Norwegian Institute for Water Research

8158-2025

Contaminants in coastal waters 2024

Report

Norsk institutt for vannforskning STI

Norwegian Institute for Water Research

Serial no: 8158-2025

ISBN 978-82-577-7896-5
ISSN 1894-7948

This report has been quality assured according to NIVA's quality system and has been approved by:

Merete Schøyen
Project Manager

Sissel Ranneklev
Quality Assurance

Morten Jartun
Research leader

Cover image:
Merete Schøyen

www.niva.no

Title
Contaminants in coastal waters 2024
Miljøgifter i kystområdene 2024

Pages
100 + supplementary data

Date
19.12.2025

Author(s)
Merete Schøyen, Merete Grung, Espen Lund, Dag Ø. Hjermann, Anders Ruus, Sigurd Øxnevad, Guttorm Christensen (Akvaplan-niva), Bjørnar Beylich, Marthe T. S. Jenssen, Lise Tveiten, Jarle Håvardstun, Kjetil Sagerup (NINA), Veronica Eftevåg, Dorna Misaq, and Kine Bæk

Topic group
Monitoring

Distribution
Open

Client(s)
The Norwegian Environment Agency/ Miljødirektoratet

Client's contact person
Gunn Lise Haugestøl

Published by NIVA
Project number 210200

Client's publication:
M-3096|2025

Abstract
The Norwegian environmental monitoring programme "Contaminants in coastal waters" (Miljøgifter i kystområdene - MILKYS) examines the levels, trends, and effects of contaminants annually in biota along the Norwegian fjords and coastline including Svalbard. The 2024 investigation included analyses of more than 180 different contaminants or biological effect methods (BEM) in five species (blue mussel, cod, dogwhelk, common periwinkle, and common eider). The contaminants measured include metals, TBT, PCBs, PAHs, PBDEs, PFAS, HBCDs, chlorinated paraffins, siloxanes, and pesticides. BEM includes imposex (VDSI) and intersex (ISI), PAH-metabolites, ALA-D, and EROD. The 2024 optional monitoring also included sediment cores (Oslo, Bergen, and Tromsø) and alternative species (whiting, pollack, and haddock) for cod in the Inner Oslofjord. In this report, 37 contaminants and in addition, BEM were chosen for in-depth presentations. EQSs (Environmental Quality Standards) were exceeded in blue mussel (16%), cod (37%), and common eider (22%) expressed as datapoints (contaminants x stations). Contaminants above EQSs were mercury (Hg), sumPCB7, and sumBDE6. PROREFs (Norwegian provisional high reference contaminant concentrations) were exceeded in blue mussel (35%) and cod (11%) expressed as datapoints (contaminants x stations), and exceedances were higher in mussel (10-20x PROREF) than for cod (5-10x PROREF). Significant downward time trends for specific contaminants/effects dominated both recent (≤10 years) and whole period (>10 years) where trends could be statistically detected. The OSPAR method for time trends, HARSAT was used. The highest occurrences of upward whole and recent trends were found for blue mussel in the Inner Oslofjord, and for cod at Lista and Sandnessjøen. Biological effect parameters showed no effects of TBT in snail, but confirmed exposure to PAH and lead in cod. The additional monitoring showed that sediments from the Inner Oslofjord had higher frequency of exceedances of EQS than close to Bergen and Tromsø. Whiting seems to be the most appropriate species for monitoring as an alternative to cod, compared to pollack and haddock, based on biology and comparisons of contaminant levels in the Inner Oslofjord.

Keywords: 1 Environmental contaminants in biota, 2 Levels and trends, 3 Biological effects, 4 Norwegian coast
Emneord: 1 Miljøgifter i biota, 2 Nivåer og trender, 3 Biologiske effekter, 4 Norskekysten

Table of contents

Preface

The Norwegian environmental monitoring programme “Contaminants in Coastal Waters” (Miljøgifter i kystområdene - MILKYS) conducts annual assessments of contaminants in selected marine organisms, including blue mussel (*Mytilus edulis*), Atlantic cod (*Gadus morhua*), dogwhelk (*Nucella lapillus*), common periwinkle (*Littorina littorea*), and common eider (*Somateria mollissima*). This report presents the results from the 2024 monitoring campaign, representing the fourth year of the current five-year cycle (2021-2025). The coastal monitoring program for contaminants has been in operation since 1981.

In addition, this report also presents results from additional survey, which is normally not part of the regular MILKYS monitoring programme. These options included: contaminants in sediment cores close to Oslo, Bergen, and Tromsø (Option 3), and considering the alternative fish species to cod from the Inner Oslofjord; whiting (*Merlangius merlangus*), haddock (*Melanogrammus aeglefinus*), and pollack (*Pollachius pollachius*) (Option 11). The programme was implemented by the Norwegian Institute for Water Research (NIVA, Norsk institutt for vannforskning) contracted by the Norwegian Environment Agency (NEA, Miljødirektoratet). The NEA coordinator is Gunn Lise Haugestøl, with Bård Nordbø as deputy coordinator. The project manager at NIVA is Merete Schøyen, supported by deputy project manager Merete Grung.

Acknowledgments
We extend our sincere gratitude to colleagues at NIVA, Akvaplan-niva (APN), Eurofins (EF), NILU, the Institute for Energy Technology (IFE), The Geological Survey of Norway (NGU), and the University of Copenhagen (UCHP). The division of responsibilities was as follows:

- **Fieldwork and/or sample processing**: Espen Lund, Bjørnar Beylich, Marthe Torunn Solhaug Jenssen, Lise Tveiten, Marijana Stenrud Brkljacic, Rita Næss, Siri Moy, Maia Røst Kile, Kate Hawley, Merete Schøyen, Øyvind Herman Torp, Anders Ruus, Janne Gitmark, Amy Lusher, Kirk Meyer, Anne Luise Ribeiro, Ragnhild Torstensen, Helga Øen Åsnes, Charles Lavin, Frida Sol Svendsen (NIVA), Kjetil Sagerup (NINA, former APN), and Guttorm Christensen (APN).
- **Chemical analyses**: Moe Moe Twe Win, Thomas Rundberget, Dorna Misaq, and their colleagues (NIVA); Beate Sjøberg and her colleagues (EF, Moss, and Gfa and WEJ, Germany); and Stine Marie Bjørneby, Linda Hanssen, and their colleagues (NILU).
- **X-ray radiographic imaging (XRI) of sediment cores**: Henning Jensen (NGU). Thanks to Henning for assistance in interpreting the XRI data.
- **Sediment core dating**: Thorbjørn Joest Andersen (UCHP).
- **Stable isotope analyses**: Ingar Johansen (IFE).
- **Imposex/intersex analyses**: Lise Tveiten, Rita Næss, Bjørnar Beylich, and Merete Schøyen (NIVA).
- **Biological effect measurements**: Maria Thérése Hultman, Tânia Cristina Gomes, Ana Catarina Almeida, and Maria Christou (NIVA).
- **Analytical quality assurance**: Veronica Eftevåg, Dorna Misaq, Kine Bæk, and colleagues (NIVA).
- **Data entry**: Dag Hjermann, Espen Lund, Viviane Girardin, and Lise Tveiten (NIVA).
- **Data processing and management**: Dag Hjermann, Espen Lund, and Merete Grung (NIVA).
- **Data reporting to Vannmiljø, ICES, and OSPAR**: Dag Hjermann (NIVA).
- **Project support responsible**: Nina Engen (NIVA).
- **Financial support responsible**: Karoline Slettebø Arvidsson (NIVA).
- **Scientific reporting**: Merete Grung (disciplinary responsibility), Merete Schøyen, Espen Lund, Anders Ruus (biological effect methods), Sigurd Øxnevad (sediments), and Dag Hjermann (statistical analyses) (NIVA).
- **Quality assurance**: Sissel Brit Ranneklev and Morten Jartun (NIVA).

We also thank the many fishermen and their boat crews for their collaboration and major efforts.

Merete Schøyen
Project Manager at NIVA
Oslo 19.12.2025

Summary

The monitoring programme “Contaminants in coastal waters” (Miljøgifter i kystområdene - MILKYS) examines the levels, trends, and effects of contaminants along the Norwegian coast, fjords, and Svalbard. The programme provides a basis for assessing the state of the contaminants in Norwegian coastal waters. The monitoring makes an important contribution to national administration and to the international organizations such as the Oslo-Paris Convention’s (Convention for the Protection of the Marine Environment of the North-East Atlantic, OSPAR), Coordinated Environmental Monitoring Programme (CEMP), the international Council for Marine Research (International Council for the Exploration of the Sea, ICES), and the European Environment Agency (EEA).

The 2024 investigation monitored the concentration of contaminants in blue mussel (*Mytilus edulis*) at 24 stations, Atlantic cod (*Gadus morhua*) at 18 stations, dogwhelk (*Nucella lapillus*) at eight stations, common periwinkle (*Littorina littorea*) at one station, and common eider (*Somateria mollissima*) at one station. The stations are located both in areas with known or presumed point sources of contaminants, in areas with diffuse loads of contaminants such as city harbour areas, and in more remote regions with presumed low exposure to pollution.

In addition, the 2024 investigation also included additional monitoring of contaminants in sediment cores close to Oslo, Bergen, and Tromsø (Option 3), and considering the alternative fish species whiting (*Merlangius merlangus*), haddock (*Melanogrammus aeglefinus*), and pollack (*Pollachius pollachius*) as substitutes for cod in the Inner Oslofjord (Option 11).

In 2024, the following contaminants were monitored:

- metals (mercury (Hg), cadmium (Cd), lead (Pb), copper (Cu), zinc (Zn), silver (Ag), arsenic (As), nickel (Ni), chromium (Cr), and cobalt (Co))
- tributyltin (TBT)
- polychlorinated biphenyls (sumPCB7)
- dichlorodiphenyltrichloroethane (DDT, using dichlorodiphenyldichloroethylene (p,p'-DDE) - principale metabolite of DDT as an indicator)
- hexachlorobenzene (HCB) and pentachlorobenzene (QCB)
- polycyclic aromatic hydrocarbons (PAHs)
- polybrominated diphenyl ethers (PBDEs)
- per- and polyfluoroalkyl substances (PFAS)
- hexabromocyclododecanes (HBCD)
- short and medium chained chlorinated paraffins (SCCP and MCCP)
- siloxanes (the cyclic volatile methyl siloxanes, cVMS: D4, D5, and D6)

In addition, the following contaminants were analysed in the sediments (Option 3, only in 2024):

- long chained chlorinated paraffins (LCCP)
- other brominated compounds
- quaternary ammonium compounds

Biological effect methods (BEM) and parameters were applied in the monitoring. These were imposex and intersex parameters in marine snails as biomarkers of TBT-exposure, OH-pyrene in cod bile as a marker of PAH-exposure, δ-aminolevulinic acid dehydrase inhibition (ALA-D) in red blood cells from cod as a marker of exposure to lead, and cytochrome P450 1A-activity (ethoxyresorufin-O-deethylase, EROD) in cod liver as a marker of exposure to coplanar PCBs, PAHs, and dioxins.

Stable isotopes of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) were included in the monitoring as useful indicators of food origin and trophic levels. The isotope signatures show a spatial trend that is stable over time, and isotope signatures in blue mussels provide valuable information about the baseline for $\delta^{13}C$ and $\delta^{15}N$ along the Norwegian coast.

Significant downward time trends for contaminants dominated where trends could be detected. The main findings in 2024 can be summarized as follows:

Levels

- The environmental quality standards (EQSs) were exceeded in blue mussel (16%) and cod (37%) expressed as datapoints (contaminants x stations) and in common eider (22%) (datapoints also included tissue), and the contaminants above these limits were mercury (Hg), sumPCB7 (sum of the following congeners: 28, 52, 101, 118, 138, 153, and 180), and sumBDE6 (sum of the following congeners: 28, 47, 99, 100, 153, and 154).
- The Norwegian provisional high reference contaminant concentrations (PROREFs) were exceeded in blue mussel (35%) and cod (11%) expressed as datapoints (contaminants x stations), and exceedances were higher in blue mussel (10-20x PROREF) than cod (5-10x PROREF).

