretic follicles**
X1 (16)	M	4.90	2.05	0.25	0.09	4.42	6			

***Vitellogenin (ng/ml); **Acetylcholin esterase activity (nmol ATC/min/mg protein); ***Micronucleii (MN/1000 cells).**

Micronucleii were counted in 4 fish, and 4000 cells were counted per fish. In these, no more than 0.25 micronucleii were observed per 1000 cells (Table 12). According to ICES (2011), the background assessment criteria for micronucleii in cod erythrocytes is 0.4 per 1000 cells.

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 mercury inhibited AChE activity in the head of the common goby (*Pomatoschistus microps*), also leading to decreased swimming performance. However, in 2015, Acetylcholinesterase (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 mercury (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, acetylcholinesterase (AChE) activity in the liver of cod showed statistically significant negative relationships with the weight of cod (Figure 39), but not length (p=0.0505) or age (p=0.1180). Furthermore, no relationship could be observed between acetylcholinesterase (AChE) activity and Hg liver concentrations.

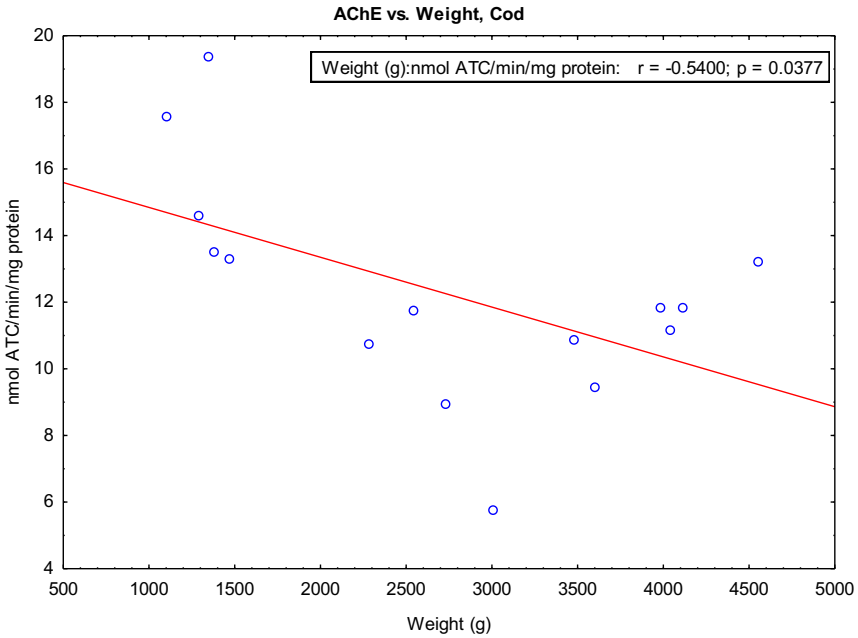


Figure 39. Acetylcholinesterase (AchE) activity in liver of cod from the Inner Oslofjord against weight (g) of cod.

3.6 Eggshell thickness

As previously observed (Ruus et al. 2015; Ruus et al. 2016; The Norwegian Environment Agency M-375 and M-601), a statistically significant positive relationship was found between the eggshell thickness and the trophic position of the eggs (determined from the fraction of stable nitrogen isotopes, $\delta^{15}N$; Figure 40). This suggests that the shell thickness of eggs in the present study was not affected negatively by compounds that increase in concentration with higher trophic position.

Given this relationship, not unexpectedly statistically significant positive relationships (log-log) were found between eggshell thickness and egg concentrations of several compounds: PCB-52, -101, -141, -149 and -187, BDE-28, -49, -100 and -184, p,p′-DDD, D5, As, Ag and Pb. BDE-85 showed a statistically significant negative relationship with trophic position.

Adult female and egg was sampled from the same nest (i.e. mother and future offspring). There was no statistically significant relationship between the trophic position of the gull (mother) and the thickness of eggshells from the same nests. There were, however, statistically significant positive relationships that could be shown between the concentrations of several compounds in the blood of birds and the eggshell thickness of eggs from the same nest: HCB, PCB-47, -66, -74, -99, -105, -118, -128, -138, -153, -156, -157, -167, -170, -180, -183, -187, -194 and -209, BDE-47, -100 and -154, and PFOS. As such this suggest that the shell thickness of eggs in the present study was not affected negatively by increasing concentrations of compounds in the blood of the herring gulls.

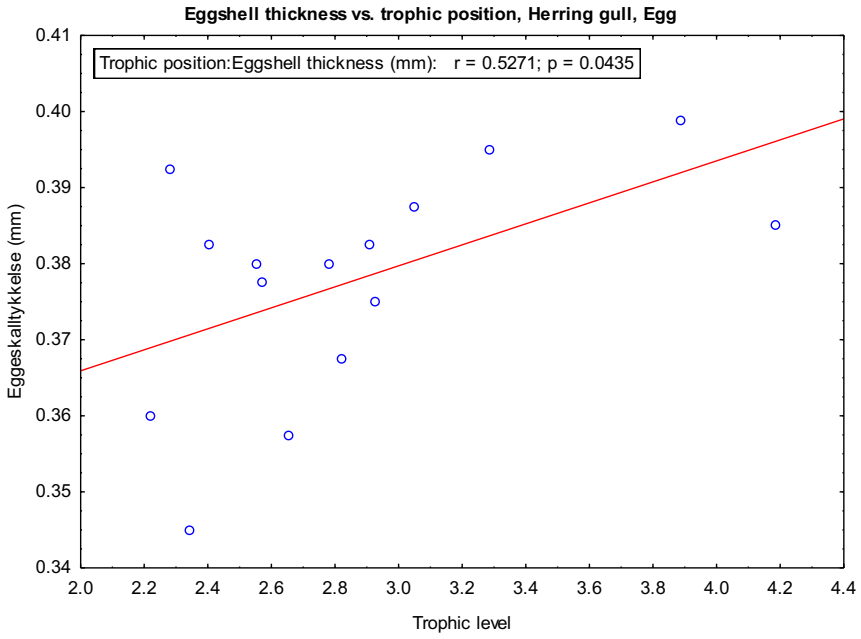


Figure 40. Eggshell thickness (mm) against Trophic position (determined from the fraction of stable nitrogen isotopes, $\delta^{15}N$), in eggs of herring gull from the Oslofjord area.

3.7 Mixture toxicity / cumulative risk

Of the measured contaminants, $PNEC_{pred,}$ $PNEC_{oral}$ and/or EQS_{biota} values were only found for 27 compounds or compound groups (Table 13). The values were obtained from Andersen et al. (2012), EU risk assessment reports, the EQS directive (2013) and M-608. All values ($PNEC_{pred}$, $PNEC_{oral}$ and EQS_{biota}) are hereby referred to as $PNEC_{pred}$ and refer to secondary poisoning of terrestrial organisms from eating contaminated prey. The risk of secondary poisoning of seabirds feeding on blue mussels, polychaetes or herring was calculated by summing up the $MEC/PNEC_{pred}$ values as described earlier and is presented in the following subchapters.

Table 13.
Available PNEC values for the analysed contaminants (µg/kg).

Compound	$PNEC_{pred}$ [a]	$PNEC_{oral}$	QS_{biota} [b]
Bisphenol A	2670		
Cadmium (Cd)		160[c]	
Decamethylcyclopentasiloxane (D5)	13000		15217
Hexachlorobenzene (HCB)			10
Dodecamethylcyclohexasiloxane (D6)		667000[g]	
Sum DDT (50-29-3, 789-02-6, 72-55-9, 72-54-8)			609
Lead (Pb)	3600		
Medium chained chloroparafins (MCCP)	10000		170
Mercury (Hg)	400		20
Nickel (Ni)	8500[d]		
Nonylphenol (4-)	10000		3000
OctaBDE (BDE183, 184, 191, 196, 197, 202, 206, 207)	6700		
Octamethylcyclotetrasiloxane (D4)		1700[f]	
Octylphenols (octylphenol and 4-tert-octylphenol)	10000		0.004 (4t only)
PeCB			50
PCBs (sum 7 PCBs)			1
PentaBDE (BDE-99 + BDE-100)	1000		
DecaBDE (BDE-209)	833000		
Sum PBDE (BDE-28, -47, -99, -100, -153, -154)			0.0085
PFOA			91.3
PFOS	13		9.1
Short chained chloroparafins (SCCP)	5500		6000
TCEP			7304
TCP	1700		
TCPP	11600		
tetrabromobisphenol A	667000		
Triclosan	33300	1670[e]	15217

[a]Obtained from Andersen et al. (2012)
[b] M-608 and EQS directive 2013/39/EU
[c]EU RAR Cd 2007
[d]EU RAR Ni 2008
[e]ECHA 2015,
[f]Brooke et al., 2009b.
[g]Brooke et al., 2009a

3.7.1 Risk of secondary poisoning for predators of blue mussels

The sum of MEC/$PNEC_{pred}$ values based on measured concentrations in blue mussels was 9.98 which is indicative of a risk to predators of these organisms. The main risk drivers for secondary poisoning of seabirds feeding on blue mussels are the sum of PBDEs (MEC/$PNEC_{pred}$ = 7.02), sum of 7 PCBs (MEC/$PNEC_{pred}$ = 1.69) and Cd (MEC/$PNEC_{pred}$ = 1.08), constituting 98% of the total sum of MEC/$PNEC_{pred}$ (Figure 41). All main risk drivers had a MEC/PNEC ratio above 1 indicating that they constitute a risk by themselves. Eight of the detected compounds (PFHxS, PFOSA, TBA, DBDPE, TPP, TBEP, EHDP, and TEHP) were not included in the calculations due to a lack of $PNEC_{pred}$ values potentially leading to an underestimation of the risk. On the other hand, the risk contribution of the main risk drivers (sum PBDE and Sum PCB7) are calculated by the use of $QS_{biota,hh}$ values which are more conservative than $PNEC_{pred}$, $PNEC_{oral}$ and $QS_{biota,\ secpois}$ values, potentially leading to an overestimation of the risk.

Table 14.
Calculation of MEC/PNECpred ratios for blue mussels.

Compound	$MEC_{average}$ (µg/kg)	MEC/PNEC
Sum PBDE (BDE-28, -47, -99, -100, -153, -154)	0.060	7.02[a]
Sum 7 PCB	1.7	1.69[a]
Cd	170	1.08
Pb	370	0.10
Ni	370	0.04
Hg	15	0.04
PFOS	0.070	$5.4E^{-3}$
HCB ($QS_{biota,\ hh}$)	0.0079	$7.9E^{-4}$[a]
SCCP	1.9	$3.5E^{-4}$
BDE-209	0.22	$2.7E^{-7}$
Sum MEC/PNEC		9.98

[a] MEC/PNEC values calculated based on $QS_{biota,hh}$ values

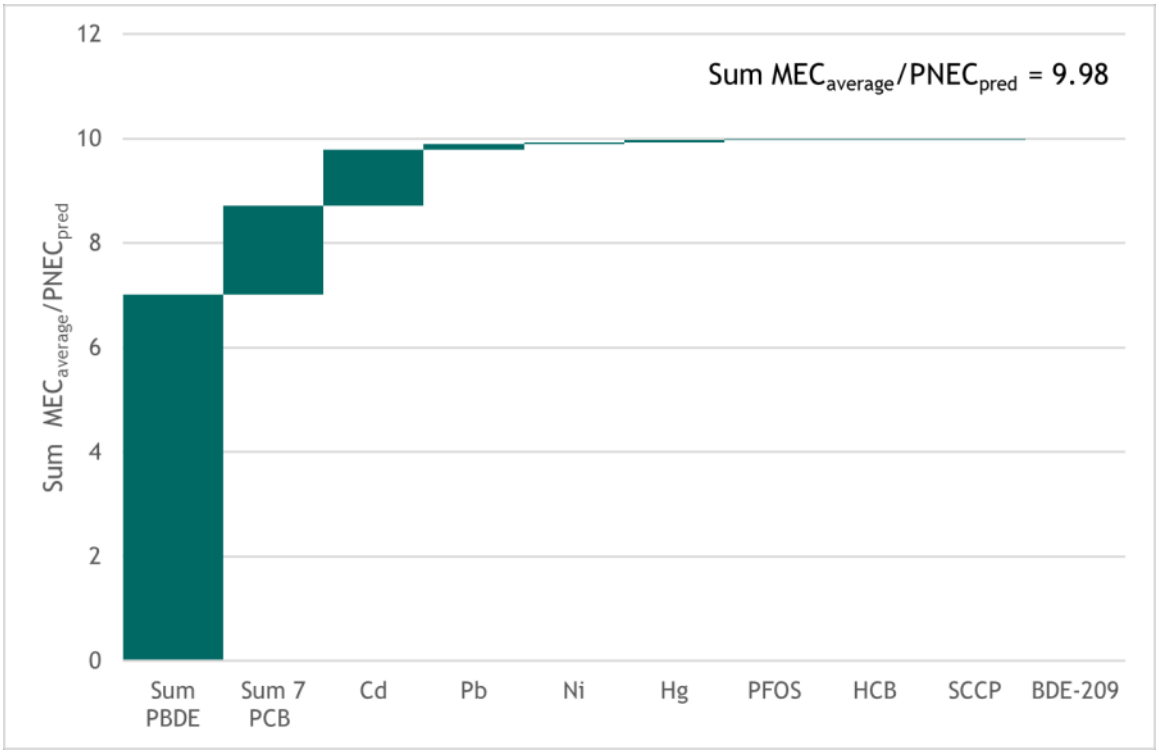


Figure 41. Contribution plot of MEC/PNEC$_{pred}$ summation for values measured in blue mussels. Values for sum PBDE (BDE-28, -47, -99, -100, -153, -154), sum PCB7 and HCB were calculated based on QS$_{biota,hh}$, whereas all other values were calculated based on PNEC$_{pred}$ values.

3.7.2 Risk of secondary poisoning for predators of polychaetes

The sum of MEC/PNEC$_{pred}$ values based on measured concentrations in polychaetes was 22.95 which is indicative of a risk to predators of these organisms. The individual MEC/PNEC$_{pred}$ ratios are presented in Table 15. The main risk drivers for secondary poisoning of seabirds feeding on polychaetes are the sum of BDEs (MEC/PNEC$_{pred}$ = 11.4), sum of 7 PCBs (MEC/PNEC$_{pred}$ = 8.6), Cd (MEC/PNEC$_{pred}$ = 1.4) and Pb (MEC/PNEC$_{pred}$ = 0.86), constituting 97% of the total sum of MEC/PNEC$_{pred}$ (Figure 41). All main risk drivers except for Pb had a MEC/PNEC ratio above 1 indicating that they constitute a risk by themselves. Of the detected compounds in polychaetes, 39 were excluded from the cumulative risk prediction due to lack of PNEC$_{pred}$ values.