Time trends

- Downward time trends dominated both recent (≤ 10 years) and whole period where trends could be statistically detected. The highest occurrence of upward whole and recent trends was found for blue mussel in the Inner Oslofjord, and for cod at Lista and Sandnessjøen.
- Upward whole trend for mercury was found in cod fillet from the Inner Oslofjord where several contaminants occur at higher concentrations than other areas along the coast.

Effects

- Biological effect parameters (biomarker analysis) showed no effects of TBT in snails, but confirm exposure to PAH and lead in cod.

EQSs

A total of 311 assessments of EQSs for 20 contaminants have been evaluated. EQSs were exceeded in blue mussel (16%), cod (37%), and common eider (22%) expressed as datapoints (contaminants x stations). No exceedances of EQSs were observed in snails.

Contaminants often exceeding EQSs were mercury (there are no EQS values for other metals in biota), sumBDE6, and sumPCB7 for blue mussel, cod, and eider eggs, and mercury also for eider blood. MCCP exceeded EQS at one station for cod.

Blue mussel in the Inner and Outer Oslofjord, in harbour areas, and in the industrialized Sørfjord had highest number of exceedances of EQSs. For cod, EQSs were exceeded at all stations for sumPCB7 and sumBDE6, and for all stations for mercury except for Longyearbyen at Svalbard.

PROREF

We have assessed 25 selected contaminants by comparing them with PROREF (provisional high reference contaminant concentrations). PROREF is a NIVA-developed method intended to determine reference values for classifying whether the concentration for a given contaminant at a given station is close to low/background concentration (either natural concentration or resulting from only diffuse exposure). Blue mussel exceeded PROREF for 35% of the datapoints (contaminants x stations), and 11%

of the datapoints could not be classified vs. PROREF since the limit of quantification (LOQ) was higher than PROREF. In cod, 11% of the samples exceeded PROREF, and the exceedances were lower for cod (5-10x PROREF) compared to mussel (10-20x PROREF).

Blue mussel stations in the Inner Oslofjord had many exceedances of PROREFs, and among these, Akershuskaia had the most exceedances, while Gressholmen had the highest exceedance (PCB118). PCBs had the highest exceedances, which were observed in several urban stations; harbours of Bergen, Ålesund, and Bodø.

Exceedances of PROREF in cod were most often observed at the station in the Inner Oslofjord, followed by Langesundfjord, Bergen harbour, and Ålesund. Sandnessjøen, Tromsø harbour, Hammerfest, and Isfjorden at Svalbard had levels below PROREF for all compounds in cod.

Time trends

In 2024, the OSPAR method of estimating time trends, HARSAT (Harmonised Regional Seas Assessment Tool), was used. A total of 823 time trends (both whole trend (>10 years) and recent trend (≤10 years)) were estimated for the contaminants presented in the extended summary.

Of selected recent time trends, mainly no trends (51%) were detected. Where trends could be detected, most trends were decreasing (25%) rather than increasing (6%).

For 10-25% of the time series, trends could not be determined due to too few data in the dataset. For blue mussel, whole trends were dominated by no trends followed by downward trends indicating decreasing contaminant concentrations. However, upward trends were also observed in about 5-10% of the cases indicating increasing contaminant concentrations. For blue mussel more upward trends for recent trends than whole trends were observed.

Roughly the same picture was observed for cod, with more downward trends and fewer upward trends observed.

Eider has not been monitored long enough to observe whole trends, and for recent trends, no trend dominated followed by downward trends where trends could be observed. No upward trends were observed in eider.

Biological effects

The data confirmed the annual results dating back to 2017 indicating no effects of TBT on dogwhelk (imposex parameter Vas Deferens Sequence Index, VDSI=0).

Concentrations of OH-pyrene in bile from cod at Lista (15B) and Bømlo (23B) were below the ICES/OSPAR assessment criterion (background assessment criteria), however, with large variation, especially at Lista. OH-pyrene concentrations were highest in the Inner Oslofjord (30B) and Sørfjord (53B), where concentrations were significantly different from those at Lista (15B) and Bømlo (23B).

ALA-D activities in cod blood in the Inner Sørfjord and Inner Oslofjord were significantly lower than at the reference station (Bømlo). Reduced activities of ALA-D reflect higher exposure to lead, and hepatic lead concentrations in cod were significantly higher in the Inner Oslofjord and Inner Sørfjord, than at Bømlo.

The median EROD activity appeared lower at Bømlo (reference station), than in the Inner Oslofjord and Inner Sørfjord, however the differences were not statistically significant. Median EROD activities were below the ICES/OSPAR assessment criterion (background assessment criteria), at all stations.

Sediments (additional task in 2024)

The sediment station in the Inner Oslofjord-Steilene had the highest sedimentation rate, and the 12-14 cm layer was dated to be 24 years (from the year 2000). The sediments from the Inner Oslofjord-Steilene had higher frequency of exceedances of EQSs (exceedances for As, Hg, Ni, Zn, PFOS, D5) than sediments from Bergen-Raunefjord (all below EQS) and Tromsø-Nordbotn (only exceedance for PFOS).

The X-ray radiographic imaging (XRI) was used to examine the structure of the sediment cores. Results showed that there was bioturbation in sediments from the Inner Oslofjord, Bergen and Tromsø. The bioturbation does not appear to have significantly displaced the chemical signals, and the age dating of the cores as well as the chemical results from the different sections seem therefore to be reliable.

Alternative species to cod (additional task in 2024)

The population of cod in the Oslofjord has declined and it is difficult to obtain sufficient sample material for chemical analysis. Whiting seems to be the most appropriate species as an alternative to cod, compared to pollack and haddock, based on biology and comparisons of contaminant levels. The fat content of liver was higher in whiting than cod, but not significantly different. The delta N15 (trophic level) was lower in whiting than cod, but not significantly different. Matched pairs statistics showed an overall agreement of concentrations of contaminants in whiting and cod with good correlation. The overall agreement of contaminant concentrations was better for whiting than both pollack and haddock. However, also for whiting, some contaminants had significantly different concentrations in whiting and cod. The differences need to be taken into account if whiting is to be used as alternative species to cod in monitoring.

Sammendrag

Basisovervåkingen «Miljøgifter i kystområdene - MILKYS» (Contaminants in coastal waters) undersøker nivåer, trender og effekter av miljøgifter langs norskekysten, fjorder og på Svalbard. Programmet gir grunnlag for å vurdere miljøtilstanden mht. miljøgifter i norske kystfarvann. Overvåkingen gir viktig bidrag til nasjonal forvaltning og til internasjonale organisasjoner som Oslo-Paris konvensjonen (Convention for the Protection of the Marine Environment of the North-East Atlantic, OSPAR) sitt koordinerte miljøovervåkingsprogram (Coordinated Environmental Monitoring Programme, CEMP), Det internasjonale havforskningsrådet (International Council for the Exploration of the Sea, ICES) og Det europeiske miljøbyrået (European Environment Agency, EEA).

I 2024 omfattet overvåkingen miljøgifter i blåskjell (*Mytilus edulis*) fra 24 stasjoner, torsk (*Gadus morhua*) fra 18 stasjoner, purpursnegl (*Nucella lapillus*) fra åtte stasjoner, strandsnegl (*Littorina littorea*) fra én stasjon og ærfugl (*Somateria mollissima*) fra én stasjon. Stasjonene er plassert i områder med kjente eller antatt kjente punktkilder for tilførsler av miljøgifter, i områder med diffus tilførsel av miljøgifter slik som byens havneområder, og i fjerntliggende områder med antatt lav eksponering for miljøgifter.

I tillegg omfattet undersøkelsen i 2024 også opsjon for overvåking av miljøgifter i sedimentkjerner nær Oslo, Bergen og Tromsø (opsjon 3), samt vurdering av alternative fiskearter for torsk fra indre Oslofjord som hvitting (*Merlangius merlangus*), hyse (*Melanogrammus aeglefinus*) og lyr (*Pollachius pollachius*) (opsjon 11).

Overvåkingen i 2024 omfattet analyser av bl.a.

- metaller (kvikksølv (Hg), kadmium (Cd), bly (Pb), kobber (Cu), sink (Zn), sølv (Ag), arsen (As), nikkel (Ni), krom (Cr) og kobolt (Co))
- tributyltinn (TBT)
- polyklorerte bifenyler (sumPCB7)
- diklordifenyltrikloretan (DDT, bruker diklordifenyldikloretylen (p,p'-DDE) metabolitt av DDT som indikator)
- heksaklorbenzen (HCB) og pentaklorbenzen (QCB)
- polysykliske aromatiske hydrokarboner (PAHer)
- polybromerte difenyletere (PBDEer)
- perfluorerte alkylforbindelser (PFAS)
- heksabromsyklododekan (HBCD)
- korte- og mellomkjedete klorparafiner (SCCP og MCCP)
- siloksaner (sykliske flyktige metylsiloksaner, cVMS: D4, D5 og D6)

I tillegg omfattet overvåkingen også analyser i sedimenter (opsjon 3, kun i 2024):

- langkjedete klorparafiner (LCCP)
- andre bromerte forbindelser
- kvaternære ammoniumforbindelser

Biologiske effektmetoder (BEM) og -parametere ble brukt i overvåkingen. Dette var imposex og intersex i marine snegler som biomarkører for TBT-eksponering, OH-pyren i torskegalle som markør for PAH-eksponering, d-aminolevulinsyre dehydrase (ALA-D) i røde blodceller fra torsk som markør for eksponering for bly og cytokrom P450 1A-aktivitet (ethoxyresorufin-O-deethylase, EROD) i torskelever som markør for eksponering for PAHer, dioksiner og dioksinliknende PCBer.

Stabile isotoper av karbon ($\delta^{13}C$) og nitrogen ($\delta^{15}N$) ble brukt i overvåkingen som nyttige indikatorer for matkildens opprinnelse og trofiske nivåer. Isotopsignaturene viser en romlig trend som er stabil over tid, og isotopsignaturer i blåskjell gir verdifull informasjon om bakgrunnsnivåene for $\delta^{13}C$ og $\delta^{15}N$ langs norskekysten.

Signifikante nedadgående tidstrender for miljøgifter dominerte der hvor trender kan påvises. Hovedfunnene i 2024 kan oppsummeres slik:

Nivåer

- Det var overskridelser av EQS i blåskjell (16 %) og torsk (37 %) målt ved datapunkter (miljøgifter x stasjoner) og i ærfugl (22 %) (datapunkter inkluderer også vev), og miljøgiftene som overskred disse grensene var kvikksølv (Hg), sumPCB7 (sum av følgende kongenere: 28, 52, 101, 118, 138, 153, og 180) og sumBDE6 (sum av de følgende kongenere: 28, 47, 99, 100, 153, og 154).
- Det var overskridelser av PROREF i blåskjell (35 %) og torsk (11 %) målt ved datapunkter (miljøgifter x stasjoner), og overskridelsene var høyere i blåskjell (10-20x PROREF) enn torsk (5-10x PROREF).

Tidstrender

- Nedadgående tidstrender dominerte både på kort sikt (≤ 10 år) og for hele perioden der hvor tidstrender kunne påvises statistisk. Høyest forekomst av oppadgående lang- og korttidstrender ble funnet for blåskjell i indre Oslofjord, og for torsk ved Lista og Sandnessjøen.
- Oppadgående langtidstrend for kvikksølv ble funnet i torskefilét fra indre Oslofjord, hvor flere miljøgifter forekommer i høyere konsentrasjoner enn andre områder langs kysten.