Table 15.
Calculation of MEC/PNECpred ratios for polychaetes

Compound	MECaverage (µg/kg)	MEC/PNEC
Sum PBDE (BDE-28, -47, -99, -100, -153, -154)	0.097	11.40[a]
Sum 7 PCB	8.6	8.6[a]
Cd	220	1.38
Pb	3104	0.86
Ni	2755	0.32
Hg	91	0.23
PFOS	1.4	0.10
HCB	0.16	0.02[a]
4-tert-octylphenol	98	$9.82E^{-3}$
D5	118	$9.1E^{-3}$
bisphenol A	19	$7.2E^{-3}$
D4	6.1	$3.6E^{-3}$
PeCB	0.055	$1.1E^{-3a}$
TCPP	6.7	$5.8E^{-4}$
SCCP	2.9	$5.2E^{-4}$
MCCP	1.0	$1.0E^{-4}$
TCP	0.060	$3.5E^{-5}$
TCEP	0.20	$2.7E^{-5a}$
Sum MEC/PNEC		22.95

[a] MEC/PNEC values calculated based on $QS_{biota,hh}$ values

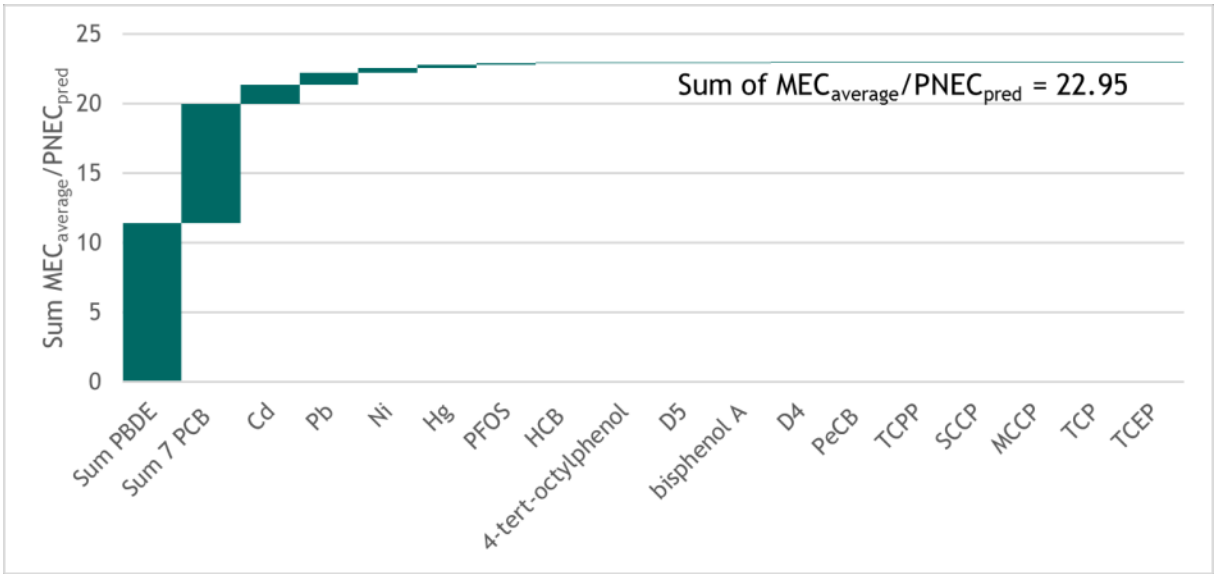


Figure 42. Contribution plot of MEC/PNEC$_{pred}$ summation for values measured in polychaetes. Values for sum PBDE (BDE-28, -47, -99, -100, -153, -154), sum PCB7, HCB, PeCB and TCEP were calculated based on QS$_{biota,hh}$, whereas all other values were calculated based on PNEC$_{pred}$ values.

3.7.3 Risk of secondary poisoning for predators of herring

The sum of MEC/PNEC$_{pred}$ values based on measured concentrations in herring was 135.4 which is indicative of a risk to predators of these organisms. The individual MEC/PNEC$_{pred}$ ratios are presented in Table 16. The main risk drivers for secondary poisoning of seabirds feeding on herring are sum PBDE (MEC/PNEC$_{pred}$ = 112.8) and sum of 7 PCBs (MEC/PNEC$_{pred}$ =22.3), constituting 99.8% of the total sum of MEC/PNEC$_{pred}$. These main risk drivers were the only compounds(group) that had a MEC/PNEC ratio above 1, indicating that they constitute a risk by themselves. Of the detected compounds in herring, 12 were excluded from the cumulative risk prediction due to lack of PNEC$_{pred}$ values.

Table 16.
Calculation of MEC/PNECpred ratios for herring

Compound	$MEC_{average}$ (µg/kg)	MEC/PNEC
Sum PBDE (BDE-28, -47, -99, -100, -153, -154)	0.96	112.80[a]
Sum PCB7	22	22.33[a]
Hg	80	0.20
HCB	0.69	0.07[a]
PFOS	0.17	0.01
D5	151	0.01
Ni	65	$7.7E^{-3}$
Cd	0.81	$5.1E^{-3}$
D4	3.7	$2.2E^{-3}$
PeCB	0.078	$1.6E^{-3a}$
SCCP	3.9	$7.2E^{-4}$
Pb	2.5	$7.1E^{-4}$
TCPP	0.23	$2.0E^{-5}$
D6	4.98	$7.5E^{-6}$
octaBDE	0.0068	$1.02E^{-6}$
BDE-209	0.34	$4.1E^{-7}$
Sum MEC/PNEC		135.45

[a] MEC/PNEC values calculated based on $QS_{biota,hh}$ values

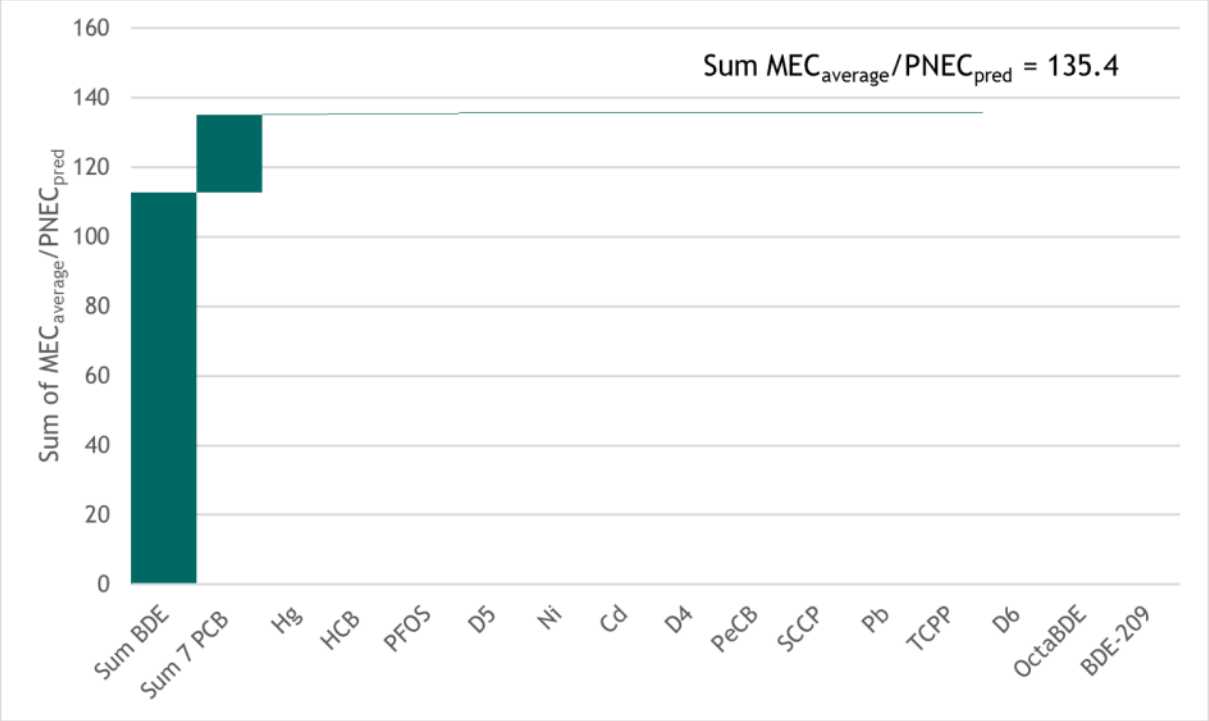


Figure 43. Contribution plot of MEC/$PNEC_{pred}$ summation for values measured in herring. Values for sum PBDE (BDE-28, -47, -99, -100, -153, -153, -154), sum PCB7, HCB, and PeCB were calculated based on $QS_{biota,hh}$, whereas all other values were calculated based on $PNEC_{pred}$ values.

For all food sources, Sum PBDE and Sum PCB were the main risk drivers. The limit values used for these compound groups are the $QS_{biota,secpois,hh}$. As explained previously, this value has a different protection goal than $PNEC_{pred}$ values and could lead to a more conservative risk estimate for these compound groups, potentially overestimating the risk. The results should therefore be interpreted with caution. The sum of $MEC_{average}/PNEC_{pred}$ for all food sources differ from last year where Hg were observed to be the main risk driver. The differences can be explained by the choice between QS_{biota} and $PNEC_{pred}$ values. For the 2015 data, the QS_{biota} for Hg was used (20 µg/kg), which is 20 times lower than the $PNEC_{pred}$ value used for the 2016 data (400 µg/kg). Re-calculating the 2015 data using the $PNEC_{pred}$ value of 400 µg/kg showed that the risk contribution from Hg has decreased from 0.26 to 0.20 in herring from 2015 to 2016, and increased from 0.18 to 0.23 in polychaetes in the same time period.

For the 2016 data, QS_{biota} values were compiled alongside $PNEC_{pred}$ and $PNEC_{oral}$ values to extend the list of compounds that could be included in the cumulative risk assessment. The choice of values were made more consistent by prioritising $PNEC_{pred}$ and $PNEC_{oral}$ values over $QS_{biota\ sec\ pois}$ and $QS_{biota,hh}$ values, hence the $PNEC_{pred}$ value for Hg was chosen over the QS_{biota} value used for the 2015 data. The PBDE congeners covered by $PNEC_{pred}$ for penta PBDEs overlap with the QS_{biota} value for sum PBDE. As the QS_{biota} for sum PBDEs covers more congeners (PBDE-28, -47, -99, -100, -153, -154) than the $PNEC_{pred}$ value for penta-PBDEs, the QS_{biota} value was used when assessing the 2016 data to cover as many compounds as possible. In addition, QS_{biota} for sum PCB7 which was not used for the 2015 data was included for assessing the 2016 data. Therefore, the total sum of $MEC_{average}/PNEC_{pred}$ cannot be compared between the two years. However, comparison between the risk contribution for individual compounds is still possible. For predators of polychaetes and blue mussels, Cd was the

third largest contributor to the total sum of MEC/$PNEC_{pred}$ in 2016 with a value above 1, indicating that this compound also poses a risk to predators of these species by itself. The risk contribution from Cd has increased slightly from 1.01 in blue mussels sampled in 2015 to 1.08 in blue mussels sampled in 2016. The same was observed in polychaetes where the risk contribution from Cd increased from 1.15 to 1.38 in the same time period.

The combination of $PNEC_{pred}$, $PNEC_{oral}$ and $QS_{biota,secpois,hh}$ limit values was performed in order to include as many compounds as possible in these assessments. The large contribution of sum PBDEs and sum PCB7 indicate that the data source from which the $PNEC_{pred}$ is based, is of importance, and the combination of $PNEC_{pred}$ and $QS_{biota,secpois,hh}$ add some uncertainty to the estimates. In addition, no grouping of chemicals based on their mode of action or adverse effects were performed, potentially contributing to an overestimation of the risk. Another aspect adding uncertainty to the performed assessment is that $PNEC_{pred}$ values were only found for a limited number of compounds and compound groups (27), leading to exclusion of several detected compounds from the risk estimation, potentially contributing to an underestimation of the risk. As several aspects in the performed cumulative risk assessment can potentially lead to an over- or under-estimation of the risk, the results should be interpreted with caution and considered as a first tier screening for potential cumulative risk.

3.7.4 Risk for effects on herring gull from exposure in eggs

The approach of summing up MEC/$PNEC_{pred}$ values is considered a conservative first-tier approach in order to filter out scenarios with low environmental risk. The calculated sum of MEC/$PNEC_{pred}$ based on blue mussels, polychaetes or herring as food source all indicated a risk of secondary poisoning, mainly by the risk drivers sum PBDEs, sumPCB7 and Cd. In order to evaluate the risk for birds based on the measured concentrations, relevant toxicity data for the same species group with the same exposure concentration denomination (e.g. ng/g egg) as the measured concentrations is required.

In a recent study from the Norwegian Environment Agency (Andersen et al. 2014), the combined risk of effects in sea bird eggs were calculated by comparing MEC in eggs with effect data from exposure in eggs compiled from literature. These effect data were adopted in this study in order to evaluate the combined risk for effects on Herring gull eggs. As the effect data does not separate between type of effect (e.g. mortality, reduced number of eggs) or effect level (e.g. LOEC, EC(D)10, EC(D)50), and assessment factors are not used in this study, the applied approach is considered as an approximation to the environmental risk assessment of chemical mixtures, tier-two. The results should therefore be interpreted with caution. The risk of combined effects of the compounds was calculated based on average (MECa) and median (MECm) values of the measured egg concentrations in 15 eggs. As seen from Table 17, using average measured concentrations led to a higher sum of MEC/Effect ratios than when using median measured concentrations. In both cases (average and median values) the sum was higher than 1, indicating a risk for effect on the eggs of the mixture of contaminants.

Only sum PCBs had MEC/effect ratios above 1 in both approaches (using average or median concentration), showing that there is a risk of effects of PCBs alone. The main contributors to the sum of MECm/effect in addition to sum PCBs was Cu and Ni. (Figure 44). These findings are similar to that observed by Herzke et al. (2015; The Norwegian Environment Agency M-354) where a sum MEC/effect for compounds measured in sparrowhawk eggs were higher than 1.

Table 17.
Calculation of MEC/effect ratios for Herring gull eggs

Compound	MECa (ng/g egg)	MECm (ng/g egg)	Effect value (ng/g egg)*	MECa/effect	MECm/effect
Sum PCB	503	421	400	1.26	1.05
Cu	708	701	1160	0.610	0.605
Ni	458	193	1000	0.458	0.193
As	51.6	34.2	180	0.287	0.190
Hg	78.6	34.9	400	0.196	0.0872
PFOS	19.5	15.8	100	0.195	0.158
BDE-99	1.87	1.61	10	0.187	0.161
BDE-100	1.12	0.814	10	0.112	0.0814
p,p'-DDE	45.1	29.7	3000	0.0150	0.0099
BDE-85	0.0399	0.0297	10	0.00399	0.00297
BDE-119	0.0249	0.0203	10	0.00249	0.00203
Cd	0.0499	0	100	0.000499	0
BDE-126	0.00496	0	10	0.000496	0
EHDP	0.0718	0	1100	$6.52E^{-5}$	0
Sum				3.33	2.54

*Effect values were obtained from Andersen et al. (2014)

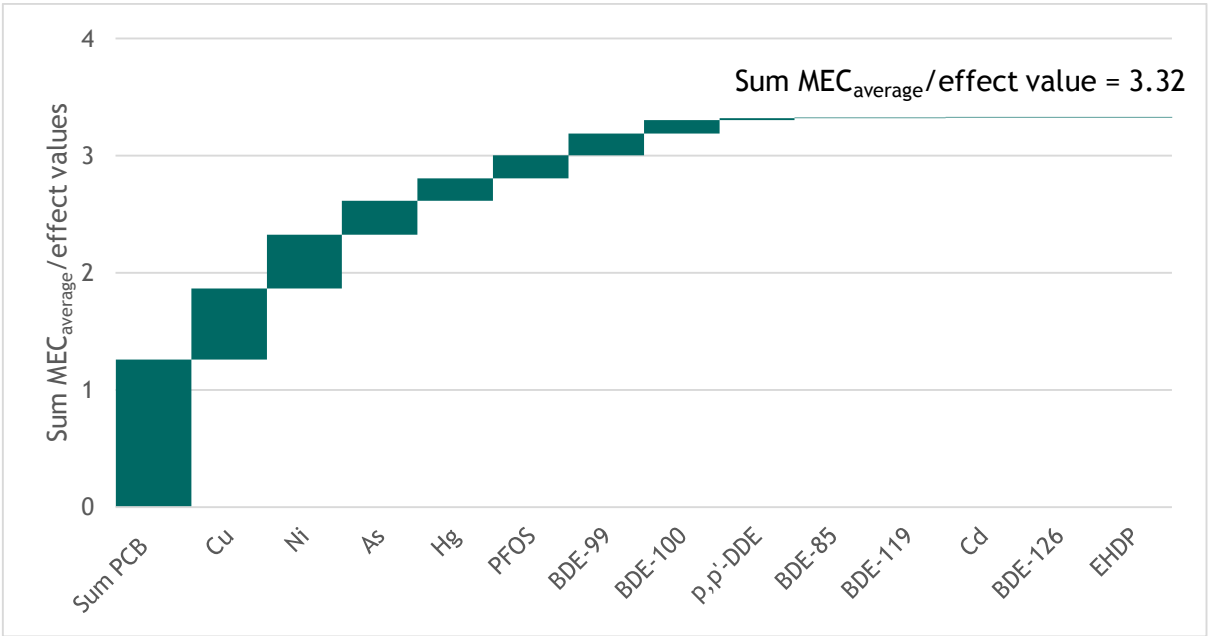


Figure 44. Contribution plot of MEC/PNEC$_{pred}$ summation for values measured in herring gull eggs.

Based on the measured concentrations of pollutants in Herring gull and effect data compiled by Andersen et al. (2014), there is a risk for effects of combined effects, mainly driven by the sum of PCBs and the metals Cu and Ni. As many as 58 detected compounds were excluded from the assessment due to lack of effect data, adding some uncertainty to the estimation and a potential underestimation of the risk. The results should be interpreted with caution due to the nature of the effect data. The effect data do not correspond to the same endpoint, the same species or the same effect level, adding additional uncertainty to the performed assessment.

3.8 Concluding remarks

In this programme, a large number of chemical parameters have been quantified, in addition to biological effect parameters and support parameters, and concentrations of different chemicals in different compartments of the Inner Oslofjord marine ecosystem are documented. Furthermore, this report presents some relationships between the contaminant concentrations and various biological variables, such as fish length.

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, representing *inter alia* PCBs, PBDEs, S/MCCPs, siloxanes, PFRs, phenolic compounds, metals, PFAS compounds and UV chemicals. Inputs to the fjord via storm water for several of the compounds is also shown (siloxanes not measured in storm water). Some compounds exceeded environmental quality standards. These were in sediments: D5, PCB7, Zn, As, Ni, Hg and PFOS, and in in storm water: Bisphenol A, Cu, Zn, As, Cr, Pb, 4-*tert*-octylphenol and PFOS.

The sampling programme in 2016 was identical to that in 2015, when changes were made, to sample a more representative food web. The results of the stable isotope analysis suggest that the species sampled in 2015 and 2016 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 spanned over 2 to 3 (~2.9) trophic levels with blue mussel defined at trophic level 2.

The biomagnifying potential of contaminants were 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 (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.

UV-chemicals (octocrylene, benzophenone and ethylhexylmethoxycinnamate) and anti-bacterial compounds (Triclosan and Triclocarban) were detected in very few samples in 2016, corresponding to the findings in 2015. Furthermore, phenolic compounds were detected in few samples in 2016, however, the limit of detection was high for some of the compounds, due to blank issues (high

concentrations in blank samples). In 2017 these compounds are planned to be analysed in the bile of cod in an attempt to avoid matrix effects.

Biological effect parameters in cod, such as gonad histopathology, vitellogenin in blood plasma, micronucleii in blood cells, acetylcholinesterase activity in muscle, liversomatic index and gonadosomatic index were investigated. There were only 3 individuals with pathological changes in gonads. These were females with granulomatous inflammation together with fibrosis appearing during normal spawning process as utilization of aretic hydrated oocytes (AHO). Micronucleii, a marker for chromosome break/genotoxicity, were counted in 4 fish, and 4000 cells were counted per fish. In these samples, no more than 0.25 micronucleii were observed per 1000 cells, which is below the ICES background assessment criteria for micronucleii in cod erythrocytes. This corresponds to findings in 2015, and micronuclei will be omitted from the "Urban fjord programme in 2017, since this method offers limited information for cod in the Inner Oslofjord.

In 2016, acetylcholinesterase (AChE) activity in the muscle of cod showed statistically significant negative relationships with the weight of cod, but not length or age. Furthermore, no relationship could be observed between acetylcholinesterase (AChE) activity in muscle and Hg liver concentrations in 2016. As such, a correlation between AChE and mercury, as found in 2015 (mercury then analysed in muscle), was not shown. The parameter AChE will be included in the 2017 Urban fjord programme to see if the results from 2015 are reproduced.

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 sampled from remote colonies in Norway (Sklinna and Røst) in 2012. Mean D5 concentration in eggs from the present study was also a factor of ~140 higher than those observed in herring gull eggs from the remote colonies (Sklinna and Røst; sampled in 2012), indicating urban influence. On the other hand, concentrations of "legacy" contaminants, such as PCB-153 and p,p′-DDE appeared lower in the eggs from Oslofjorden, than those observed in herring gull eggs from remote colonies (Sklinna and Røst), suggesting that these contaminants (associated with diffuse pollution) accumulate to somewhat higher concentrations in gulls foraging to a larger degree on marine prey organisms. In 2017, the Urban fjord programme will include a herring gull reference station in the Outer Oslofjord.

In 2016 a student conducted her MSc-thesis measuring DNA-damage in the herring gulls of the Oslofjord, in addition to measuring DNA-damage and selected contaminants in herring gulls of a remote colony (Hornøya, Northern Norway). The study showed that concentrations of siloxanes were apparently higher in blood of herring gulls from the Inner Oslofjord, compared to the rural colony at Hornøya. On the other hand, concentrations of HCB and PCBs were higher in the gulls from the rural Hornøya colony. The findings seem to corroborate the above comparison of herring gull eggs from the Oslofjord with eggs from more remote marine colonies at Sklinna and Røst. Higher frequency of DNA-damage was found in herring gulls from the Inner Oslofjord, compared to the rural colony at Hornøya. This suggest higher stress associated with urban influence, although it is difficult to relate this to contaminants, specifically.

While the concentrations of PCBs in sparrow hawk eggs from the Oslo area appeared higher than in the herring gull eggs from the 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.

Adult female gulls and eggs were sampled from the same nest (i.e. mother and future offspring), and statistically significant relationships between the stable isotope ratios ($\delta^{13}C$, $\delta^{15}N$ and $\delta^{34}S$), as well as concentrations of several compounds, in the blood and in the egg were observed. This suggest that eggs to some degree may reflect maternal contaminant patterns.

The risk of secondary poisoning of seabirds feeding on blue mussels, polychaetes or herring was calculated by summing up the MEC/$PNEC_{pred}$ values. Available $PNEC_{pred}$ values ($PNEC_{pred}$ and $QS_{biota,secpois,hh}$ for compounds where no $PNEC_{pred}$ was available) were only found for 27 compounds or compound groups leading to exclusion of several detected compounds from the cumulative risk estimation. All three food sources were estimated to pose a risk for the predating seabirds, with sum BDE and sum PCBs being the main risk drivers in all food sources and with the addition of Cd in polychaetes and blue mussels. As the values used for calculation of sum PBDE and sum PCB7 are the $QS_{biota,secpois,hh}$ it should be noted that these values are considered to be more conservative than $PNEC_{pred}$ values, leading to a potential overestimation of the risk and the results should be interpreted with caution. The combination of $PNEC_{pred}$ and $QS_{biota,secpois,hh}$ add uncertainty to the estimates as they are derived by different methods.

The combined risk of effects in herring gull eggs were calculated by comparing average (MECa) and median (MECm) values of the measured egg concentrations in 15 eggs with effect data from exposure in eggs. Only sum PCBs had MEC/effect ratios above 1 in both approaches (using average or median concentration), showing that there is a risk of effects of PCBs alone. The main contributors to the sum of MECm/effect in addition to sum PCBs were Cu and Ni.

Overall, the combined risk assessments showed that seabirds might be at risk with sum PCBs and metals being the main contributors when looking at concentrations in prey and in the eggs. Although Sum PBDEs was also identified as main contributor in the prey, the $QS_{bioa,secpois,hh}$ value for sum PBDEs are very low and the results should be interpreted with caution.

In summary, it is shown that sediments and organisms in the inner Oslofjord contain different contaminants in different concentrations, both legacy contaminants and contaminants of more emerging concern. Some pathways for these contaminants into the fjord is also shown. For instance, PFRs apparently constitute a major proportion of the contaminants in storm water, and were also found in sediment and mussels to some degree. PCBs constituted the largest proportion of the sum of contaminants in the lipid rich cod livers. Furthermore, siloxanes were important constituents of the sum of contaminants in cod liver, as in sediment, polychaetes, krill and herring. A combined risk assessment showed that apex predators, such as seabirds, might be at risk to negative effects of contaminants. Legacy contaminants were still important risk drivers.

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Appendix

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

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

Area	<63 µm (% dry wt.)	TOC (µg/mg dry wt.)
Inner Oslofjord (station Cm21)	67	33.6

Table A2.
Support parameters measured for Herring gull eggs from the 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	JCH22	9.28	-27.20	8.95	6.63	2.57	70.27	0.38
2	JCH23	10.92	-26.19	8.32	6.64	2.40	70.3	0.38
3	JCH25	8.89	-22.10	15.08	6.22	4.18	79.79	0.39
4	JCH27	14.16	-24.13	11.66	6.21	3.28	88.44	0.40
5	JCL13	8.95	-26.87	8.88	6.33	2.55	75.18	0.38
6	JCL43	12.52	-24.55	10.29	5.46	2.92	91.38	0.38
7	JCL48	17.63	-23.59	13.96	7.27	3.89	85.82	0.40
8	JCL51	9.19	-27.00	9.27	6.28	2.65	71.75	0.36
9	JCL52	9.10	-27.18	8.08	6.64	2.34	74.03	0.35
10	JCU50	12.84	-25.84	9.74	6.68	2.78	64.89	0.38
11	JCX20	11.47	-26.42	9.90	6.60	2.82	75.06	0.37
12	JCX95	11.81	-25.70	10.24	5.72	2.91	74.7	0.38
13	JCX96	11.09	-26.21	10.77	7.01	3.05	80.94	0.39
14	JCX00	8.89	-27.04	7.85	7.29	2.28	70.85	0.39
15	JCH28	7.25	-27.26	7.62	6.42	2.22	81.62	0.36

Table A3.
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	JCH22	10.23	-24.43	8.18	3.26	2.37	412	119.8	910
2	JCH23	7.27	-24.21	7.30	3.16	2.14	416	120.2	950
3	JCH25	13.78	-21.88	11.99	3.24	3.37	850	111.5	424
4	JCH27	14.41	-22.00	10.34	3.14	2.94	426	116.1	940
5	JCL13	10.45	-24.30	8.42	3.15	2.43	426	120.5	930
6	JCL43	11.35	-24.02	8.59	3.18	2.48	411	113.6	910
7	JCL48	17.36	-21.09	12.49	3.13	3.50	448	115.1	1010
8	JCL51	11.34	-23.92	8.57	2.99	2.47	423	112.8	810
9	JCL52	13.21	-24.23	9.10	2.96	2.61	437	120.1	970
10	JCU50	13.71	-22.39	10.98	2.95	3.11	446	116.9	930
11	JCX20	9.60	-24.52	8.86	2.98	2.55	427	118.2	920
12	JCX95	10.97	-24.37	9.36	2.93	2.68	435	118.4	950
13	JCX96	11.66	-23.65	10.20	2.97	2.90	426	116.8	975
14	JCX00	8.61	-24.58	7.95	2.96	2.31	-	-	-
15	JCH28	10.73	-24.50	8.39	2.93	2.42	416	117	935

Table A4.
Support parameters measured for Cod from the Inner Oslofjord (including some extra specimens of which some effect parameters were measured).

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	-17.32	19.13	2.76	4.88	9	72	3600	165	38.7	F
2	-16.97	18.83	2.74	4.80	6	63	2730	155	23.7	F
3	-17.06	18.88	2.76	4.82	6	65	2540	84	37.3	F
4	-17.85	18.03	2.52	4.59	9	75	4040	198	20.7	M
5	-18.10	17.34	2.68	4.41	5	60	3010	389	123	F
6	-17.39	18.65	2.78	4.76	5	61	2280	98	17.9	F
7	-15.58	15.90	2.53	4.03	6	52	1470	28	6	M
8	-17.11	18.87	2.65	4.81	5	53	1350	95	10.4	F
9	-17.32	17.92	2.54	4.56	2	47	1100	18	10	F
10	-17.31	17.94	2.70	4.57	4	50	1130	16	13.2	F
11	-17.96	17.50	2.59	4.45	4	73	3980	260	32.2	F
12	-17.47	18.68	2.76	4.76	6	74	4550	111	24.9	F
13	-17.14	19.71	2.79	5.03	6	71	3480	95	16.3	F
14	-18.90	17.44	2.75	4.44	3	52	1290	26	8	F
15	-17.92	17.64	2.78	4.49	3	59	4110	155	11	F
X1 (16)	-17.31	18.91	2.54	4.82	5	61	1380	61	1.2	M

Table A5.
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	-19.45	11.57	3.98	2.89
Polychaeta	2	-18.28	10.77	3.42	2.68
Polychaeta	3	-19.24	13.19	3.43	3.32
Blue mussel	1	-12.00	8.19	1.90	2.00
Blue mussel	2	-19.06	8.09	3.65	1.97
Blue mussel	3	-19.28	8.27	3.68	2.02
Krill	1	-20.25	12.43	3.32	3.12
Krill	2	-20.22	12.48	3.13	3.13
Krill	3	-20.18	12.65	3.16	3.17
Prawns	1	-17.41	14.41	2.62	3.64
Prawns	2	-17.34	14.46	2.81	3.65
Prawns	3	-17.46	14.47	2.76	3.66
Herring	1	-21.27	13.64	4.25	3.44
Herring	2	-21.47	13.97	4.12	3.52
Herring	3	-20.99	14.00	3.91	3.53
Cod (pool 1)	1	-17.23	17.62	2.65	4.48
Cod (pool 2)	2	-17.21	18.95	2.74	4.83
Cod (pool 3)	3	-17.83	17.93	2.67	4.56

Biometric measures of Herring gull from the Oslofjord area (this study) and from Hornøya (Northern Norway; from Keilen, 2017), and lipid (%), stable isotope data ($\delta^{13}C$, $\delta^{15}N$ and $\delta^{34}S$, as well %C, %N and %S), frequency of DNA damage (comet assay; %; baseline, after treatment with H_2O_2 and recovery after H_2O_2 treatment), as well as concentrations of various contaminants. The concentrations are presented as ng/g wet wt., except for limits of detection (LoD) of HCHs, PCBs, PBDEs, DPDPE, and PBT, PBEB, DPTE, HBB, EHTBB and BTBTE in the gulls from Hornøya, which are presented as pg/g wet wt.