Effekter

- For biologiske effektparametere (biomarkøranalyser) var det ingen effekter av TBT i snegler, men undersøkelsene bekrefter eksponering av PAH og bly i torsk.

EQS

Det er gjort totalt 311 vurderinger av EQS for 20 miljøgifter. EQS ble overskredet i blåskjell (16 %), torsk (37 %) og ærfugl (22 %) målt ved datapunkter (miljøgifter x stasjoner). Det var ingen overskridelser av EQS i snegl.

Miljøgifter som ofte overskrider EQS var kvikksølv (det finnes ikke EQS-verdier for andre metaller i biota), sumBDE6 og sumPCB7 for blåskjell, torsk og ærfugl egg, og kvikksølv også i ærfugl blod. EQS for MCCP ble overskredet ved én torskestasjon.

Blåskjell fra indre og ytre Oslofjord, i havneområder og i områder som industrialiserte Sørfjorden hadde flest overskridelser av EQS. For torsk var det overskridelser av EQS på alle stasjoner for sumPCB7 og sumBDE6, og for alle stasjoner for kvikksølv unntatt for Longyearbyen på Svalbard.

PROREF

Vi har vurdert 25 utvalgte miljøgifter ved å sammenligne dem med referanseverdien PROREF (provisional high reference contaminant concentrations). PROREF er en NIVA-utviklet metode for å bestemme referanseverdier som kan klassifisere konsentrasjoner av en gitt miljøgift som nær lav verdi/bakgrunnsverdi (enten naturlig konsentrasjon eller kun utsatt for diffus eksponering). I blåskjell ble PROREF overskredet i 35 % av datapunktene (miljøgifter x stasjoner), og 11 % av datapunktene kunne ikke klassifiseres vs. PROREF, fordi kvantifiseringsgrensene (limit of quantification, LOQ) var

høyere enn PROREF. For torsk var 11 % av prøvene over PROREF, og de høyeste overskridelsene var lavere for torsk (5-10X PROREF) sammenliknet med blåskjell (10-20x PROREF).

Blåskjellstasjoner i indre Oslofjord hadde mange overskridelser av PROREF, og blant disse hadde Akershuskaia flest overskridelser, mens Gressholmen hadde den høyeste overskridelsen (PCB118). Det var størst overskridelser av PCB, som ble påvist på flere urbane stasjoner: havner i Bergen, Ålesund og Bodø.

Overskridelser av PROREF i torsk ble oftest observert ved stasjonene i indre Oslofjord, etterfulgt av Langesundsfjorden, Bergen havn og Ålesund. Sandnessjøen, Tromsø havn, Hammerfest og Isfjorden på Svalbard hadde nivåer under PROREF for alle de undersøkte forbindelsene i torsk.

Tidstrender

I 2024 ble OSPAR-metoden for å estimere tidsserier, HARSAT (Harmonised Regional Seas Assessment Tool), brukt. Totalt 823 tidstrender (både langtidstrender (> 10 år) og korttidstrender (≤10)) ble utregnet for miljøgifter presentert i det utvidede sammendraget.

Av utvalgte korttidstrender ble det hovedsakelig ikke påvist noen trend (51 %). Der trender kunne påvises, var de fleste synkende (25 %) heller enn økende (6 %).

For 10-25 % av tidsseriene kunne ikke trender utregnes på grunn av for få data i datasettet. For blåskjell var langtidstrender dominert av «ingen trend», etterfulgt av nedadgående trender som indikerer reduserte konsentrasjoner av miljøgifter. Det ble imidlertid også observert oppadgående trender i omtrent 5-10 % av tilfellene, noe som indikerer økende konsentrasjoner. For blåskjell ble det observert flere oppadgående korttidstrender enn for langtidstrender.

Omtrent det samme bildet ble observert for torsk, med flere nedadgående trender og færre oppadgående trender.

Ærfugl er ikke overvåket lenge nok til å bestemme langtidstrender, og for kortidstrender dominerte ingen trend, etterfulgt av nedadgående trender der hvor trender kunne bestemmes. Ingen oppadgående trender ble observert for ærfugl.

Biologiske effekter

Dataene bekreftet resultatene siden 2017 om ingen effekter av TBT for purpursnegl (imposex parameter Vas Deferens Sequence Index, VDSI=0).

Konsentrasjoner av OH-pyren i galle fra torsk fra Lista (15B) og Bømlo (23B) var under ICES/OSPARs vurderingskriterium for bakgrunnsnivå («background assessment criteria», BAC), men variasjonen var stor, særlig ved Lista. OH-pyrenkonsentrasjonene var høyest i Indre Oslofjord (30B) og Sørfjorden (53B), hvor konsentrasjonene var signifikant forskjellige fra de ved Lista (15B) og Bømlo (23B).

ALA-D-aktivitet i torskeblod fra Indre Sørfjorden og Indre Oslofjord var signifikant lavere enn ved referansestasjonen (Bømlo). Redusert aktivitet av ALA-D tyder på høyere eksponering for bly, og hepatiske konsentrasjoner av bly i torsk var høyere i Indre Oslo fjord og Indre Sørfjorden, enn ved Bømlo.

Median EROD-aktivitet fremsto lavere ved Bømlo (referansestasjon) enn i Indre Oslofjord og Indre Sørfjorden, men forskjellene var ikke statistisk signifikante. EROD-aktiviteter (medianer) var lavere enn ICES/OSPARs vurderingskriterium for bakgrunnsnivå (BAC) på alle stasjoner.

Sedimenter (tilleggsoppgave i 2024)

Sedimentstasjonen i indre Oslofjord-Steilene hadde den høyeste sedimentasjonsraten, og snittet på 12-14 cm ble datert til å være 24 år (fra år 2000). Sedimentene i indre Oslofjord-Steilene hadde høyere frekvens av overskridelser av EQS (overskridelser for As, Hg, Ni, Zn, PFOS, D5) enn fra Bergen-Raunefjorden (alle under EQS) og Tromsø-Nordbotn (kun overskridelse for PFOS).

Røntgenradiografisk avbildning (XRI) ble anvendt for å undersøke strukturen i sedimentkjerner. Resultater viste at det var bioturbasjon i sediment fra indre Oslofjord, Bergen og Tromsø. Bioturbasjonen ser ikke ut til å ha forstyrret aldersdateringen eller kjemiske resultater, og disse fremstår som pålitelige.

Alternative arter for torsk (tilleggsoppgave i 2024)

Torskebestanden i Oslofjorden har gått tilbake, og det er vanskelig å skaffe tilstrekkelig prøvemateriale til kjemiske analyser. Hvitting ser ut til å være den mest egnede arten som alternativ til torsk, sammenlignet med lyr og hyse, basert på biologi og sammenligninger av forurensningsnivåer. Fettinnholdet i lever var høyere i lever fra hvitting enn fra torsk, men ikke signifikant forskjellig. Delta N15 (trofisk nivå) var lavere for hvitting enn torsk, men nivåene var ikke signifikant forskjellige. Parvise sammenligninger av konsentrasjoner i hvitting og torsk viste samlet sett at konsentrasjonene var sammenlignbare mellom hvitting og torsk og korrelasjonen var god. Konsentrasjonene samlet sett var i bedre overensstemmelse mellom torsk og hvitting enn mellom torsk og de to andre artene (lyr og hyse). Imidlertid viste den parvise sammenligningen at for noen miljøgifter var det signifikante forskjeller mellom nivåer i torsk og hvitting. Disse forskjellene må hensyntas dersom hvitting skal erstatte torsk i overvåking.

1 Introduction

1.1 Background

The national monitoring programme “Contaminants in coastal waters” (Miljøgifter i kystområdene - MILKYS) is financed by the Norwegian Environment Agency (NEA). MILKYS monitors the levels, trends, and effects of hazardous substances in fjords and coastal waters in Norway including Svalbard on an annually basis. The main objective of this monitoring programme is to obtain an overview of updated information on levels and trends of selected environmental pollutants. The programme also provides a basis for assessing the state of the environment in Norwegian coastal waters. The monitoring contributes to the Oslo and Paris Commission’s (OSPAR’s) Coordinated Environmental Monitoring Programme (CEMP). Results in this report are considered part of the Norwegian contribution to the European Environment Agency (EEA) as part of the assessment under the EU Water Framework Directive (WFD). NEA uses the data for international chemical regulation, reporting, and national knowledge dissemination. The results are also sent by NEA to the Norwegian Food Safety Authority (Mattilsynet) to assess warnings for seafood consumption.

1.2 Purpose

MILKYS provides data to State of the Environment Norway (Norges klima- og miljømål (miljodirektoratet.no)) which provides the latest information about the state and development of the environment in Norway. This is important as input to Norway's national and international efforts to protect the environment against pollution and to reduce existing pollution. MILKYS data is part of the Norwegian contribution to CEMP which aims to deliver comparable data from across the OSPAR Maritime Area. These data can be used in assessments to address the specific questions raised in the OSPAR's Joint Assessment and Monitoring Programme (JAMP), and is designed to address issues relevant to OSPAR (OSPAR, 2022) including OSPAR priority substances [1, 2]. The OSPAR Hazardous Substances Strategy is to prevent pollution by hazardous substances, by eliminating their emissions, discharges, and losses, to achieve levels that do not give rise to adverse effects on human health or the marine environment. Under OSPAR, data from MILKYS and other monitoring programmes support this strategy by:

1. Monitoring the levels of a selection of hazardous substances in biota.
2. Evaluating the bioaccumulation of priority hazardous substances in biota of coastal waters.
3. Provide a basis for assessing the effectiveness of previous remedial action.
4. Provide a basis for considering the need for additional remedial action.
5. Assessing the risk to biota in coastal waters.
6. Contribute with monitoring data that is reported in international environmental cooperation Norway is committed to.

MILKYS also contributes data to support the implementation of the Water Framework Directive (WFD) (Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 Establishing a Framework for Community Action in the Field of Water Policy, 2000) and the Environmental Quality Standards Directive (EQSD) (Directive 2013/39/EU, 2013). These directives set criteria for achieving good chemical status in water bodies. MILKYS contributes by assessing contaminant concentrations against the EQSs, which indicate whether the chemical status meet the required standards. Of the 45

[1] *https://www.ospar.org/work-areas/hasec/hazardous-substances/priority-action*

[2] *https://www.ospar.org/work-areas/hasec/hazardous-substances/overview*

priority substances in the EQSD, 24 have assigned an EQS in biota (when including priority substances, and DDT, which have Norwegian derived EQSs for biota). Of these 24 biota EQSs, 14 were assessed in MILKYS. In addition, Norway has derived biota EQS for 10 river basin specific pollutants (RBSP), of which 6 are assessed in MILKYS.

The results from MILKYS can also be useful in addressing aspects, like Descriptor 8 (Contaminants) and Descriptor 9 (Contaminants in Seafood), of the EU Marine Strategy Framework Directive (MSFD) (Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 Establishing a Framework for Community Action in the Field of Marine Environmental Policy (Marine Strategy Framework Directive) (Text with EEA Relevance), 2008). One of the goals of the WFD and MSFD is to achieve concentrations of hazardous substances in the marine environment near background values for naturally occurring substances and close to zero for anthropogenic substances. OSPAR has also adopted this goal [3].

MILKYS data are also used in reporting for the national monitoring group for marine ecosystems (Overvåkingsgruppa) for the integrated management plans for the Norwegian sea areas: the Barents Sea and Lofoten, the Norwegian Sea, and the North Sea and Skagerrak. MILKYS data are used in the marine indicators presented on Miljøstatus for blue mussel, cod, snails, and for statistical analysis of time series.