Location	Hgnr	Ringnr	Sex	wing.mm	weight.g	head.mm	egg	chick	lipid%	d13CVPDB	d15NAIR	W%C	W%N	C/N ratio	d34SCDT	W%S
Hornoya	1	JU675	female	431	1020	128	NA	2	0.8	-20.66	14.44	46.78	14.26	3.28	19.44	0.75
Hornoya	2	JU676	male	NA	1220	135	3	NA	0.6	-21.04	14.29	46.62	14.63	3.19	20.57	0.79
Hornoya	3	JU689	male	450	1340	131	3	NA	0.6	-20.43	14.81	46.40	14.18	3.27	19.23	0.78
Hornoya	4	JU666	female	415	990	120	NA	2	0.6	-21.09	14.40	46.37	14.47	3.20	20.55	0.78
Hornoya	5	JU688	male	437	1250	135	2	NA	0.7	-20.89	15.49	45.08	13.96	3.23	20.66	0.82
Hornoya	6	JU683	female	420	1020	123	2	NA	0.5	-21.01	13.87	46.59	14.33	3.25	19.29	0.82
Hornoya	7	JU687	male	474	1280	142	2	NA	0.5	-20.61	15.36	46.64	14.63	3.19	20.19	0.81
Hornoya	8	JU694	female	430	1020	123	2	NA	1.1	-20.97	15.15	44.70	13.74	3.25	18.51	0.89
Hornoya	9	JU680	female	420	1070	116	3	NA	0.8	-21.95	14.62	45.78	14.26	3.21	18.81	0.78
Hornoya	10	JU678	female	429	960	119	NA	1	0.9	-21.18	14.52	45.33	13.99	3.24	20.18	0.80
Hornoya	11	JX511	female	436	990	118	2	NA	0.9	-21.04	14.81	45.67	14.35	3.18	19.87	0.83
Hornoya	12	JX951	male	449	1240	134	2	NA	0.5	-20.47	16.00	46.72	14.74	3.17	20.76	0.81
Hornoya	13	JX510	male	454	1320	135	2	NA	0.9	-20.50	15.81	46.79	14.64	3.20	20.58	0.77
Hornoya	14	JX512	male	445	1280	131	2	NA	0.7	-20.46	14.80	46.33	14.57	3.18	19.07	0.84
Hornoya	15	JX513	male	467	1230	131	2	NA	0.6	-20.43	15.47	46.86	14.62	3.21	20.52	0.80
Hornoya	16	JU684	female	415	880	116	NA	1	0.5	NA	NA	NA	NA	NA	NA	NA
Hornoya	17	JU674	male	NA	NA	134	NA	2	0.5	-20.26	15.51	46.67	14.75	3.16	20.43	0.81
Oslo	18	JCH22	female	412	910	120	3	NA	1.5	-24.43	8.18	44.89	13.76	3.26	10.23	0.65
Oslo	19	JCH23	female	416	950	120	3	NA	0.4	-24.21	7.30	44.77	14.17	3.16	7.27	0.74
Oslo	20	JCH25	female	424	850	112	3	NA	1	-21.88	11.99	45.17	13.96	3.24	13.78	0.69
Oslo	21	JCH27	female	426	940	116	3	NA	0.6	-22.00	10.34	45.05	14.34	3.14	14.41	0.73
Oslo	22	JCL13	female	426	930	121	3	NA	4.2	-24.30	8.42	44.93	14.27	3.15	10.45	0.70
Oslo	23	JCL43	female	411	910	114	NA	NA	0.6	-24.02	8.59	45.86	14.44	3.18	11.35	0.64
Oslo	24	JCL48	female	448	1010	115	3	NA	1.5	-21.09	12.49	45.95	14.70	3.13	17.36	0.70
Oslo	25	JCL51	female	423	810	113	3	NA	0.8	-23.92	8.57	43.28	14.46	2.99	11.34	0.69
Oslo	26	JCL52	female	437	970	120	3	NA	2.7	-24.23	9.10	42.32	14.30	2.96	13.21	0.53
Oslo	27	JCU50	female	446	930	117	3	NA	1.3	-22.39	10.98	42.59	14.46	2.95	13.71	0.70
Oslo	28	JCX20	female	427	920	118	3	NA	14.8	-24.52	8.86	42.19	14.16	2.98	9.60	0.69
Oslo	29	JCX95	female	435	950	118	3	NA	0.8	-24.37	9.36	41.56	14.19	2.93	10.97	0.86
Oslo	30	JCX96	female	426	975	117	2	NA	0.9	-23.65	10.20	42.31	14.24	2.97	11.66	0.71
Oslo	31	JCX00	female	NA	NA	NA	3	NA	1.6	-24.58	7.95	42.65	14.41	2.96	8.61	0.71
Oslo	32	JCH28	female	416	935	117	2	NA	0.8	-24.50	8.39	42.51	14.52	2.93	10.73	0.69

Location	Hgnr	Ringnr	DNA_H2O2	DNA_norm	DNA_recov	hg	D4	D5	D6	o,p-DDE	p,p-DDE	o, p DDD	p, p-DDD	o,p-DDT	p,p- DDT
Hornoya	1	JU675	4.59	0.19	5.81	283.53	2.50	<LOQ (1.6)	2.26	<0.004	13.28	<0.0108	<0.01	<0.014	<0.013
Hornoya	2	JU676	4.37	0.33	11.14	239.09	2.01	<LOQ (1.6)	<LOQ (2.0)	<0.0044	23.02	<0.0064	<0.0059	<0.0079	<0.0077
Hornoya	3	JU689	9.18	0.96	22.73	187.38	2.44	<LOQ (1.6)	<LOQ (2.0)	<0.0031	10.89	<0.0043	<0.004	<0.0054	<0.0052
Hornoya	4	JU666	12.00	1.20	12.80	196.06	1.53	<LOQ (1.6)	NA	<0.0036	11.87	<0.0064	<0.0058	<0.0079	<0.0077
Hornoya	5	JU688	8.40	0.45	2.58	139.78	1.56	<LOQ (1.6)	2.44	<0.0019	15.95	<0.0075	<0.0069	<0.0093	0.0521
Hornoya	6	JU683	1.22	1.37	6.22	110.32	1.81	<LOQ (1.6)	2.37	<0.0029	9.81	<0.0086	<0.0079	<0.011	0.036
Hornoya	7	JU687	6.32	2.45	4.36	170.85	NA	NA	NA	<0.0017	34.90	<0.0058	<0.0053	<0.0071	<0.0069
Hornoya	8	JU694	3.66	0.73	1.72	96.86	1.53	<LOQ (1.6)	<LOQ (2.0)	<0.0034	7.66	<0.0037	<0.0034	<0.0046	0.04
Hornoya	9	JU680	1.76	0.36	4.80	106.92	<LOQ (1.5)	<LOQ (1.6)	<LOQ (2.0)	<0.0032	10.18	<0.002	<0.0018	<0.0024	0.084
Hornoya	10	JU678	6.88	0.97	7.19	176.19	1.57	<LOQ (1.6)	<LOQ (2.0)	<0.0043	13.61	<0.0066	<0.0061	<0.0082	0.03
Hornoya	11	JX511	6.14	0.43	3.96	156.43	<LOQ (1.5)	<LOQ (1.6)	<LOQ (2.0)	<0.0027	6.23	<0.0056	<0.0052	0.6775	<0.0068
Hornoya	12	JX951	11.83	21.50	14.97	260.05	1.55	<LOQ (1.6)	<LOQ (2.0)	<0.0011	9.61	<0.0035	<0.0032	0.626	<0.0042
Hornoya	13	JX510	11.87	28.13	22.27	329.04	1.70	<LOQ (1.6)	<LOQ (2.0)	<0.0026	8.61	<0.0035	<0.0032	<0.007	0.058
Hornoya	14	JX512	1.80	0.17	7.96	249.80	1.98	<LOQ (1.6)	2.44	<0.0029	9.45	<0.0042	<0.0038	<0.0043	0.028
Hornoya	15	JX513	66.42	2.56	27.33	432.65	1.62	<LOQ (1.6)	2.09	<0.002	9.81	<0.0082	<0.0076	<0.0043	0.0413
Hornoya	16	JU684	NA	NA	NA	171.54	2.07	2.20	2.70	<0.0095	7.35	<0.02	<0.02	<0.0052	<0.025
Hornoya	17	JU674	NA	NA	NA	287.96	3.40	5.10	5.67	<0.0017	7.32	<0.0051	<0.0047	<0.01	<0.0062
Oslo	18	JCH22	77.21	4.80	28.24	NA	2.24	2.71	<LOQ (2.5)	<0.0361	2.5200	<0.0197	<0.0387	<0.0526	<0.136
Oslo	19	JCH23	5.91	1.10	29.93	NA	2.80	2.56	<LOQ (2.5)	<0.0482	<2.66	<0.0263	<0.0516	<0.0701	<0.181
Oslo	20	JCH25	34.30	4.74	17.82	NA	2.37	4.02	<LOQ (2.5)	<0.0482	5.2200	<0.0263	<0.0516	<0.0701	<0.181
Oslo	21	JCH27	21.10	0.94	18.35	NA	<LOQ (2.0)	2.77	<LOQ (2.5)	<0.0222	1.8900	<0.0121	0.0899	<0.0324	<0.0836
Oslo	22	JCL13	29.29	2.71	21.88	NA	<LOQ (2.0)	2.78	<LOQ (2.5)	<0.0482	<2.66	<0.0263	<0.0516	<0.0701	<0.181
Oslo	23	JCL43	27.02	1.17	35.41	NA	<LOQ (2.0)	1.42	2.45	<0.0723	<3.99	<0.0394	<0.0774	<0.105	<0.272
Oslo	24	JCL48	13.09	3.21	26.56	NA	NA	NA	NA	<0.0145	14.8000	<0.0079	<0.0155	<0.021	<0.0544
Oslo	25	JCL51	51.23	6.67	42.57	NA	NA	NA	NA	<0.0413	4.0000	<0.0225	<0.0442	<0.0601	<0.155
Oslo	26	JCL52	23.27	11.82	16.45	NA	<LOQ (2.0)	1.73	<LOQ (2.5)	<0.0181	<0.998	<0.0099	<0.0193	<0.0263	<0.0679
Oslo	27	JCU50	43.78	14.99	37.63	NA	2.02	1.67	<LOD (1.1)	<0.0361	<2	<0.0197	<0.0387	<0.0526	<0.136
Oslo	28	JCX20	16.76	32.97	17.25	NA	<LOQ (2.0)	<LOQ (1.3)	<LOD (1.1)	<0.0241	<1.33	<0.0131	<0.0258	<0.0351	<0.0906
Oslo	29	JCX95	58.99	7.67	32.94	NA	<LOQ (2.0)	1.43	<LOD (1.1)	<0.0321	<1.77	<0.0175	<0.0344	<0.0467	<0.121
Oslo	30	JCX96	25.92	4.32	34.45	NA	2.61	10.11	<LOQ (2.5)	<0.0361	2.2800	<0.0197	<0.0387	<0.0526	<0.136
Oslo	31	JCX00	21.73	1.60	75.25	NA	3.04	2.45	<LOQ (2.5)	<0.0321	<1.77	<0.0175	<0.0344	<0.0467	<0.121
Oslo	32	JCH28	24.06	5.58	48.98	NA	2.21	1.68	<LOQ (2.5)	<0.0206	<1.14	<0.0113	<0.0221	<0.03	<0.0777

Location	Hgnr	Ringnr	PeCB	aHCH	bHCH	gHCH	dHCH	HCB	Oxychlordane	trans-chlordane	cis-chlordane	trans-nonachlor	cis-nonachlor	mirex
Hornoya	1	JU675	0.102	0.003	0.149	<LOD (3.7)	NA	2.508	0.459	0.003	0.055	0.601	0.392	0.483
Hornoya	2	JU676	0.102	<LOD(2)	0.097	<LOD (3.7)	NA	2.667	2.160	0.003	0.042	0.657	0.285	0.899
Hornoya	3	JU689	0.094	0.004	0.131	<LOD (3.7)	NA	2.222	0.801	0.020	0.185	1.360	0.302	0.387
Hornoya	4	JU666	0.097	0.003	0.110	<LOD (3.7)	NA	2.678	2.446	0.012	0.124	0.652	0.253	0.650
Hornoya	5	JU688	0.102	0.003	0.107	<LOD (3.7)	NA	2.919	1.300	0.004	0.062	0.390	0.384	0.912
Hornoya	6	JU683	0.093	0.003	0.108	0.004	NA	2.675	1.098	0.006	0.128	0.819	0.505	0.627
Hornoya	7	JU687	0.155	<LOD(2)	0.319	<LOD (3.7)	NA	3.801	4.285	0.012	0.093	2.499	0.389	2.127
Hornoya	8	JU694	0.065	0.005	0.070	0.004	NA	2.165	0.803	0.024	0.170	1.240	0.219	0.848
Hornoya	9	JU680	0.077	0.004	0.064	<LOD (3.7)	NA	2.179	0.973	0.027	0.249	1.670	0.326	0.842
Hornoya	10	JU678	0.102	0.002	0.100	<LOD (3.7)	NA	3.054	3.237	0.009	0.108	0.444	0.341	0.855
Hornoya	11	JX511	0.074	<LOD(2)	0.054	<LOD (3.7)	NA	2.346	1.384	0.006	0.096	0.429	0.212	0.382
Hornoya	12	JX951	0.094	0.002	0.075	<LOD (3.7)	NA	2.473	0.919	0.003	0.068	0.369	0.315	0.437
Hornoya	13	JX510	0.092	0.003	0.058	<LOD (3.7)	NA	2.343	1.022	0.019	0.216	0.655	0.325	0.507
Hornoya	14	JX512	0.094	0.002	0.091	0.004	NA	2.522	1.093	0.003	0.061	0.454	0.242	0.436
Hornoya	15	JX513	0.079	0.002	0.146	0.005	NA	2.500	0.466	0.003	0.092	0.483	0.328	0.427
Hornoya	16	JU684	0.125	0.005	0.079	0.014	NA	2.964	1.125	0.007	0.101	0.422	0.428	0.490
Hornoya	17	JU674	0.091	<LOD(2)	0.078	0.004	NA	2.362	1.115	0.003	0.063	0.297	0.256	0.336
Oslo	18	JCH22	< 0.068	<0.0283	<0.0267	<0.0326	<0.0202	0.1780	NA	NA	NA	NA	NA	NA
Oslo	19	JCH23	< 0.091	<0.0378	<0.0355	<0.0435	<0.0363	0.1680	NA	NA	NA	NA	NA	NA
Oslo	20	JCH25	< 0.091	<0.0378	0.0433	<0.0435	<0.028	0.3410	NA	NA	NA	NA	NA	NA
Oslo	21	JCH27	< 0.042	<0.0174	<0.0164	<0.0201	<0.0149	0.0963	NA	NA	NA	NA	NA	NA
Oslo	22	JCL13	< 0.091	<0.0378	<0.0355	<0.0435	<0.0222	0.3120	NA	NA	NA	NA	NA	NA
Oslo	23	JCL43	< 0.136	<0.0566	<0.0533	<0.0652	<0.0489	< 0.212	NA	NA	NA	NA	NA	NA
Oslo	24	JCL48	0.0376	<0.0113	0.0412	<0.013	<0.0079	0.7820	NA	NA	NA	NA	NA	NA
Oslo	25	JCL51	< 0.078	<0.0324	<0.0305	<0.0373	<0.036	< 0.121	NA	NA	NA	NA	NA	NA
Oslo	26	JCL52	< 0.034	<0.0142	<0.0133	<0.0163	<0.0089	0.0665	NA	NA	NA	NA	NA	NA
Oslo	27	JCU50	< 0.068	<0.0283	<0.0267	<0.0326	<0.033	< 0.106	NA	NA	NA	NA	NA	NA
Oslo	28	JCX20	< 0.045	<0.0189	<0.0178	<0.0217	<0.0191	0.4340	NA	NA	NA	NA	NA	NA
Oslo	29	JCX95	< 0.060	<0.0252	<0.0237	<0.029	<0.0234	0.2240	NA	NA	NA	NA	NA	NA
Oslo	30	JCX96	< 0.068	<0.0283	<0.0267	<0.0326	<0.0173	0.1340	NA	NA	NA	NA	NA	NA
Oslo	31	JCX00	< 0.060	<0.0252	<0.0237	<0.029	<0.071	1.1800	NA	NA	NA	NA	NA	NA
Oslo	32	JCH28	< 0.039	<0.0162	<0.0152	<0.0186	<0.0111	0.1230	NA	NA	NA	NA	NA	NA

Location	Hgnr	Ringnr	PCB 28	PCB 47	PCB 52	PCB 66	PCB 71	PCB 99	PCB 101	PCB 105	PCB 118	PCB 128	PCB 138	PCB 153	PCB 180	PCB 183	PCB 187
Hornoya	1	JU675	0.190	0.542	0.058	1.013	0.531	4.331	0.042	2.016	7.105	2.736	17.019	25.603	7.197	5.584	1.491
Hornoya	2	JU676	0.153	0.332	0.432	0.695	0.460	3.590	0.414	1.856	6.348	2.617	15.462	24.514	8.050	2.829	1.631
Hornoya	3	JU689	0.180	0.246	0.069	0.577	0.393	1.992	0.065	1.232	3.993	1.467	8.652	11.628	2.821	1.881	0.640
Hornoya	4	JU666	0.185	0.298	0.046	0.708	0.496	2.286	0.043	1.161	4.123	1.389	8.798	11.344	3.448	1.319	0.726
Hornoya	5	JU688	0.187	0.423	0.127	0.950	0.537	3.139	0.091	1.855	6.384	1.504	12.617	17.373	5.150	3.367	1.091
Hornoya	6	JU683	0.155	0.321	0.142	0.634	0.454	2.066	0.083	1.443	4.210	1.419	7.660	10.020	3.243	1.746	0.667
Hornoya	7	JU687	0.407	0.959	0.031	2.172	1.317	9.140	<LOD (3)	6.261	20.271	7.722	43.423	57.921	17.626	4.310	3.458
Hornoya	8	JU694	0.110	0.206	0.088	0.473	0.361	1.702	0.098	1.146	3.678	1.210	7.721	10.663	4.217	1.484	0.813
Hornoya	9	JU680	0.143	0.266	0.211	0.577	0.422	2.104	0.141	1.341	4.312	1.472	9.216	12.653	4.417	1.640	0.910
Hornoya	10	JU678	0.241	0.456	0.046	1.020	0.674	3.299	0.037	1.506	5.476	1.771	12.586	15.911	4.912	1.876	0.988
Hornoya	11	JX511	0.235	0.274	0.034	0.600	0.411	1.549	0.016	0.932	2.964	0.992	6.357	8.116	2.690	0.923	0.520
Hornoya	12	JX951	0.175	0.276	0.149	0.657	0.441	2.287	0.065	1.462	4.959	1.627	8.977	11.738	3.407	1.247	0.700
Hornoya	13	JX510	0.171	0.281	0.096	0.660	0.415	2.264	0.097	1.150	4.147	1.480	10.235	14.295	4.769	2.003	0.940
Hornoya	14	JX512	0.185	0.269	0.073	0.684	0.481	2.086	0.039	1.433	4.694	1.437	9.283	11.158	3.050	1.211	0.661
Hornoya	15	JX513	0.170	0.285	0.109	0.629	0.385	2.273	0.081	1.225	4.181	1.511	9.553	12.632	3.824	2.321	0.796
Hornoya	16	JU684	0.195	0.343	0.086	1.894	0.759	2.120	0.079	1.219	3.693	1.163	7.720	11.111	3.892	3.745	0.771
Hornoya	17	JU674	0.134	0.245	0.049	0.534	0.360	1.637	0.037	0.873	2.834	1.056	6.018	7.711	2.068	1.075	0.458
Oslo	18	JCH22	<0.049	0.134	<0.060	0.255	NA	0.647	<0.118	0.301	1.100	0.252	2.070	3.310	0.472	0.226	1.020
Oslo	19	JCH23	<0.065	<0.041	<0.081	<0.080	NA	0.181	<0.157	0.107	0.379	0.086	0.713	1.180	0.275	0.064	0.296
Oslo	20	JCH25	0.125	0.820	0.214	1.830	NA	3.490	0.295	1.580	5.090	0.918	8.260	12.000	2.120	0.505	1.720
Oslo	21	JCH27	0.058	0.538	0.382	1.190	NA	2.860	1.620	1.600	4.460	1.250	8.220	11.100	2.550	1.430	3.600
Oslo	22	JCL13	<0.065	0.055	<0.081	0.123	NA	0.265	<0.157	0.167	0.544	0.142	1.220	1.970	0.363	0.158	0.563
Oslo	23	JCL43	<0.097	0.350	<0.121	0.989	NA	2.010	<0.236	1.010	3.410	0.607	5.730	8.400	1.930	0.837	1.740
Oslo	24	JCL48	0.629	3.490	0.238	7.460	NA	16.400	1.230	9.800	26.700	8.570	38.100	41.500	7.910	4.370	13.600
Oslo	25	JCL51	<0.056	0.116	<0.069	0.266	NA	0.691	<0.135	0.388	1.230	0.274	2.360	3.010	0.524	0.212	0.641
Oslo	26	JCL52	<0.024	0.021	<0.030	0.037	NA	0.091	<0.059	0.039	0.167	0.060	0.513	1.010	0.200	0.091	0.416
Oslo	27	JCU50	<0.049	0.138	<0.060	0.403	NA	0.783	<0.118	0.446	1.380	0.323	2.670	3.320	0.393	0.278	1.020
Oslo	28	JCX20	<0.032	0.126	<0.040	0.172	NA	0.972	<0.079	0.416	1.570	0.362	2.760	3.600	0.573	0.257	0.893
Oslo	29	JCX95	<0.043	0.158	<0.054	0.356	NA	1.240	<0.105	0.524	1.970	0.479	3.940	4.830	0.968	0.369	0.990
Oslo	30	JCX96	<0.049	0.167	0.140	0.355	NA	0.905	0.194	0.458	1.470	0.333	2.940	3.770	0.607	0.352	1.280
Oslo	31	JCX00	<0.043	0.204	<0.054	0.333	NA	1.650	<0.105	0.939	3.060	0.785	5.420	7.470	1.930	1.060	2.110
Oslo	32	JCH28	<0.028	0.069	<0.034	0.107	NA	0.373	<0.068	0.175	0.655	0.154	1.230	1.870	0.326	0.181	0.546

Location	Hgnr	Ringnr	6:2FTS	PFOSA	PFBS	PFPS	PFHxS	PFHpS	brPFOS	PFOS	PFNS	PFDcS	PFHxA	PFHpA	PFOA	PFNA	PFDcA	PFUnA	PFDoA	PFTriA	PFTeA
Hornoya	1	JU675	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	17.40	<LOD	<LOD	<LOD	<LOD	<LOD	1.307	1.156	6.503	<LOD	1.575	<LOD
Hornoya	2	JU676	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	22.62	<LOD	<LOD	<LOD	<LOD	<LOD	1.279	1.000	5.296	0.796	1.954	<LOD
Hornoya	3	JU689	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	16.89	<LOD	<LOD	<LOD	<LOD	<LOD	1.196	1.315	6.990	<LOD	1.828	<LOD
Hornoya	4	JU666	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	12.43	<LOD	<LOD	<LOD	<LOD	<LOD	1.666	0.961	5.785	<LOD	1.204	<LOD
Hornoya	5	JU688	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	11.33	<LOD	<LOD	<LOD	<LOD	<LOD	1.464	0.920	5.699	<LOD	1.695	<LOD
Hornoya	6	JU683	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	6.27	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	0.364	3.660	<LOD	0.610	<LOD
Hornoya	7	JU687	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	61.76	<LOD	<LOD	<LOD	<LOD	<LOD	2.342	2.800	14.110	<LOD	4.306	0.315
Hornoya	8	JU694	<LOD	<LOD	<LOD	<LOD	0.245	<LOD	<LOD	5.34	<LOD	<LOD	<LOD	<LOD	<LOD	0.492	0.379	2.512	<LOD	0.568	<LOD
Hornoya	9	JU680	<LOD	<LOD	<LOD	<LOD	0.687	<LOD	<LOD	38.39	<LOD	<LOD	<LOD	<LOD	<LOD	1.560	1.136	4.512	<LOD	1.962	0.338
Hornoya	10	JU678	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	17.51	<LOD	<LOD	<LOD	<LOD	<LOD	0.769	0.955	4.965	<LOD	1.451	0.215
Hornoya	11	JX511	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	10.24	<LOD	<LOD	<LOD	<LOD	<LOD	0.524	0.486	3.537	<LOD	1.261	<LOD
Hornoya	12	JX951	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	10.11	<LOD	<LOD	<LOD	<LOD	<LOD	1.238	1.082	5.152	<LOD	1.944	<LOD
Hornoya	13	JX510	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	13.66	<LOD	<LOD	<LOD	<LOD	<LOD	1.878	1.106	4.953	<LOD	1.770	0.150
Hornoya	14	JX512	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	14.16	<LOD	<LOD	<LOD	<LOD	<LOD	0.525	1.035	6.283	<LOD	1.303	<LOD
Hornoya	15	JX513	<LOD	<LOD	<LOD	<LOD	0.368	<LOD	<LOD	19.75	<LOD	<LOD	<LOD	<LOD	<LOD	2.303	1.478	6.457	<LOD	1.910	<LOD
Hornoya	16	JU684	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	18.40	<LOD	<LOD	<LOD	<LOD	<LOD	1.073	0.562	3.596	<LOD	0.751	<LOD
Hornoya	17	JU674	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	18.24	<LOD	<LOD	<LOD	<LOD	<LOD	1.467	1.390	7.035	<LOD	2.047	<LOD
Oslo	18	JCH22	<0.3	<0.1	<0.1	<0.2	0.600	<0.2	NA	3.30	<0.2	<0.2	<0.5	<0.5	<0.5	0.700	<0.5	<0.4	<0.4	<0.4	<0.4
Oslo	19	JCH23	<0.3	<0.1	<0.1	<0.2	0.200	<0.2	NA	4.34	<0.2	<0.2	<0.5	<0.5	<0.5	0.800	<0.5	<0.4	<0.4	<0.4	<0.4
Oslo	20	JCH25	<0.3	<0.1	<0.1	<0.2	0.700	<0.2	NA	22.80	<0.2	0.200	<0.5	<0.5	<0.5	0.900	1.000	1.700	0.700	1.000	0.400
Oslo	21	JCH27	<0.3	0.200	<0.1	<0.2	0.500	<0.2	NA	12.50	<0.2	<0.2	<0.5	<0.5	<0.5	0.500	0.470	0.700	0.500	0.500	0.350
Oslo	22	JCL13	<0.3	<0.1	<0.1	<0.2	0.200	<0.2	NA	1.90	<0.2	<0.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.4	<0.4	<0.4	<0.4
Oslo	23	JCL43	<0.3	<0.1	<0.1	<0.2	0.200	0.200	NA	37.20	<0.2	0.500	<0.5	<0.5	2.200	1.400	<0.5	0.400	0.600	0.360	<0.4
Oslo	24	JCL48	<0.3	0.300	<0.1	<0.2	0.500	<0.2	NA	55.10	<0.2	0.300	<0.5	<0.5	<0.5	0.900	1.500	2.300	1.000	0.700	0.370
Oslo	25	JCL51	<0.3	<0.1	<0.1	<0.2	0.400	<0.2	NA	1.47	<0.2	<0.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.4	<0.4	<0.4	<0.4
Oslo	26	JCL52	<0.3	<0.1	<0.1	<0.2	0.200	<0.2	NA	1.60	<0.2	<0.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.4	<0.4	<0.4	<0.4
Oslo	27	JCU50	<0.3	<0.1	<0.1	<0.2	0.600	<0.2	NA	8.82	<0.2	<0.2	<0.5	<0.5	<0.5	0.500	0.450	0.400	0.400	<0.4	<0.4
Oslo	28	JCX20	<0.3	<0.1	<0.1	<0.2	0.200	<0.2	NA	3.73	<0.2	<0.2	<0.5	<0.5	2.400	1.600	<0.5	<0.4	<0.4	<0.4	<0.4
Oslo	29	JCX95	<0.3	<0.1	<0.1	<0.2	0.400	<0.2	NA	7.06	<0.2	<0.2	<0.5	<0.5	<0.5	0.800	<0.5	<0.4	<0.4	0.350	<0.4
Oslo	30	JCX96	<0.3	<0.1	<0.1	<0.2	0.300	<0.2	NA	6.50	<0.2	<0.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.4	<0.4	<0.4	<0.4
Oslo	31	JCX00	<0.3	<0.1	<0.1	<0.2	0.200	<0.2	NA	3.40	<0.2	<0.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.4	<0.4	<0.4	<0.4
Oslo	32	JCH28	<0.3	<0.1	<0.1	<0.2	0.100	<0.2	NA	3.02	<0.2	<0.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.4	<0.4	<0.4	<0.4