The MILKYS programme investigates contaminants in blue mussel, cod, dogwhelk, common periwinkle, and common eider on an annual basis. This report presents the findings from monitoring performed in 2024, the fourth year of the five-year period (2021-2025). The program started in 1981 and has since been developed. The reporting format was changed from the 2020 investigation (Schøyen, Lund, et al., 2024) to a shorter data report for the 2022 investigation (Schøyen, Grung, Lund, Hjermann, Ruus, Øxnevad, Christensen, Beylich, Jenssen, Tveiten, Håvardstun, Eftevåg, et al., 2024). More complementary information regarding previous programs, such as background history, abbreviations for contaminants, maps etc., can be found in the previous reports and from the last report for the 2023 investigation (Schøyen, Grung, Lund, Hjermann, Ruus, Øxnevad, Christensen, Beylich, Jenssen, Tveiten, Håvardstun, Sagerup, et al., 2024). This report also presents the results from the additional monitoring of sediments and alternative species for cod in 2024. Parts in this report reuse text from our previous annual reports as listed above.

[3] *https://www.ospar.org/work-areas/hasec/hazardous-substances*

2 Extended summary of MILKYS 2024

2.1 Samples, localities and chemical analyses

Location of stations sampled in MILKYS 2024 are shown in **Figure 1** and number of samples at each station are listed in **Table 1**. Overview of the contaminants selected for presentation of results in extended summary are listed in **Table 2**. The contaminants were primarily selected based on EQS and/or PROREF exceedance, and secondly because they represent the contaminant group (for example D5 represents siloxanes, while D4 and D6 are shown in supplementary). This extended summary presents the main results. Several contaminants in addition to those discussed in the extended summary were determined, and figures for those contaminants are shown, but not discussed any further in **Supplementary data**. The data is reported to Vannmiljø, ICES, and OSPAR.

2.1.1. Samples and monitoring stations

Location of stations sampled in MILKYS 2024 are shown in **Figure 1** and number of samples at each station are listed in **Table 1**. **Table 2** gives an overview of contaminants that are assessed for exceedance of EQSs (**chapter 3.1**) and PROREFs (**chapter 3.2**).

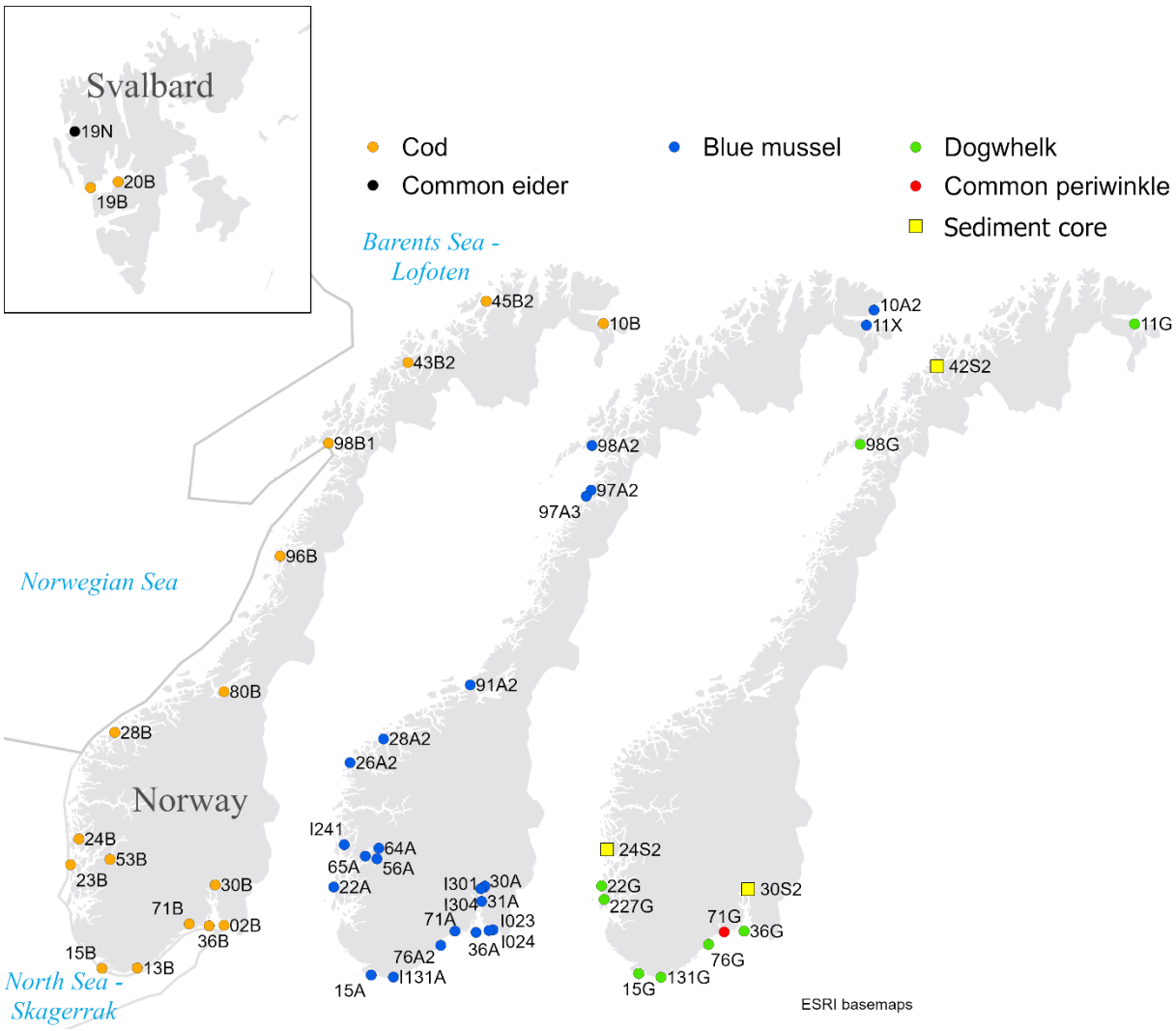


Figure 1. Stations where cod (*Gadus morhua*) and common eider (*Somateria mollissima*) (left), blue mussel (*Mytilus edulis*) (middle), dogwhelk (*Nucella lapillus*), common periwinkle (*Littorina littorea*), and sediments (right) were sampled in Norway and Svalbard (inset). The alternative species whiting (*Merlangius merlangus*), haddock (*Melanogrammus aeglefinus*) and pollack (*Pollachius pollachius*) were sampled at cod station 30B Inner Oslofjord. The North Sea-Skagerrak, Norwegian Sea, and Barents Sea-Lofoten in this figure correspond to the areas defined in the Norwegian ocean management plans, which do not necessarily align with other delineations of boundaries for these seas.

Table 1. Number of samples of blue mussel (pooled samples), cod (pooled for some liver main samples), common eider, dogwhelk (pooled), and common periwinkle (pooled). Number of samples for Option 3 sediments and Option 11 alternative fish species whiting (*Merlangius merlangus*), haddock (*Melanogrammus aeglefinus*), and pollack (*Pollachius pollachius*) to cod in the Inner Oslofjord are also included. The stations are ordered along the coastline starting north moving south. Station names in Vannmiljø are listed in **Table S4** in **Supplementary** data. The marine areas in this table corresponds to the areas defined in the Norwegian ocean management plans, which do not necessarily align with other delineations of boundaries for these seas.

Species	Station code	Station name	Marine areas	Latitude	Longitude	Bile	Blood	Egg	Liver main	Liver siloxanes	Liver BEM*	Fillet	Whole soft body	Sediment
Blue mussel (*Mytilus edulis*)	11X	Brashavn, Varangerfjord	Barents Sea and Lofoten	69.8993	29.741								3	
	10A2	Skallnes, Varangerfjord	Barents Sea and Lofoten	70.1373	30.3417								3	
	98A2	Svolvær airport	Barents Sea and Lofoten	68.2492	14.6627								3	
	97A2	Mjelle, Bodø	Norwegian Sea	67.4127	14.6219								3	
	97A3	Bodø harbour	Norwegian Sea	67.2963	14.3956								3	
	91A2	Ørland airport	Norwegian Sea	63.6514	9.5639								3	
	28A2	Ålesund harbour	Norwegian Sea	62.4659	6.2396								3	
	26A2	Måløy, Nordfjord	North Sea and Skagerrak	61.9362	5.0488								3	
	I241	Bergen harbour	North Sea and Skagerrak	60.4008	5.304								3	
	56A	Kvalnes, Mid Sørfjord	North Sea and Skagerrak	60.2205	6.602								3	
	65A	Vikingneset, Mid Hardangerfjord	North Sea and Skagerrak	60.2423	6.1527								3	
	64A	Utne, Outer Sørfjord	North Sea and Skagerrak	60.4239	6.6223								3	
	22A	Espevær, Bømlo	North Sea and Skagerrak	59.5871	5.152								3	
	15A	Ullerøy, Farsund	North Sea and Skagerrak	58.0461	6.9159								3	
	I131A	Lastad, Søgne	North Sea and Skagerrak	58.0556	7.7083								3	
	76A2	Risøy, Risør	North Sea and Skagerrak	58.7327	9.281								3	
	71A	Bjørkøya, Langesundfjord	North Sea and Skagerrak	59.0233	9.7537								1	
	36A	Færder, Outer Oslofjord	North Sea and Skagerrak	59.0274	10.525								3	
	I304	Gåsøya, Inner Oslofjord	North Sea and Skagerrak	59.8513	10.589								3	
	I301	Akershuskaia, Inner Oslofjord	North Sea and Skagerrak	59.9053	10.7363								3	
	30A	Gressholmen, Inner Oslofjord	North Sea and Skagerrak	59.8836	10.711								3	
	31A	Solbergstrand, Mid Oslofjord	North Sea and Skagerrak	59.6155	10.6515								3	
	I024	Kirkøy, Hvaler	North Sea and Skagerrak	59.0791	10.9873								3	
	I023	Singlekalven, Hvaler	North Sea and Skagerrak	59.0951	11.1368								3	
Cod (*Gadus morhua*)	20B	Longyearbyen, Svalbard	Barents Sea and Lofoten	78.2623	15.4795				13	15		15		
	19B	Isfjorden, Svalbard	Barents Sea and Lofoten	78.17	13.46				15	15		15		
	10B	Varangerfjord	Barents Sea and Lofoten	69.8162	29.7602				15	15		15		
	45B2	Hammerfest harbour	Barents Sea and Lofoten	70.65	23.6333				13			15		
	43B2	Tromsø harbour	Barents Sea and Lofoten	69.653	18.974				14	15		15		
	98B1	Lofoten	Barents Sea and Lofoten	68.1858	14.7081				15	15		15		