Location	Hgnr	Ringnr	TBA	PBDE 17	PBDE 28	PBDE 47	PBDE 49	PBDE 66	PBDE 71	PBDE 77	PBDE 85	PBDE 99	PBDE 100	PBDE 119	PBDE 126
Hornoya	1	JU675	NA	NA	<LOD (14)	1.716	NA	NA	NA	NA	NA	0.264	0.803	NA	NA
Hornoya	2	JU676	NA	NA	<LOD (14)	0.990	NA	NA	NA	NA	NA	0.158	0.305	NA	NA
Hornoya	3	JU689	NA	NA	<LOD (14)	0.448	NA	NA	NA	NA	NA	0.048	0.143	NA	NA
Hornoya	4	JU666	NA	NA	<LOD (14)	0.629	NA	NA	NA	NA	NA	0.038	0.144	NA	NA
Hornoya	5	JU688	NA	NA	<LOD (14)	0.851	NA	NA	NA	NA	NA	0.079	0.285	NA	NA
Hornoya	6	JU683	NA	NA	<LOD (14)	0.720	NA	NA	NA	NA	NA	0.236	0.209	NA	NA
Hornoya	7	JU687	NA	NA	<LOD (14)	1.732	NA	NA	NA	NA	NA	0.273	0.472	NA	NA
Hornoya	8	JU694	NA	NA	<LOD (14)	0.478	NA	NA	NA	NA	NA	0.036	0.145	NA	NA
Hornoya	9	JU680	NA	NA	<LOD (14)	0.609	NA	NA	NA	NA	NA	0.043	0.171	NA	NA
Hornoya	10	JU678	NA	NA	<LOD (14)	0.944	NA	NA	NA	NA	NA	0.051	0.247	NA	NA
Hornoya	11	JX511	NA	NA	<LOD (14)	2.283	NA	NA	NA	NA	NA	3.560	0.790	NA	NA
Hornoya	12	JX951	NA	NA	<LOD (14)	0.507	NA	NA	NA	NA	NA	0.039	0.122	NA	NA
Hornoya	13	JX510	NA	NA	<LOD (14)	0.739	NA	NA	NA	NA	NA	0.075	0.252	NA	NA
Hornoya	14	JX512	NA	NA	<LOD (14)	0.536	NA	NA	NA	NA	NA	0.043	0.139	NA	NA
Hornoya	15	JX513	NA	NA	<LOD (14)	0.803	NA	NA	NA	NA	NA	0.082	0.261	NA	NA
Hornoya	16	JU684	NA	NA	<LOD (14)	0.553	NA	NA	NA	NA	NA	0.190	0.189	NA	NA
Hornoya	17	JU674	NA	NA	<LOD (14)	0.540	NA	NA	NA	NA	NA	0.037	0.154	NA	NA
Oslo	18	JCH22	<0.013	<0.0043	<0.006	0.14	<0.009	<0.0324	<0.0040	<0.0027	<0.0059	0.093	0.041	<0.0051	<0.0041
Oslo	19	JCH23	<0.017	<0.0057	<0.008	<0.076	<0.012	<0.0432	<0.0053	<0.0036	<0.0078	0.053	<0.0208	<0.0068	<0.0054
Oslo	20	JCH25	<0.017	<0.0057	<0.008	0.65	<0.012	<0.0432	<0.0053	<0.0036	<0.0078	0.127	0.132	<0.0068	<0.0054
Oslo	21	JCH27	<0.008	0.003	0.004	0.323	0.006	<0.02	<0.0024	<0.0017	<0.0036	0.065	0.083	<0.0031	<0.0025
Oslo	22	JCL13	<0.017	<0.0057	<0.008	0.269	<0.012	<0.0432	<0.0053	<0.0036	0.013	0.369	0.071	<0.0068	<0.0054
Oslo	23	JCL43	<0.026	<0.0086	<0.012	0.282	<0.017	<0.0647	<0.0079	<0.0055	<0.0117	0.073	0.064	<0.0101	<0.0081
Oslo	24	JCL48	<0.005	<0.0017	0.013	2.050	0.021	0.020	<0.0016	0.002	<0.0023	0.248	0.430	0.013	<0.0016
Oslo	25	JCL51	<0.015	<0.0049	<0.007	0.116	<0.010	<0.037	<0.0045	<0.0031	<0.0067	0.080	0.033	<0.0058	<0.0046
Oslo	26	JCL52	<0.007	<0.002	<0.003	0.108	<0.004	<0.0162	<0.0020	<0.0014	0.006	0.151	0.028	<0.0025	<0.0020
Oslo	27	JCU50	<0.013	<0.004	<0.006	0.214	<0.009	<0.0324	<0.0040	<0.0027	<0.0059	0.109	0.051	<0.0051	<0.0041
Oslo	28	JCX20	<0.009	<0.003	<0.004	0.106	<0.006	<0.0216	<0.0026	<0.0018	<0.0039	0.061	0.027	0.040	<0.0027
Oslo	29	JCX95	<0.012	<0.004	<0.005	0.222	<0.008	<0.0288	<0.0035	<0.0024	<0.0052	0.197	0.068	<0.0045	<0.0036
Oslo	30	JCX96	<0.013	<0.004	<0.006	0.234	<0.009	<0.0324	<0.0040	<0.0027	<0.0059	0.117	0.061	<0.0051	<0.0041
Oslo	31	JCX00	<0.012	<0.004	<0.005	0.142	<0.008	<0.0288	<0.0035	<0.0024	<0.0052	0.101	0.032	<0.0045	<0.0036
Oslo	32	JCH28	<0.007	<0.002	<0.003	<0.033	<0.005	<0.0185	<0.0023	<0.0016	<0.0033	<0.0111	<0.0089	<0.0029	<0.0023

Location	Hgnr	Ringnr	PBDE 138	PBDE 153	PBDE 154	PBDE 156	PBDE 183	PBDE 184	PBDE 191	PBDE 196	PBDE 197	PBDE 202	PBDE 206	PBDE 207	PBDE 209
Hornoya	1	JU675	<LOD (8)	0.127	0.297	NA	<LOD (8)	NA	NA	<LOD (6)	<LOD (6)	NA	0.027	<LOD (6)	<LOD (70)
Hornoya	2	JU676	<LOD (8)	0.115	0.148	NA	<LOD (8)	NA	NA	<LOD (6)	<LOD (6)	NA	<LOD (5)	<LOD (6)	<LOD (70)
Hornoya	3	JU689	<LOD (8)	0.030	0.068	NA	<LOD (8)	NA	NA	<LOD (6)	<LOD (6)	NA	<LOD (5)	<LOD (6)	<LOD (70)
Hornoya	4	JU666	<LOD (8)	0.020	0.087	NA	<LOD (8)	NA	NA	<LOD (6)	<LOD (6)	NA	<LOD (5)	<LOD (6)	<LOD (70)
Hornoya	5	JU688	<LOD (8)	0.054	0.167	NA	<LOD (8)	NA	NA	<LOD (6)	<LOD (6)	NA	0.0241	0.0159	0.2184
Hornoya	6	JU683	<LOD (8)	0.118	0.153	NA	0.100	NA	NA	<LOD (6)	<LOD (6)	NA	0.2734	0.0401	0.8551
Hornoya	7	JU687	<LOD (8)	0.300	0.141	NA	0.035	NA	NA	<LOD (6)	<LOD (6)	NA	0.0973	0.0117	0.2520
Hornoya	8	JU694	<LOD (8)	0.026	0.099	NA	<LOD (8)	NA	NA	<LOD (6)	<LOD (6)	NA	<LOD (5)	<LOD (6)	<LOD (70)
Hornoya	9	JU680	<LOD (8)	0.025	0.115	NA	<LOD (8)	NA	NA	<LOD (6)	<LOD (6)	NA	<LOD (5)	<LOD (6)	<LOD (70)
Hornoya	10	JU678	<LOD (8)	0.026	0.112	NA	<LOD (8)	NA	NA	<LOD (6)	<LOD (6)	NA	<LOD (5)	<LOD (6)	<LOD (70)
Hornoya	11	JX511	<LOD (8)	0.955	2.900	NA	0.399	NA	NA	<LOD (6)	<LOD (6)	NA	1.557	1.123	2.037
Hornoya	12	JX951	<LOD (8)	0.038	0.049	NA	0.070	NA	NA	<LOD (6)	<LOD (6)	NA	<LOD (5)	<LOD (6)	0.214
Hornoya	13	JX510	<LOD (8)	0.059	0.098	NA	<LOD (8)	NA	NA	<LOD (6)	<LOD (6)	NA	<LOD (5)	<LOD (6)	<LOD (70)
Hornoya	14	JX512	<LOD (8)	0.026	0.057	NA	0.034	NA	NA	<LOD (6)	<LOD (6)	NA	0.010	<LOD (6)	0.204
Hornoya	15	JX513	<LOD (8)	0.045	0.128	NA	<LOD (8)	NA	NA	<LOD (6)	<LOD (6)	NA	<LOD (5)	<LOD (6)	<LOD (70)
Hornoya	16	JU684	<LOD (8)	0.093	0.157	NA	0.099	NA	NA	<LOD (6)	<LOD (6)	NA	0.086	0.036	<LOD (70)
Hornoya	17	JU674	<LOD (8)	0.026	0.049	NA	<LOD (8)	NA	NA	<LOD (6)	<LOD (6)	NA	<LOD (5)	<LOD (6)	<LOD (70)
Oslo	18	JCH22	<0.0135	0.033	0.012	<0.0216	0.012	<0.0066	<0.0138	<0.0237	<0.0190	<0.0233	<0.0540	<0.0323	<0.7180
Oslo	19	JCH23	<0.0180	0.020	<0.0129	<0.0289	0.013	<0.0088	<0.0184	<0.0316	<0.0253	<0.0311	<0.0720	0.048	<0.9570
Oslo	20	JCH25	<0.0180	0.030	0.024	<0.0289	<0.0118	<0.0088	<0.0184	<0.0316	<0.0253	<0.0311	<0.0720	0.054	<0.9570
Oslo	21	JCH27	<0.0083	0.010	0.017	<0.0133	<0.0055	<0.0041	<0.0085	<0.0146	<0.0117	<0.0144	<0.0332	<0.0199	<0.4420
Oslo	22	JCL13	<0.0180	0.069	0.028	<0.0289	0.022	<0.0088	<0.0184	<0.0316	0.040	<0.0311	0.105	0.233	4.180
Oslo	23	JCL43	<0.027	<0.0235	<0.0194	<0.0433	<0.0177	<0.0133	<0.0276	<0.0475	<0.0379	<0.0466	<0.1080	<0.0646	1.440
Oslo	24	JCL48	<0.0054	0.047	0.055	<0.0087	0.007	<0.0027	<0.0055	<0.0095	0.017	<0.0093	<0.0216	0.032	<0.2870
Oslo	25	JCL51	<0.0154	0.020	<0.0111	<0.0247	0.015	<0.0076	<0.0158	<0.0271	<0.0217	<0.02670	<0.0617	0.052	<0.8200
Oslo	26	JCL52	<0.0068	0.034	0.011	<0.0108	0.015	<0.0033	<0.0069	0.029	0.020	<0.0117	0.080	0.178	2.080
Oslo	27	JCU50	<0.0135	0.021	0.013	<0.0216	<0.0089	<0.0066	<0.0138	<0.0237	<0.0190	<0.0233	<0.0540	0.052	0.754
Oslo	28	JCX20	<0.0090	0.012	<0.0065	<0.0144	<0.0059	<0.0044	<0.0092	<0.0158	<0.0126	<0.0155	<0.0360	0.055	0.614
Oslo	29	JCX95	<0.0120	0.044	0.017	<0.0192	0.010	<0.0059	<0.0123	<0.0211	<0.0169	<0.0207	<0.0480	0.082	1.920
Oslo	30	JCX96	<0.0135	0.032	0.015	<0.0216	0.020	<0.0066	<0.0138	<0.0237	0.025	<0.0233	<0.0540	0.077	<0.7180
Oslo	31	JCX00	<0.0120	0.025	<0.0086	<0.0192	0.013	<0.0059	<0.0123	0.023	0.027	<0.0207	0.196	0.260	3.720
Oslo	32	JCH28	<0.0077	<0.0067	<0.0055	<0.0124	<0.0051	<0.0038	<0.0079	<0.0136	<0.0108	<0.0133	<0.0309	<0.0185	<0.4100

Location	Hgnr	Ringnr	PBT	PBEB	DPTE	HBB	EHTBB	BTBTE	DBDPE
Hornoya	1	JU675	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (70)
Hornoya	2	JU676	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (70)
Hornoya	3	JU689	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (70)
Hornoya	4	JU666	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (70)
Hornoya	5	JU688	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (70)
Hornoya	6	JU683	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (70)
Hornoya	7	JU687	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (70)
Hornoya	8	JU694	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (70)
Hornoya	9	JU680	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (70)
Hornoya	10	JU678	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (70)
Hornoya	11	JX511	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (70)
Hornoya	12	JX951	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (70)
Hornoya	13	JX510	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (70)
Hornoya	14	JX512	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (70)
Hornoya	15	JX513	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (70)
Hornoya	16	JU684	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (70)
Hornoya	17	JU674	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (15)	<LOD (70)
Oslo	18	JCH22	NA	NA	NA	NA	NA	NA	NA
Oslo	19	JCH23	NA	NA	NA	NA	NA	NA	NA
Oslo	20	JCH25	NA	NA	NA	NA	NA	NA	NA
Oslo	21	JCH27	NA	NA	NA	NA	NA	NA	NA
Oslo	22	JCL13	NA	NA	NA	NA	NA	NA	NA
Oslo	23	JCL43	NA	NA	NA	NA	NA	NA	NA
Oslo	24	JCL48	NA	NA	NA	NA	NA	NA	NA
Oslo	25	JCL51	NA	NA	NA	NA	NA	NA	NA
Oslo	26	JCL52	NA	NA	NA	NA	NA	NA	NA
Oslo	27	JCU50	NA	NA	NA	NA	NA	NA	NA
Oslo	28	JCX20	NA	NA	NA	NA	NA	NA	NA
Oslo	29	JCX95	NA	NA	NA	NA	NA	NA	NA
Oslo	30	JCX96	NA	NA	NA	NA	NA	NA	NA
Oslo	31	JCX00	NA	NA	NA	NA	NA	NA	NA
Oslo	32	JCH28	NA	NA	NA	NA	NA	NA	NA

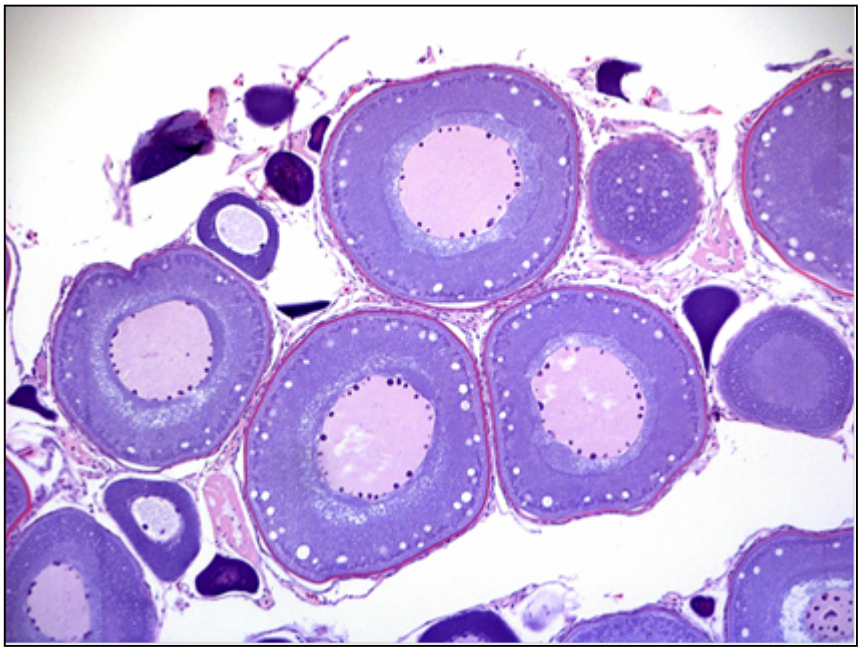
Compound	CAS
Mercury (Hg)	7439-9-76
Lead (Pb)	7439-92-1
Cadmium (Cd)	7440-43-9
Nickel (Ni)	7440-02-0
Silver (Ag)	7440-22-4
Copper (Cu)	7440-50-8
PCB 28	7012-37-5
PCB 52	35693-99-3
PCB 101	37680-73-2
PCB 118	31508-00-6
PCB 138	35065-28-2
PCB 153	35065-27-1
PCB 180	35065-29-3
PFBS	29420-49-3
PFHxS	82382-12-5
PFOS	4021-47-0
(P)FOSA	754-91-6
N-Et-FOSA	4151-50-2
N-Et-FOSE	1691-99-2
N-Me-FOSA	31506-32-8
N-Me-FOSE	24448-09-7
N-Me-FOSEA	25268-77-3
BDE 28	41318-75-6
BDE 47	5436-43-1
BDE 99	60348-60-9
BDE 100	189084-64- 8
BDE 126	366791-32-4
BDE 153	68631-49-2
BDE 154	207122-15-4
BDE 183	207122-16-5
BDE 196	32536-52-0
BDE 202	67797-09-5
BDE 206	63387-28-0
BDE 207	437701-79-6
BDE 209	1163-19-5

DBDPE	84852-53-9
Bisphenol A	80-05-7
Bisphenol S	80-09-1
Bisphenol F	620-92-8
Octylphenol	27193-28-8 (1806-26-4, 67632-66-0, 140-66-9)
(4-)nonylphenol	104-40-5 (25154-52-3, 84852-15-3)
TBBPA	79-94-7
SCCP (C10-C13)	85535-84-8
MCCP (C14-C17)	85535-85-9
p,p´-DDT	50-29-3
p,p´-DDE	82413-20-5
p,p´-DDD	72-54-8
Tri-iso-butylphosphate (TIBT)	126-71-6
Tributylphosphate (TBP)	126-73-8
Tri(2-chloroethyl)phosphate	115-96-8
Tri(1-chloro-2-propyl)phosphate (TCP	13674-84-5
Tri(1,3-dichloro-2-propyl)phosphate (T	13674-87-8
Tri(2-butoxyethyl)phosphate (TBEP)	78-51-3
Triphenylphosphate (TPhP)	115-86-6
2-ethylhexyl-di-phenylphosphate (EHI	1241-94-7
Dibutylphenylphosphate (DBPhP)	2528-36-1
Butyldiphenylphosphate (BdPhP)	2752-95-6
Tris(2-ethylhexyl)phosphate (TEHP)	78-42-2
Tris-o-cresyl phosphate (ToCrP)	78-30-8
Tricresylphosphate (TCrP)	1330-78-5
Octocrylene	6197-30-4
Benzophenone-3	131-57-7
Ethylhexylmethoxycinnamate	5466-77-3
D4	556-67-2
D5	541-02-6
D6	540-97-6
Triclosan	3380-34-5
Triclocarban	101-20-2

IRIS
International Research Institute of Stavanger

Urban Fjord 2 project 2016

Report



Urban fjord project - 2
Histopathological analysis of gonads in Atlantic cod

Daniela M. Pampanin

Report 2016/300

Project number:	7911956
Project title:	Biomonitoring screening – NIVA
Client(s):	NIVA

Stavanger, 12/12/2016

(Daniela M. Pampanin)
Project Manager

Preface

The objective of this work was to perform histological analysis of gonad of Atlantic cod collected in an Urban fjord.
The method used is considered to be the best available technology for the assessment of histological status of gonads, including histopathological conditions.
Samples were received from NIVA in Oslo, they were preserved in formalin solutions. The analyses were performed in November 2016.

Stavanger, December 2016

Daniela M. Pampanin

Contents

1. Introduction

1.1 Purpose of the study

The purpose of this work was to perform histological analysis of gonadic tissue of Atlantic cod collected in an Urban fjord area.
Fish samples were collected by NIVA and afterwards delivered to IRIS laboratory for the analysis.
The method used is considered to be the best available technology for the assessment of histological status of gonads, including histopathological conditions.

1.2 Histological evaluation of fish tissues

Histological parameters are commonly used as markers of health status in various fish species. The identification of pathologies and diseases are increasingly being used as indicators of environmental stress since they provide a definite and ecologically-relevant end-point for chronic/ sub chronic contaminant exposure (Au, 2004). The application of histological markers in fish can include measures of reproductive and metabolic condition, and allows for the detection of various pathogens that may affect population mortality. The data generated from this type of analysis in various organs (i.e. gills, gonads, digestive gland) is helpful in providing information for biomonitoring programme (Corbett et al., 2011).
Histopathological alterations illustrate a definitive endpoint of historical exposure, intermediate between initial biochemical changes and reproductive capability and growth (Stentiford et al., 2003, Salamat et al., 2013).

2. Materials and Methods

2.1 Source of fish

Samples were collected by NIVA and delivered to IRIS for the histological evaluation of gonadic tissue. In total 16 samples of Atlantic cod were analysed, 13 female and 3 male individuals.

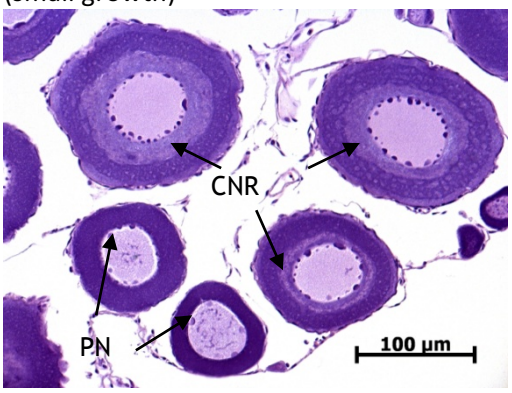
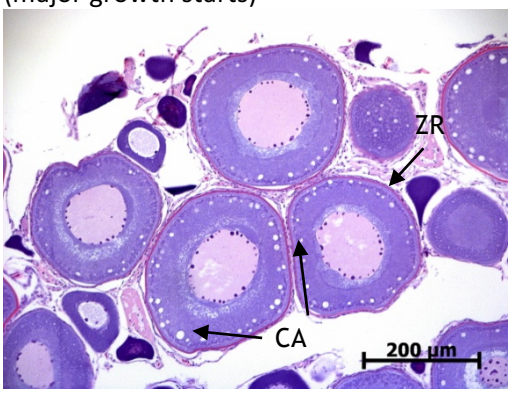
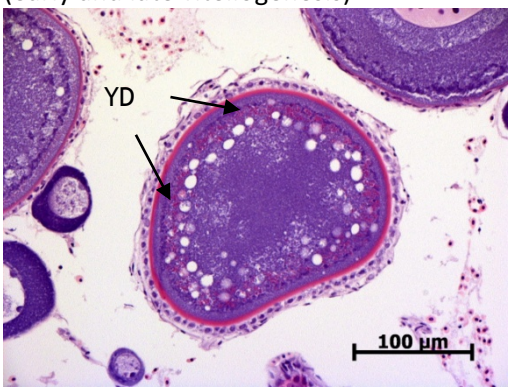
2.2 Histopathology of gonad

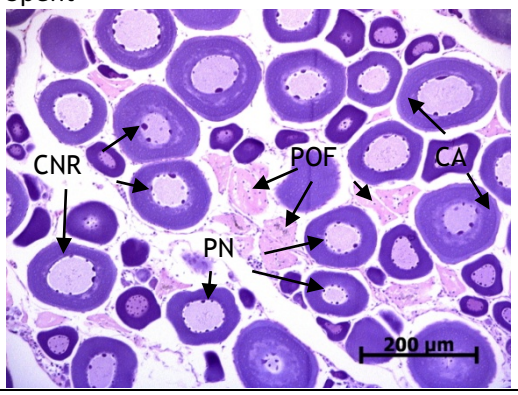
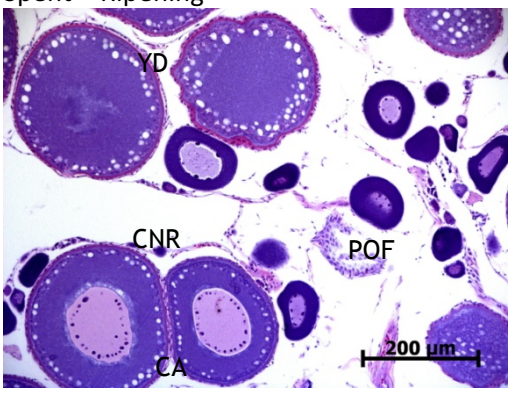
Gonad were dissected, putted in histocassette and placed into histological fixative (3.7% formaldehyde) for wax sections. Tissue samples were no thicker than 1 cm to ensure proper fixation. Samples were then stored at 4˚C until embedding.
Histological sections (3 μm) were prepared at Stavanger University Hospital (SUS). The tissues were examined for health parameters related to physiological conditions, inflammatory and non-specific pathologies and those associated with pathogen and parasites infections. Gonad abnormalities were scored using the criteria suggested by Benly et al. (2008) and Sensini et al. (2008). Each alteration was scored according to its severity and frequency (0 = absence of alteration, 1 = ≤ 10 % of the histological section showed the alteration, 2 = between 10% and 50% of the histological section showed the alteration, 3 = between 50% and 100% of the histological section showed the alteration). The presence of parasites and non-specific inflammation were scored as absent (0) or present (1). All micrographs were captured using an AxioCam MRc5 (Zeiss) digital camera mounted on a *Zeiss Axioplan 2* light microscope (Göttingen, Germany). The slides were analysed blind.
The stage of the gonads were also evaluated.

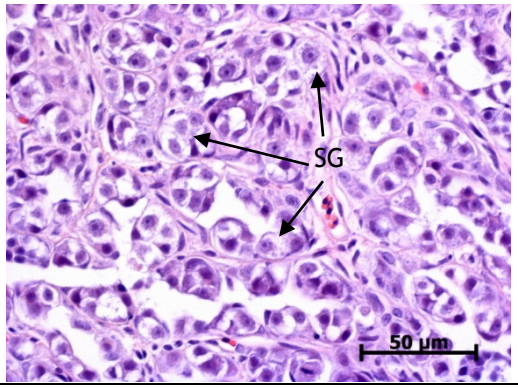
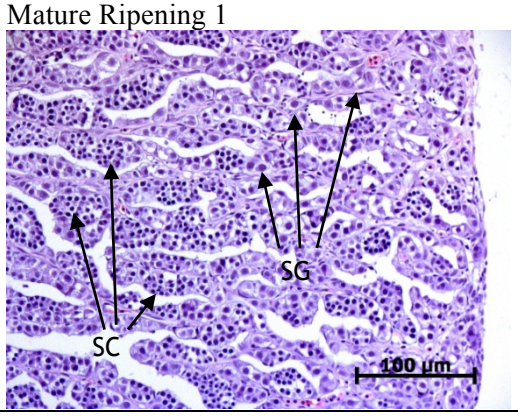
3. Results

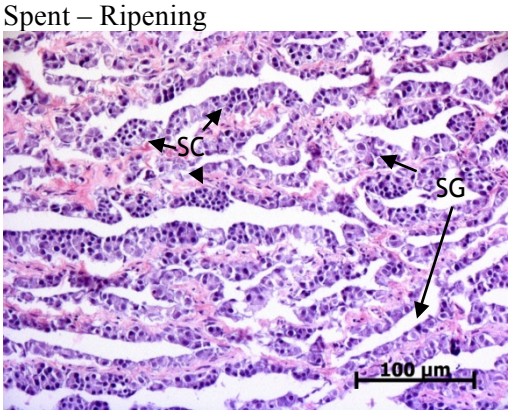
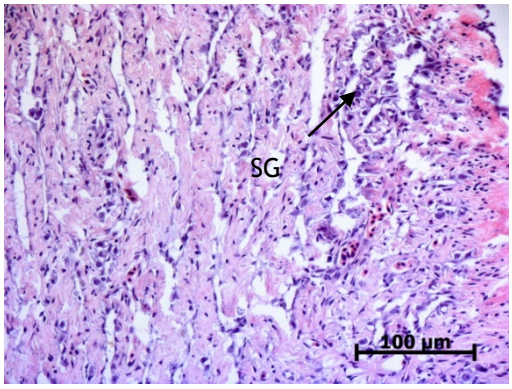
First of all an Atlas was built to score the gonad development, including some pictures (Table 1). The summary of reproductive stages of Atlantic cod, both female and male individuals, is reported in Table 1.

Table 1 - Summary of reproductive stages of Atlantic cod

Reproductive stage	Description
1. Immature (small growth) 	Ovary wall thin. Oocytes vary from small (20 µm) with pale uniform cytoplasm to larger with basophilic cytoplasm apart from a light ring of mitochondria around nucleus. Oocytes up to about 130 µm in diameter are irregular in outline, then round. Several nucleoli at periphery of nucleus – **perinuclear stage PN**. Ring of mitochondria moves away – **circumnuclear ring stage CNR.**
2. Mature Ripening 1 (major growth starts) 	Zona radiata (**ZR**) appears as eosinophilic ring. Cortical alveoli appear in peripheral cytoplasm – **CA** ***** *Image is from stage 5, to show oocytes in stage of major growth but not the characteristics of the ovary*
3. Ripening 2 (early and late vitellogenesis) 	Yolk droplets **YD** first appear as small inclusions between vesicles, then enlarge and fill whole cytoplasm, restricting CA to periphery. Zona radiate widens and forms two layers in which radial striations can be seen. Irregular outlines of nucleus, nucleoli detached from periphery ***** *Image is from stage 6 (spent ripening), to show oocytes in stage of vitellogenesis but not the characteristics of the ovary*

4. Ripe and Spawning	Oocytes hydrates in batches. Yolk as homogenous mass.
5. Spent 	Empty follicles (**post ovulatory follicles POF**) and a few atretic hydrated oocytes. Small oocytes: formation of zona radiata, CA
6. Spent – Ripening  6*. Resting (see stage 5)	Oocytes start vitellogenesis, empty follicles but no atretic hydrated oocytes Larger oocytes in CNR stage

Reproductive stage of males	Description
1. Immature 	Wall thin. Spermatogonia present single or in small groups
2. Mature Ripening 1 	Cysts of spermatocytes form
3. Ripening 2	All stages of development. Earlier stages along distal edge. In later stages cysts containing mature spermatozoa break down and coalesce to form tubules filled with spermatozoa, but lined with developing cysts. Few spermatozoa in large efferent ducts near mesochrium
4. Ripe and Spawning	All tubules and efferent ducts packed with spermatozoa. Few developing cysts left in early part of stage. Single or small groups spermatogonia in lining of tubules will give rise to SZ in next spawning season.
5. Spent	Tubules contain SZ. But few in large efferent ducts near mesochrium. Spermatogonia in distal part of testis

6. Spent – Ripening 	Cysts of spermatogonia SG and spermatocytes SC form in distal part of testis, SZ visible in proximal part
6*. Resting 	Distally only spermatogonia SG present. SZ may still be present in efferent ducts

Most of the fish were in spent stage (5 specimens) or spent-ripening (6) of development. Results are reported in Table 2 (female individuals) and Table 3 (male individuals).

Table 2 – Results of female cod

Fish code n	**1**	**2**	**3**	**5**	**6**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Stage	5	5	2	3	5	5	5	6	5	5	5	5	4
Increased oocyte atresia													
Perifollicular cell hyperplasia/hypertrophy													
Decreased													
Changes in gonadal													
Interstitial fibrosis													
Egg debris in the													
Increased vascular or interstitial													
Granulomatous						1							
Parasite													
Postovulatory follicles													
Atretic follicles (AHO)								2	1				2
mmc													

Table 3 – Results of male cod

Fish code n	**4**	**7**	**16**
Stage	6	3	6
Increased proportion of spermatogonia			
Presence of testis-ova			
Increased testicular degeneration (apoptotic)			
Interstitial (Leydig) cell hyperplasia/hypertrophy			
Decreased proportion of spermatogonia			
Interstitial fibrosis			
Increased vascular or interstitial proteinaceous fluid			
synchronous gonad development			
Altered proportions of spermatozoa or spermatocytes			
Gonadal staging			
Granulomatous inflammation			
Parasite			
mmc			

Few extra observations are reported below, including images. Some individuals were characterized by increased vascular fluid (VF) what is considered to be a normal condition for spent gonads (Fig.1 and 2).