Species	Station code	Station name	Marine areas	Latitude	Longitude	Bile	Blood	Egg	Liver main	Liver siloxanes	Liver BEM*	Fillet	Whole soft body	Sediment
	96B	Sandnessjøen	Norwegian Sea	66.0444	12.5036				12			15		
	80B	Trondheim harbour	Norwegian Sea	63.4456	10.3717				15	15		15		
	28B	Ålesund harbour	Norwegian Sea	62.4678	6.0686				15	15		15		
	24B	Bergen harbour	North Sea and Skagerrak	60.3966	5.2707				3	4		4		
	53B	Inner Sørfjord	North Sea and Skagerrak	60.0973	6.5397	15	13		9		13	15		
	23B	Bømlo	North Sea and Skagerrak	59.8956	5.1086	15	15		15	15	15	15		
	15B	Lista	North Sea and Skagerrak	58.0514	6.7469	15			15			15		
	13B	Kristiansand harbour	North Sea and Skagerrak	58.1328	7.9885				7	15		15		
	71B	Langesundfjord	North Sea and Skagerrak	59.0465	9.7028				15	15		15		
	36B	Tjøme, Outer Oslofjord	North Sea and Skagerrak	59.0405	10.4358				15	15		15		
	30B	Inner Oslofjord	North Sea and Skagerrak	59.8127	10.5518	13	15		4	15	15	15		
	02B	Hvaler	North Sea and Skagerrak	59.0648	10.9735				11			15		
Dogwhelk (*Nucella lapillus*)	11G	Brashavn, Varangerfjord	Barents Sea and Lofoten	69.8995	29.7419								1	
	98G	Svolvær airport	Barents Sea and Lofoten	68.247	14.6664								1	
	22G	Espevær, Bømlo	North Sea and Skagerrak	59.5837	5.1445								1	
	227G	Mid Karmsund	North Sea and Skagerrak	59.3396	5.3122								1	
	15G	Ullerøy, Farsund	North Sea and Skagerrak	58.0493	6.9012								1	
	131G	Lastad, Søgne	North Sea and Skagerrak	58.0284	7.699								1	
	76G	Risøya, Risør	North Sea and Skagerrak	58.728	9.2755								1	
	36G	Færder, Outer Oslofjord	North Sea and Skagerrak	59.0278	10.5256								1	
Common periwinkle (*Littorina littorea*)	71G	Fugløyskjær, Langesundfjord	North Sea and Skagerrak	58.985	9.8046								1	
Common eider (*Somateria mollissima*)	19N	Kongsfjorden, Svalbard	Barents Sea and Lofoten	79.004	12.11		15	15						
Sediments (Option 3)	42S2	Tromsø-Nordbotn	Barents Sea and Lofoten	69.67565	18.80138									7
	24S2	Bergen-Raunefjord	North Sea and Skagerrak	60.27386	5.14478									7
	30S2	Inner Oslofjord-Steilene2	North Sea and Skagerrak	59.81905	10.56727									7
Alternative species to cod (Option 11)	30B	Inner Oslofjord		59.8127	10.5518									
Haddock (*Melanogrammus aeglefinus*)			North Sea and Skagerrak						15	15		15		
Pollack (*Pollachius pollachius)*			North Sea and Skagerrak						2	4		4		
Whiting (*Merlangius merlangus*)			North Sea and Skagerrak						7	11		11		

*Biological effect methods (BEM).

Table 2. List of parameters that will be shown and discussed in more detail in this report. Number of stations where samples were analysed in blue mussel *(Mytilus edulis*), cod (*Gadus morhua*), common eider (*Somateria mollissima*), and snail (*Nucella lapillus* and *Littorina littorea*) are provided. EQS and PROREF indicate which sections (3.1 EQS and/or 3.2 PROREF) in this report the data are presented. Time trends are shown in **chapter 3.3** unless marked with "no" in this table.

Contaminant group	Contaminant	Blue mussel	Cod	Eider[1]	Snails	Presented in EQS	Presented in PROREF	Presented in time trends
Metals	**Ag**	24	18	1	0		PROREF	yes
	As	24	18	1	0		PROREF	yes
	Cd	24	18	1	0		PROREF	yes
	Co	24	18	1	0		PROREF	yes
	Cr	24	18	1	0		PROREF	yes
	Cu	24	18	1	0		PROREF	yes
	Hg	24	18	1	0	EQS	PROREF	yes
	Ni	24	18	1	0		PROREF	yes
	Pb	24	18	1	0		PROREF	yes
	Zn	24	18	1	0		PROREF	yes
PFAS	**PFOA**	6	11	1	0	EQS	PROREF	yes
	PFOS	6	11	1	0	EQS	PROREF	yes
	PFOSA	6	11	1	0		PROREF	yes
PBDE	**BDE47**	11	12	1	0		PROREF	yes
	BDE100	11	12	1	0		PROREF	yes
	BDE154	11	12	1	0		PROREF	yes
	sumBDE6[2]	11	12	1	0	EQS		
PCB	**CB118**	23	18	1	0		PROREF	yes
	CB138	23	18	1	0		PROREF	yes
	CB153	23	18	1	0		PROREF	yes
	sumPCB7[3]	23	18	1	0	EQS		
PAH	**BAA**	7	0	0	0	EQS	PROREF	yes
	BAP	7	0	0	0	EQS	PROREF	yes
	FLU	7	0	0	0	EQS	PROREF	yes
	PYR	7	0	0	0		PROREF	yes
	ANT	7	0	0	0	EQS		
	NAP	7	0	0	0	EQS		
Siloxanes	**D5**	0	13	1	0	EQS		yes
CP	**MCCP**	11	14	1	0	EQS		yes
	SCCP	11	14	1	0	EQS		yes
Pesticides	**sumDDT**	2	1	0	0	EQS		
	HCB	2	1	0	0	EQS	PROREF	yes
	sumHCH	2	1	0	0	EQS		
	QCB	2	1	0	0	EQS		
Brominated	**HBCDA**	11	14	1	0	EQS	PROREF	yes
TBT-related	**TBT**	0	0	0	9	EQS		
	TPhT	0	0	0	9	EQS		

[1] Eider were analysed at one station, but in two tissues (blood and eggs).

[2] Lower bound of sumBDE6, i.e. data below limit of quantification (LOQ) are set to 0 when sum is calculated

[3] Lower bound of sumPCB7, i.e. data below LOQ are set to 0 when sum is calculated.

3 Summary of exceedances (EQSs and PROREFs) and time trends

Exceedances of EQSs, PROREFs, and time trends are shown in mosaic plots for species and contaminants. Assessments of EQSs have been done on species and tissue as shown in **Table 1**. The EQSs refer to fish (concentrations in whole fish), except in the case of PAHs, where reference is made of crustaceans and molluscs (European Commission, 2014; Fliedner et al., 2018). Therefore, the EQS cannot be directly compared to concentrations found in specific tissues of fish or blue mussel. For example, we have in the present study measured mercury in fish fillet and other contaminants in liver, not in the whole fish. Converting mercury concentrations in fish fillet to concentrations in whole fish is uncertain. Using fillet probably represents an overestimate of the whole fish concentration because mercury accumulates more in the fillet than in other tissues (Kwaśniak & Falkowska, 2012). It is assumed, for this exercise, that the same concentration is found in all fish tissue types. Also, contaminants measured in liver samples represent an overestimation compared to the whole fish. Fliedner et al. (2018) found that for fillet concentrations, lipid soluble concentrations like PCBs and PBDEs were correlated with lipid concentrations in fillet compared to the whole fish. The cod liver is lipid rich, and therefore assessing concentrations of contaminants to EQSs in liver is conservative.

For mercury in cod, risk assessments vs. EQS and PROREF are done by using the concentrations measured directly. For the time plots and time trends, the concentrations have been converted to a cod (50 cm size) to account for variability in fish size between years (Ruus et al., 2017). The conversion makes the trends more robust against size variability over time.

How to read mosaic plots
Mosaic plots are a special type of stacked bar chart, where the width of the columns is proportional to the number of observations in each level of the variable plotted on the horizontal axis. The vertical length of the bars is proportional to the number of observations in the second variable (exceedances of EQSs and PROREFs, and time trends). Furthermore, heatmaps are illustrating exceedances and time trends for individual species and stations.

3.1 EQS

Assessments of exceedances of EQSs have been done. The contaminants listed in **Table 3** have been selected for presentation in 2024, and all have an associated EQS in biota (Miljødirektoratet, 2025) and are therefore subject to assessment. A total of 311 assessments of EQSs have been done in 2024 (combination of contaminant × station). Twenty contaminants determined in 2024 had EQSs (**Table 3**).

3.1.1. Species and contaminants

In MILKYS, the exceedances of EQSs are considered by the median concentration for each station. The species groups blue mussel, cod, and snails were analysed for contaminants with an assigned EQS, and exceedances are shown in **Figure 2**.

Table 3. List of contaminants determined in 2024 for which an EQS exist for biota. The EQSs are given in µg/kg (ng/g ww). The compound is a priority compound unless marked with "yes" in the column RBSP.

Contaminant Group	Contaminant	EQS (µg/kg ww)	River basin specific pollutants (RBSP)
Metals	Mercury (Hg)	20	
PFAS	Perfluorooctanoic acid (PFOA)	91	yes
	Perfluorooctanesulfonic acid (PFOS)	9.1	
PBDEs	Sum of PBDE congeners -28, -47, -99, -100, -153, -154	0.0085	
PAHs	Anthracene (ANT)	2,400	
	Benzo(a)anthracene (BAA)	300	yes
	Benzo(a)pyrene (BAP)	5	
	Fluoranthene (FLU)	30	
	Naphthalene (NAP)	2,400	
PCBs	Sum of PCB congeners -28, -52, -101, -118, -138, -153, and -180 (sumPCB7)	0.6	yes
Siloxanes	Decamethylcyclopentasiloxane (D5)	15,217	yes
CPs	Chlorinated paraffins (MCCP (C14-C17))	170	yes
	Chlorinated paraffins (SCCP (C10-C13)	6,000	
HBCDs	Hexabromocyclododecane (HBCDD)	167	
DDTs	Dichlorodiphenyldichloroethylene (p,p'-DDE)	610	
Pesticides	Hexachlorobenzene (HCB)	10	
	Pentachlorobenzene (QCB)	50	
	Hexachlorocyclohexane (HCHG)	61	
TBT-related	Tributyltin (TBT)	150	
	Triphenyltin (TPhT)	150	yes

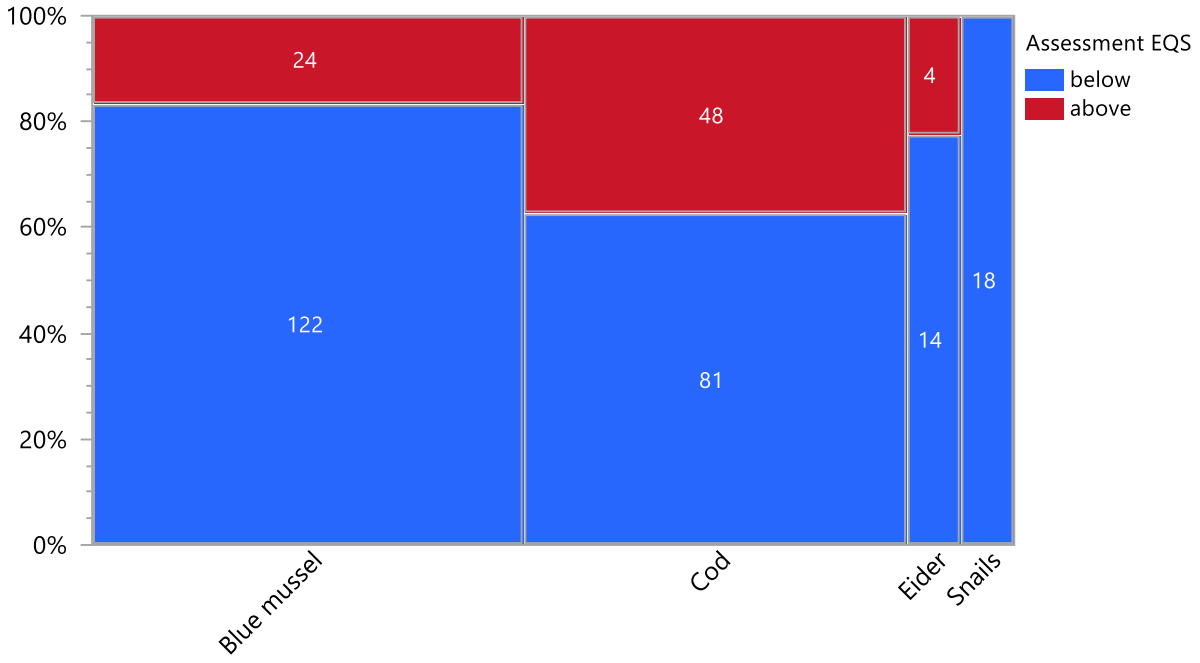


Figure 2. Exceedances of EQSs by species groups in a mosaic plot. The cells are labelled by the number of datapoints (contaminants x stations). The exceedances are considered by the median for each station and species. The colours represent below or above EQSs. The total area of the figures represents the 311 assessments of EQS.

To illustrate which contaminants that had concentrations exceeding EQSs, **Figure 3** to **Figure 6** illustrate this for blue mussel, cod, and snails, respectively. Furthermore, heatmaps of concentration exceedances at individual station and contaminant are shown in **Figure 7** and **Figure 8** for blue mussel, cod, and eider respectively.

In blue mussel (**Figure 3**), compounds with concentrations exceeding EQSs were mercury (at 4 of 24 stations), sumBDE6 (9 of 11 stations), and sumPCB7 (11 of 23 stations). The EQS for sumBDE6 is very low to protect human health (European Commission, 2014).

In cod (**Figure 4**), all median concentrations of sumBDE6 and sumPCB7 exceeded EQSs. SumPCB7 is a river basin specific pollutant (RBSP), and is frequently exceeded also in freshwater trout from supposedly pristine rivers in Norway (Eriksen et al., 2024). Only one station did not exceed EQS for mercury.

Two contaminants (TBT and TPhT) were quantified in snails (**Figure 5**), and no exceedances of EQSs were seen.

In eider (**Figure 6**) sumBDE6 and sumPCB7 exceeded EQSs in eggs, and for mercury in both blood and eggs.

Contaminants often exceeding EQSs are therefore mercury (there are no EQS values for other metals in biota), sumBDE6, and sumPCB7 for blue mussel, cod and eider eggs, and mercury also for eider blood. MCCP exceeded EQS at one station for cod.

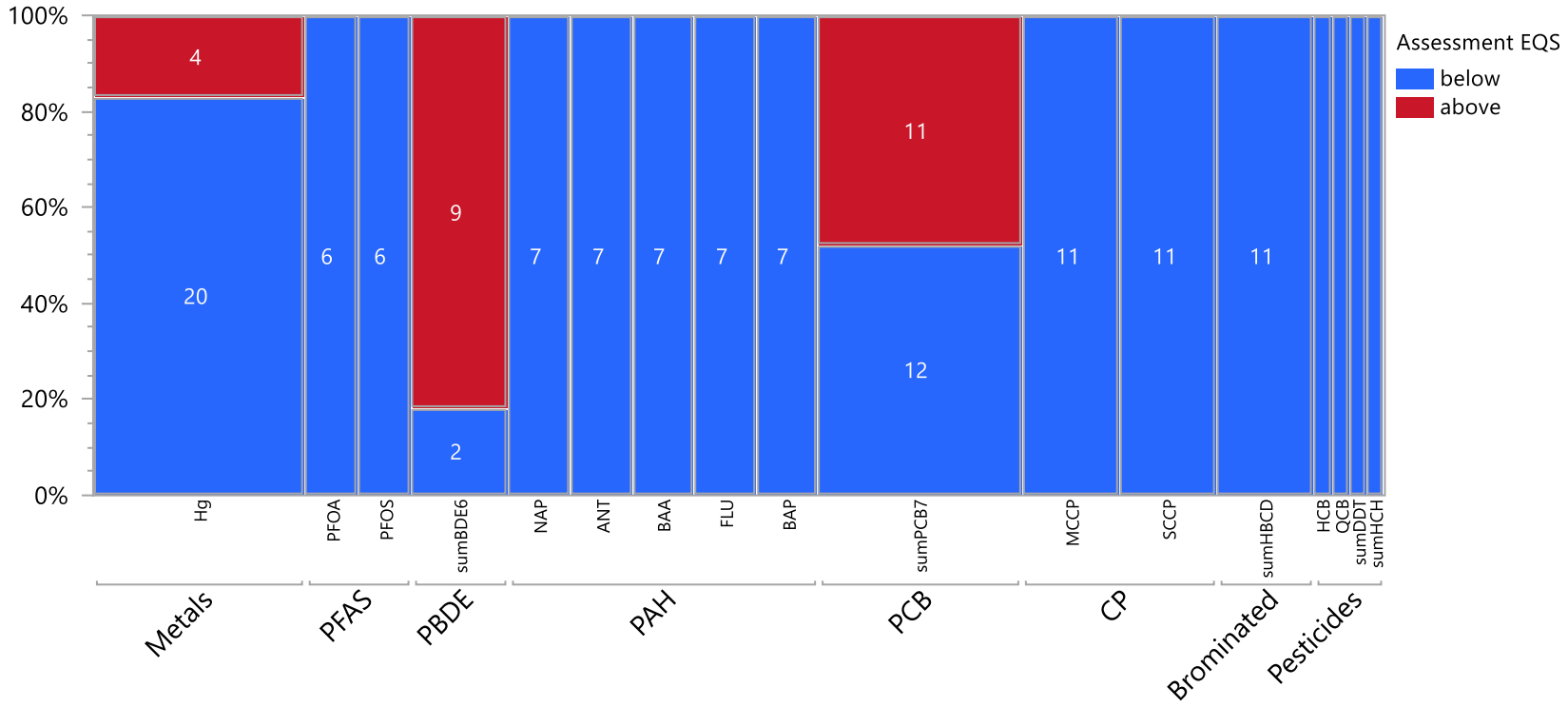


Figure 3. Exceedances of EQSs in blue mussel by contaminant and contaminant group. The cells are labelled by the number of stations in each category. The exceedances are considered by the median for each station. The colours represent below or above EQSs.

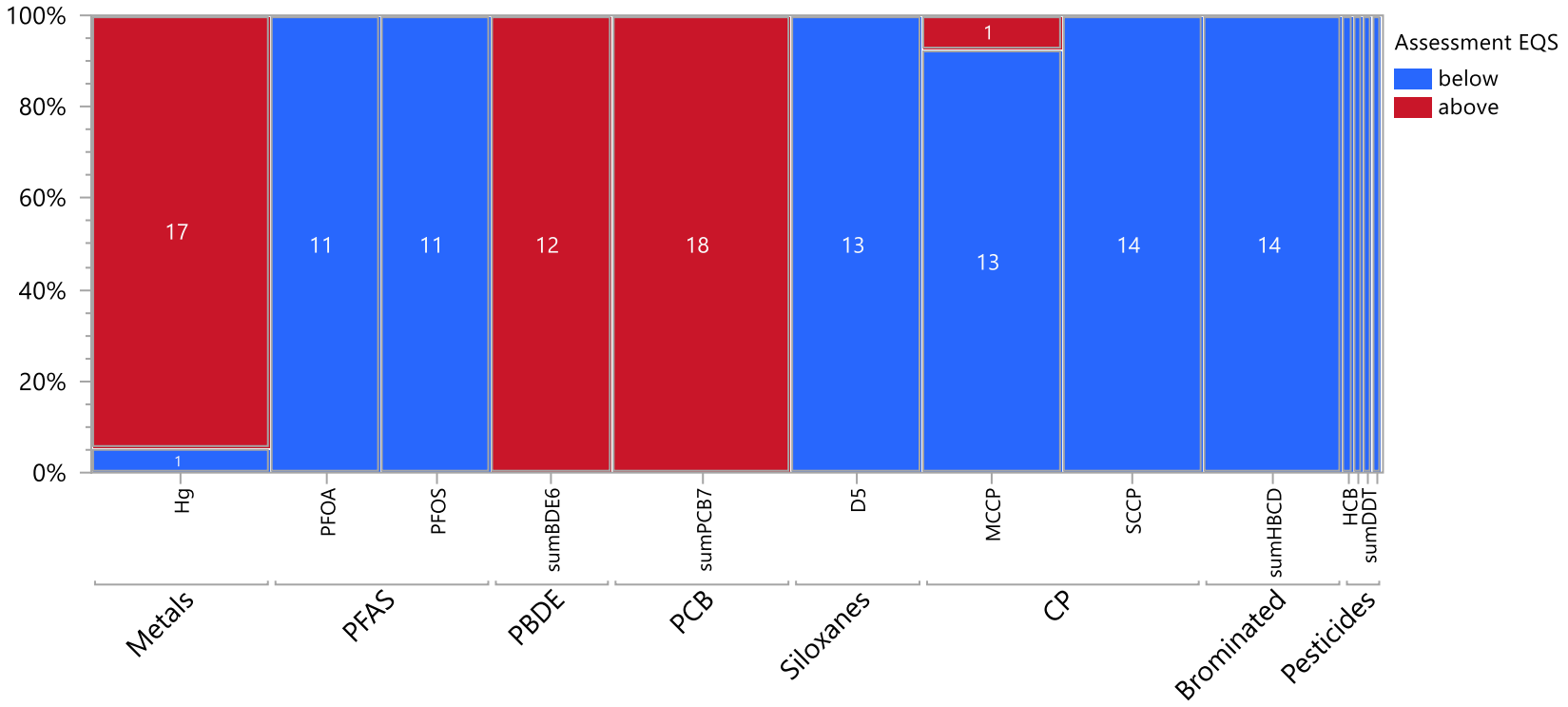


Figure 4. Exceedances of EQSs in cod by contaminant and contaminant group. The cells are labelled by the number of stations sampled. The exceedances are considered by the median for each station. The colours represent below or above EQSs.

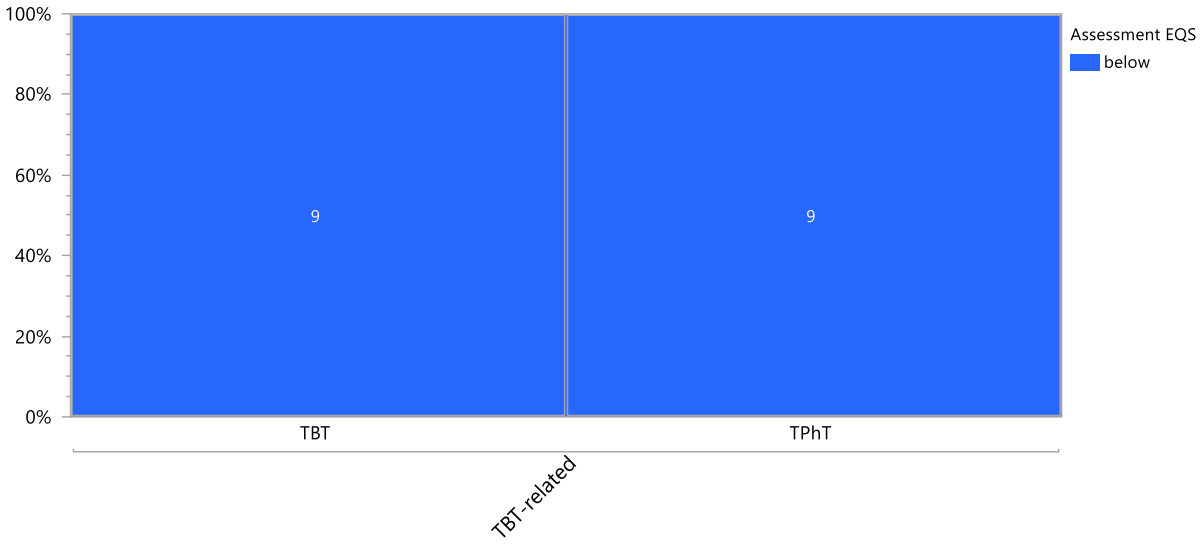


Figure 5. No exceedances of EQSs in snails (dogwhelk/common periwinkle) by contaminant. The number of stations in each group are labelled in the respective cell. The colour represents below EQSs.