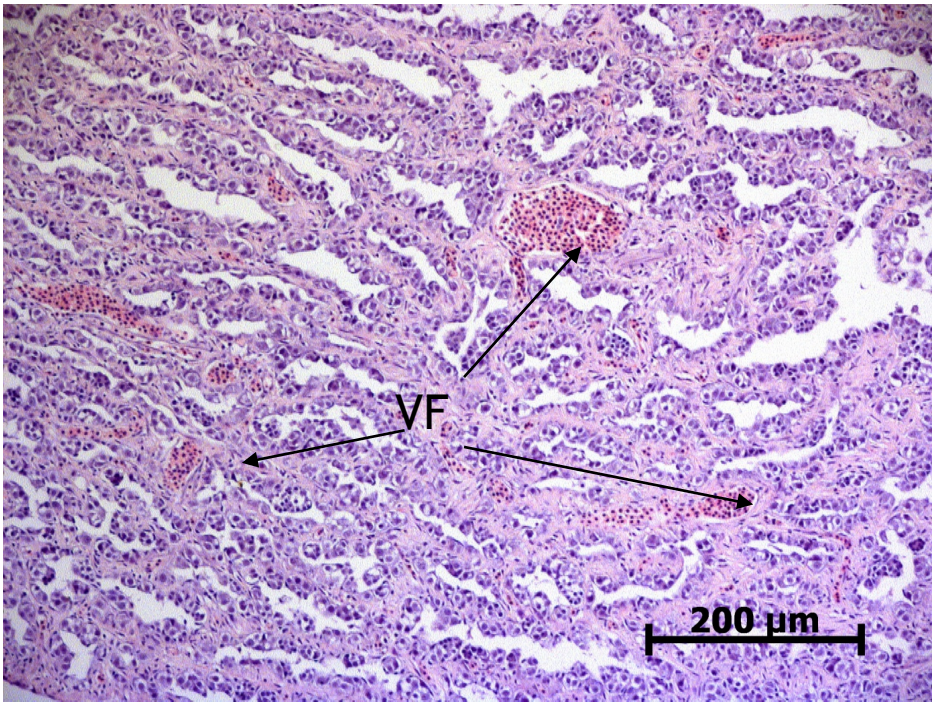


Figure 1

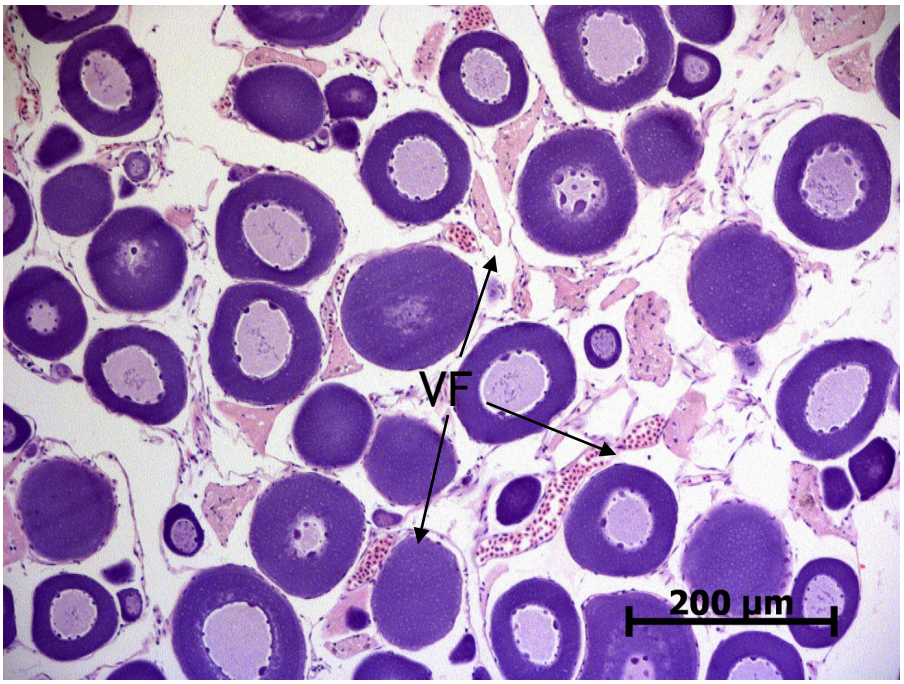


Figure 2.

In 3 females (fish code n 10, 11 and 15) granulomatous inflammation (G) together with fibrosis appeared during normal spawning process as utilization of atretic hydrated oocytes (AHO) (Fig 3). In 1 female specimen granulomas (G) were sign of pathology (mild) as utilization of oocytes failed to mature.
(Fig. 4).

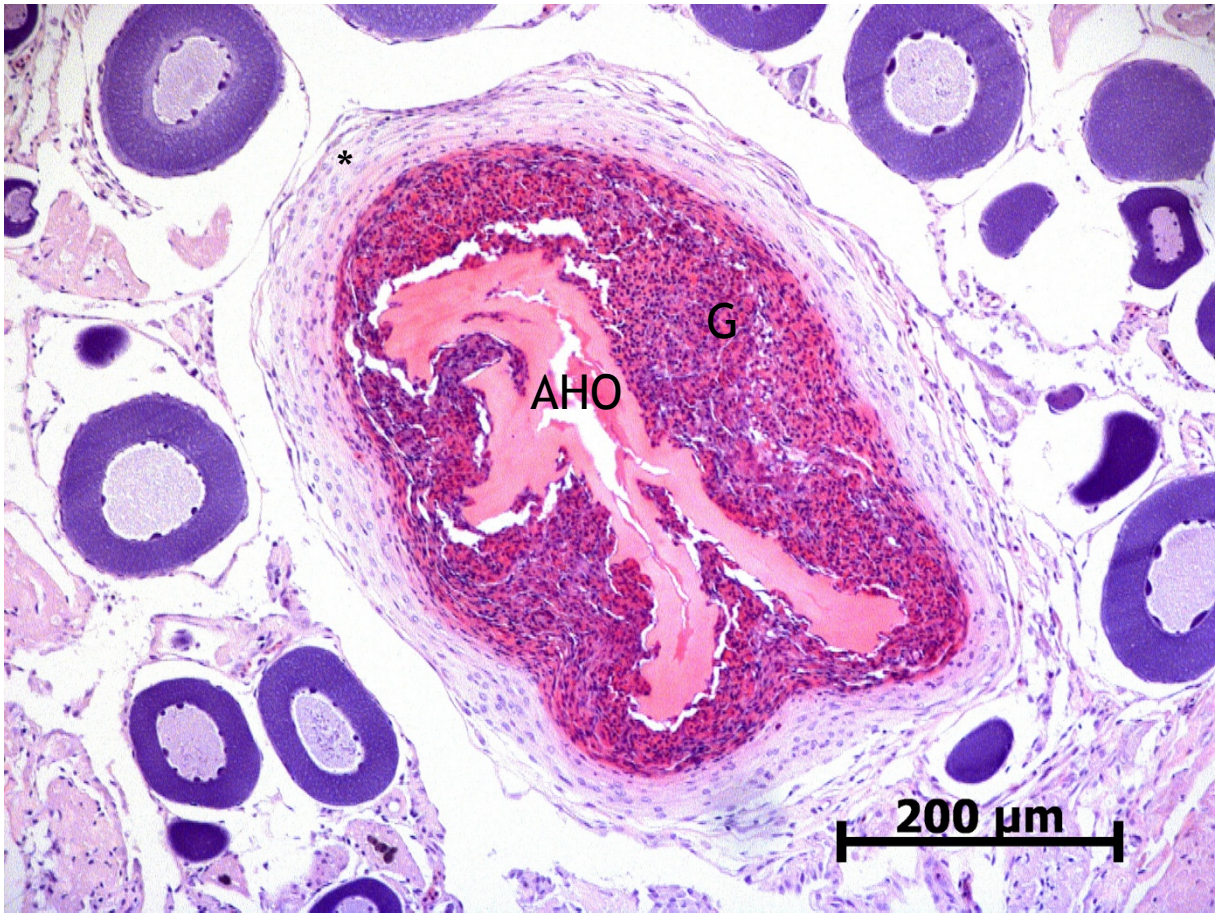


Figure 3 - * fibrous capsule: macrophages and fibroblasts; AHO – atretic hydrated oocyted; G – granulomatous inflammation.

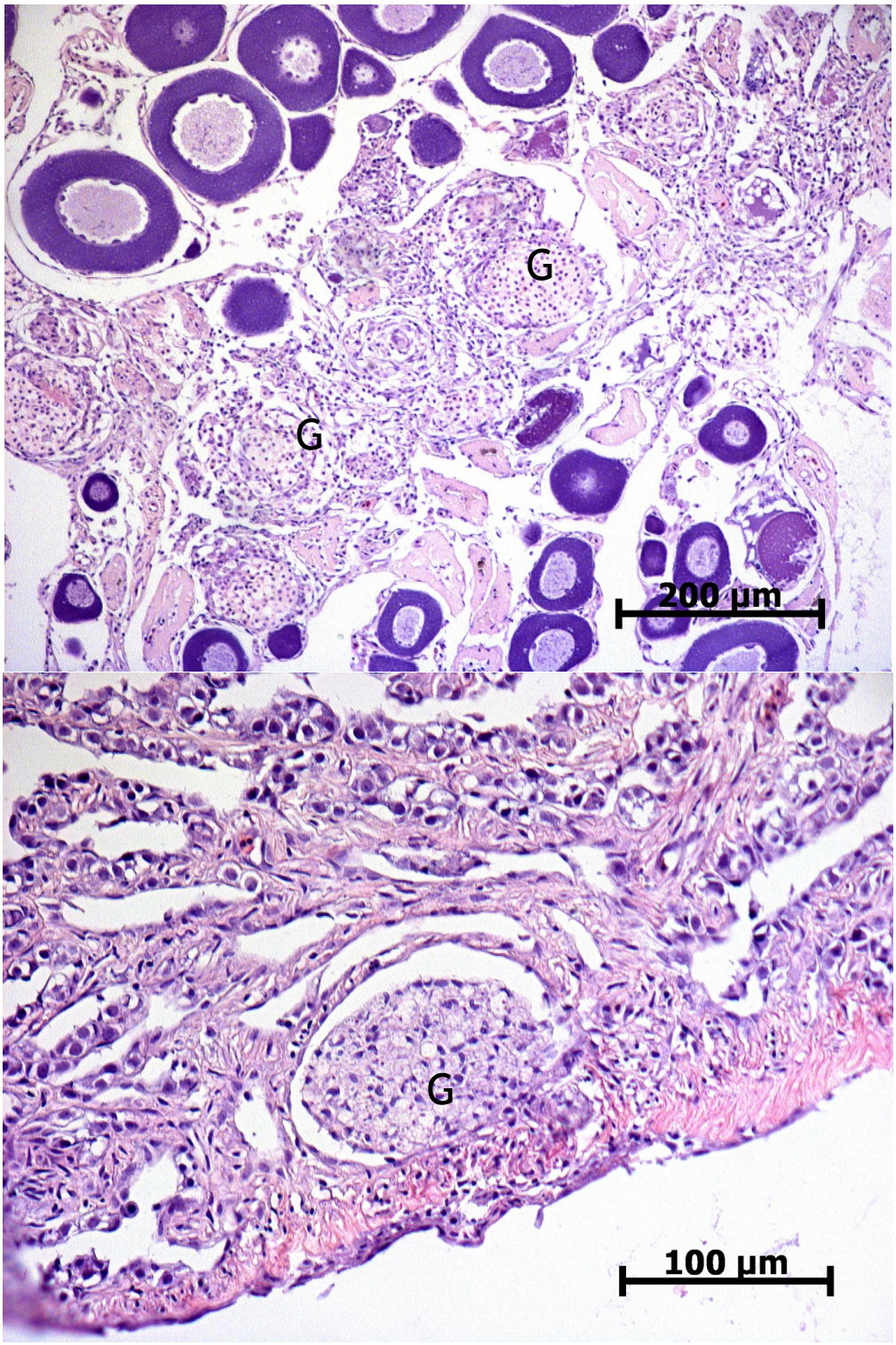


Figure 4.

The post-ovulatory follicles recorded in female simply characterize spent gonads. Occurrence of melanomacrophage complexes (MMC) was not recorded (Fig. 5).

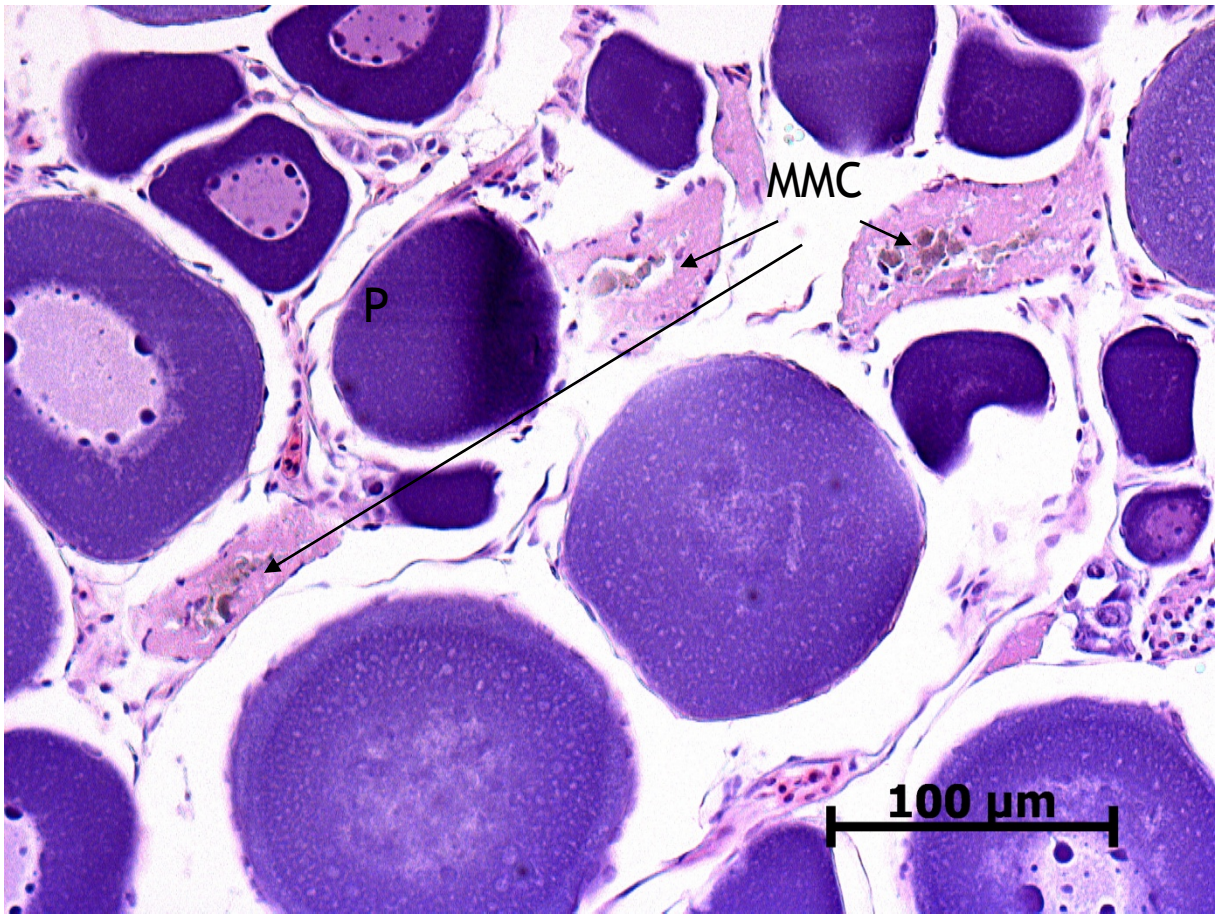


Figure 5.

It can be concluded that there were only 3 female individuals (10, 11 and 15) with pathological changes in gonads.

4. References

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