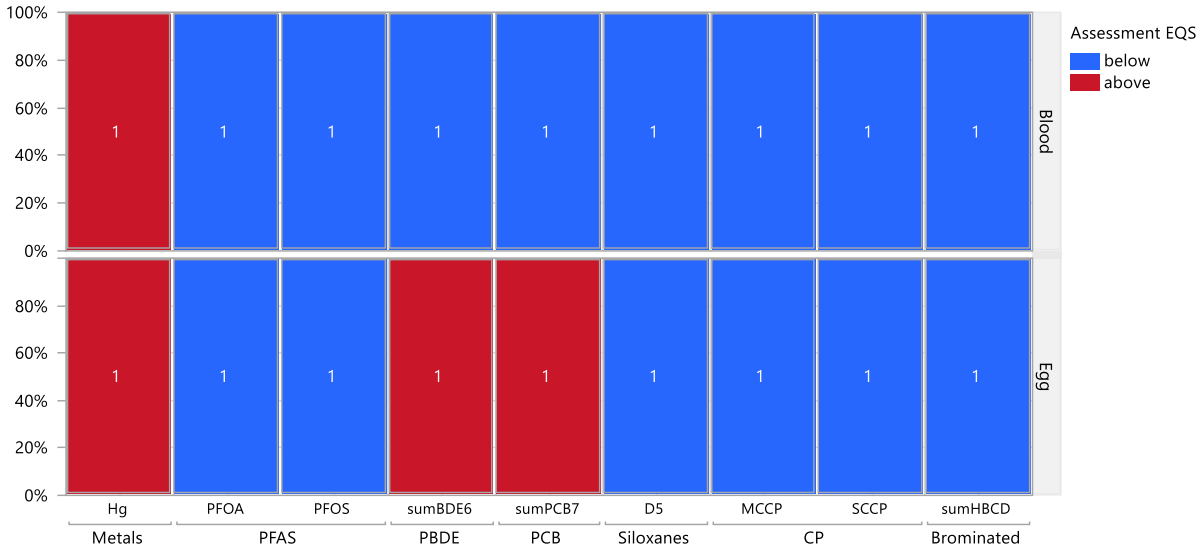


Figure 6. Exceedances of EQSs in eider in blood and eggs by contaminant and contaminant group. The exceedances are considered by the median for each year/tissue. The colours represent below or above EQSs.

3.1.2. Heatmaps for stations

To investigate potential pattern in stations exceeding EQSs, heatmaps for contaminants vs. stations are shown in **Figure 7** and **Figure 8**. No comments are made if we cannot detect any special stations standing out compared to others.

Blue mussel in the Inner and Outer Oslofjord, in other harbour areas, and in the industrialized Sørfjord had highest number of exceedances of EQSs. For cod, EQSs were exceeded at all stations for sumPCB7 and sumBDE6, and for all stations for mercury except for Longyearbyen at Svalbard.

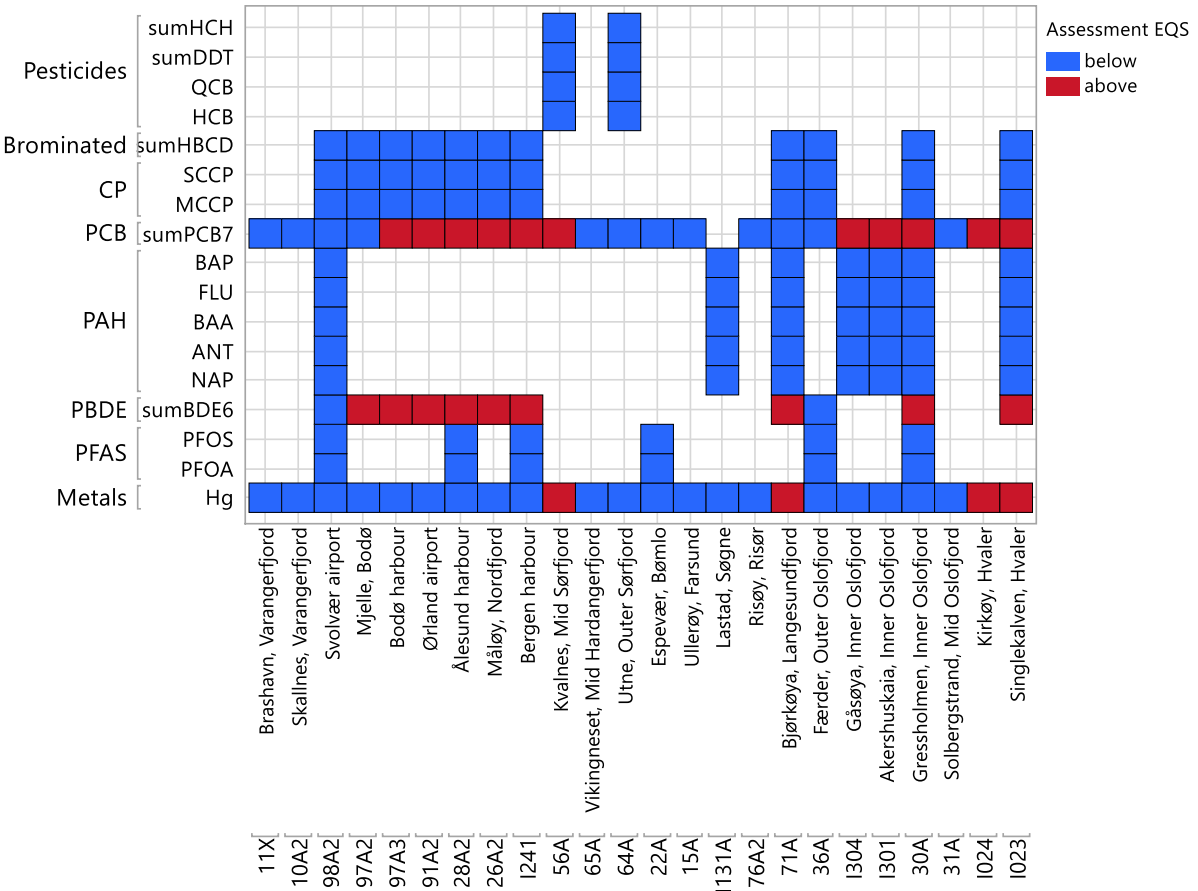


Figure 7. Heatmap of exceedances of EQSs in blue mussel. The exceedances are considered by the median for each station. The colours represent below or above EQSs. Empty "cells" mean that the contaminant was not analysed at the indicated station. Grey lines show the midpoint of each station and contaminant. The stations are ordered along the coastline starting north moving south.

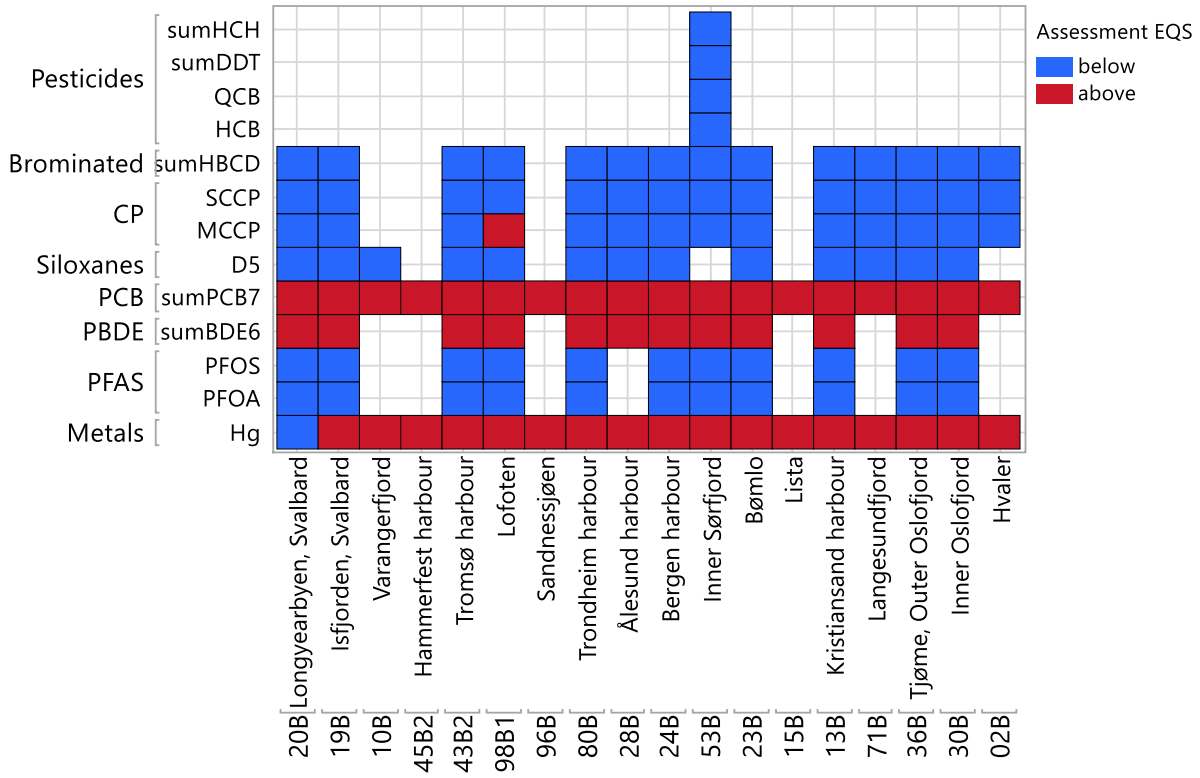


Figure 8. Heatmap of exceedance of EQSs in cod. The exceedances are considered by the median for each station. The colours represent below or above exceedance of EQSs. Empty "cells" mean that the contaminant was not determined at the indicated station. Grey lines show the midpoint of each station and contaminant. The stations are ordered along the coastline starting north moving south.

The risk quotients (RQ) are calculated as the measured concentration divided by the EQS. The RQs for contaminants for each species are shown in **Figure 9**. Each station median concentration was used to calculate the RQ. This is a complimentary view of the data that has been presented in the preceding figures. This figure focus on how much the EQS were exceeded for the different contaminants investigated.

The highest exceedances were observed for sumPCB7 followed by sumBDE6, and mercury. MCCP exceeded EQS at one station, while SCCPs concentrations were much lower than the EQS. PFOS and PAHs determined only in blue mussel were slightly below EQSs. However, the proposed EQS for PFAS are much lower than the current (European Commission, 2022). EQS for PFAS are based on human health, and the tolerable weekly intake has been lowered substantially since the derivation of the EQS. SumHBCD were almost two orders of magnitude lower than EQS. SumHCH had median concentration zero (all isomers below LOQ) and could therefore not be portrayed in a logarithmic plot. All RQs were higher in cod than in blue mussel, while eider often had higher RQ than blue mussel.

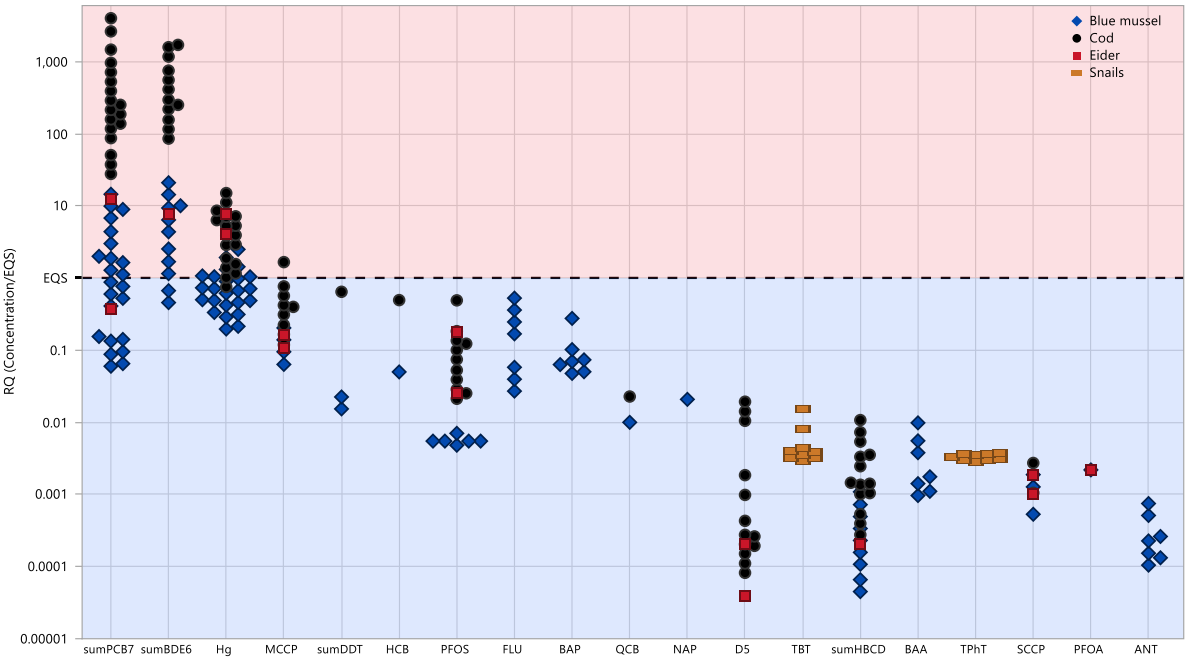


Figure 9. Risk quotients (concentration/EQS) for contaminants with an assigned EQS. Each station is represented with the median concentration. The vertical axis indicates the log10 RQ quotients and the horizontal axis shows different groups of contaminants. Included species are blue mussel, cod, snails and eider with different colours. Upper bound RQ are shown (<LOQ replaced by LOQ), and data below LOQ are included. Eiders are investigated only at one station, but both eggs and blood are represented. Data are shown in decreasing order based on the maximum RQ.

3.2 PROREF

Concentrations of contaminants were compared to PROREF (provisional high reference contaminant concentrations) levels. PROREF is a NIVA-developed concentration which can be described as “high background” as it represents the 95th percentile of concentrations found at reference stations in the MILKYS programme. The reference stations are identified among the current and previous MILKYS stations by a stepwise statistical method described more in detail in chapter **7.6.** We consider PROREF to provide a valuable method for assessing contaminant levels in addition to the risk based EQSs. We have calculated Norwegian PROREF values based on MILKYS-results for the period 1992-2016. We assessed the 25 contaminants selected for presentation for 2024 data based on the ratio between the 2024 median concentration and PROREF (**Table 4**). Assessments for other contaminants vs. PROREF values, but not selected for presentation in 2024, are given in **Supplementary** data.

It should be noted that we are in the process of revising the PROREFs (Hjermann et al. in prep). The newly developed PROREFs will be substantially lower for cod, and for most contaminants also lower for blue mussel. This is due to lower concentrations and the newly derived PROREFS being based on a later period than the currently employed PROREFs. Also, inclusion of the stations at Svalbard for cod had an impact.

3.2.1. Species and contaminants

The PROREF values are in general higher in cod than in mussels (except for three metals; cobalt, cadmium, and lead, **Table 4**). The higher concentrations in cod are probably a result of higher concentrations in liver of lipid soluble contaminants. PAHs are metabolised by cod and therefore PROREFs have not been developed for PAHs in cod.

Table 4. List of contaminants selected in 2024 for which a PROREF exist. The PROREFs are given in mg/kg ww for metals and µg/kg ww (ng/g ww) for others. Data are given with two significant digits. EQS are also shown for contaminants that has been assigned one. Some of the EQS are for the sum of several congeners – see footnote.

Contaminant group	Contaminant	Unit	PROREF blue mussel	PROREF cod	EQS
Metals	Silver (Ag)	mg/kg ww	0.0086	0.93	
	Arsenic (As)		2.5	13	
	Cadmium (Cd)		0.18	0.14	
	Cobalt (Co)		0.080	0.060	
	Chromium (Cr)		0.36	0.40	
	Copper (Cu)		1.4	14	
	Mercury (Hg)		0.012	0.056	0.02
	Nickel (Ni)		0.29	0.65	
	Lead (Pb)		0.20	0.050	
	Zinc (Zn)		18	35	
PFAS	Perfluorooctanoic acid (PFOA)	µg/kg ww	Not developed yet	10	91
	Perfluorooctanesulfonic acid (PFOS)		Not developed yet	10	9.1
	Perfluorooctanesulfonamide (PFOSA)		Not developed yet	6.2	
PBDEs	PBDE congener 47 (BDE47)		0.17	16	0.0085 [a]
	PBDE congener 100 (BDE100)		0.050	2.6	0.0085 [a]
	PBDE congener 154 (BDE154)		0.050	1.5	0.0085 [a]
PAHs	Benzo(a)anthracene (BAA)		1.5		300
	Fluoranthene (FLU)		5.4		30
	Pyrene (PYR)		1.0		
	Benzo(a)pyrene (BAP)		1.2		5
PCBs	PCB congener 118 (CB118)		0.070	100	0.6 [a]
	PCB congener 138 (CB138)		0.20	160	0.6 [a]
	PCB congener 153 (CB153)		0.26	190	0.6 [a]
Brominated	HBCDA		0.027	2.6	167 [a]
Pesticides	Hexachlorobenzene (HCB)		0.10	14	10

[a] The EQS for these contaminants are for the sum of specific congeners (BDE-28, -47, -99, -100, -153 and -154, or CB-28, 52, -101, -118, -138, -153 and -180, or α-, β- and γ-hexabromocyclododecane), and are therefore not comparable without reservation.

Assessments vs. PROREF in different species are shown in **Figure 10**. PROREF is a concentration, and the assessment shows in which concentration range the median is vs. the PROREF. If the concentration is within 1-2 times the PROREF, this is the associated range. See figures for ranges of PROREFs.

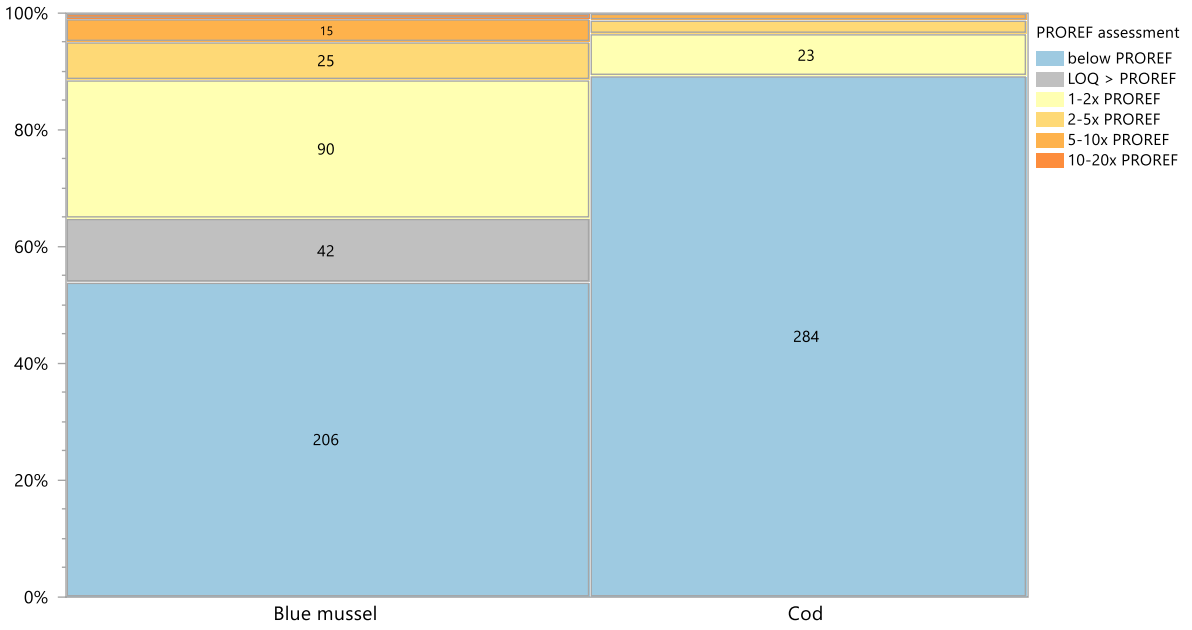


Figure 10. Assessment of PROREF ratios in a mosaic plot. The cells are labelled by the number of datapoints (contaminants x stations). The assessments are considered by the median for each station and species and are represented by colours in the figure. In cases where LOQs were higher than PROREF (grey) no assessments could be made.

For mussels, all metals except silver were found in concentrations exceeding the PROREF (**Figure 11**). Selected PBDEs did not exceed PROREF. The highest exceedances were observed for lead and CB118 (10-20x PROREF). PAHs and PCBs exceeded PROREF at several stations.

In cod, mercury, silver, and CB153 were the contaminants most frequently exceeding PROREF (**Figure 12**). Mercury had the highest frequency of exceeding PROREF followed by CB118 and CB153.

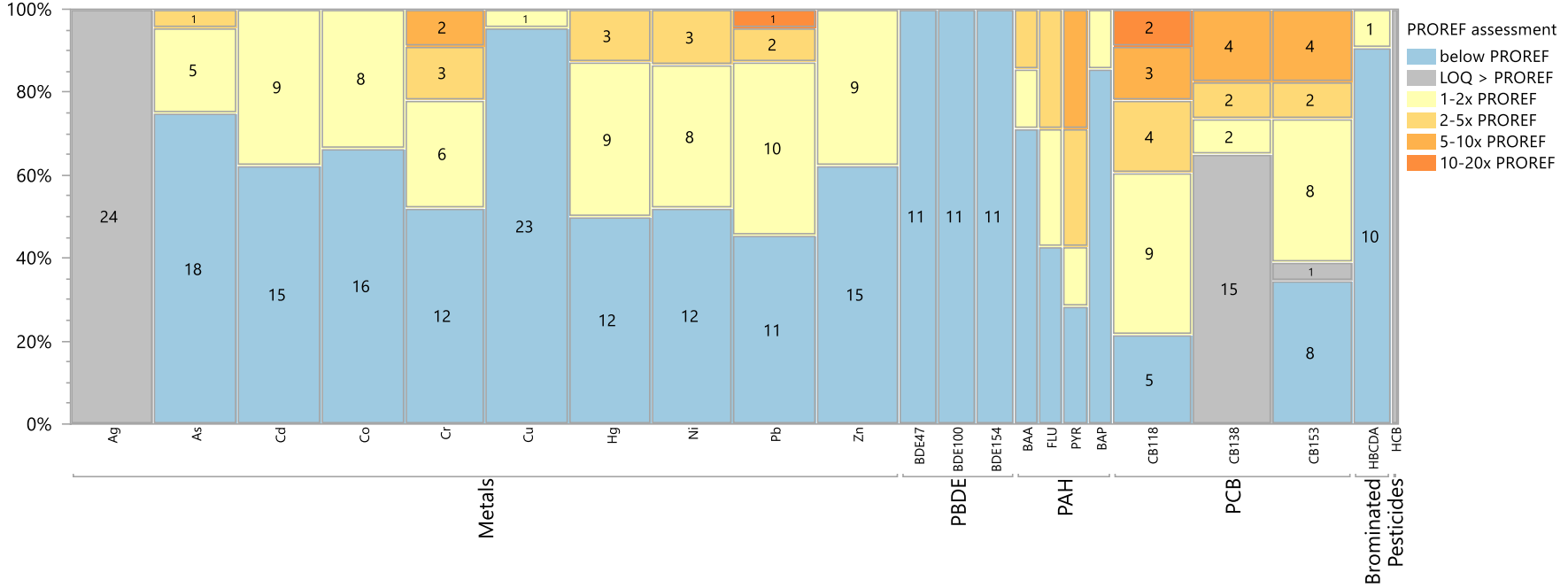


Figure 11. Assessment of PROREF ratios in blue mussel by contaminant and contaminant group. The cells are labelled by the number of datapoints (contaminants x stations). The assessments are considered by the median for each station and are represented by colours in the figure. In cases where LOQs were higher than PROREF (grey) no assessments could be made.

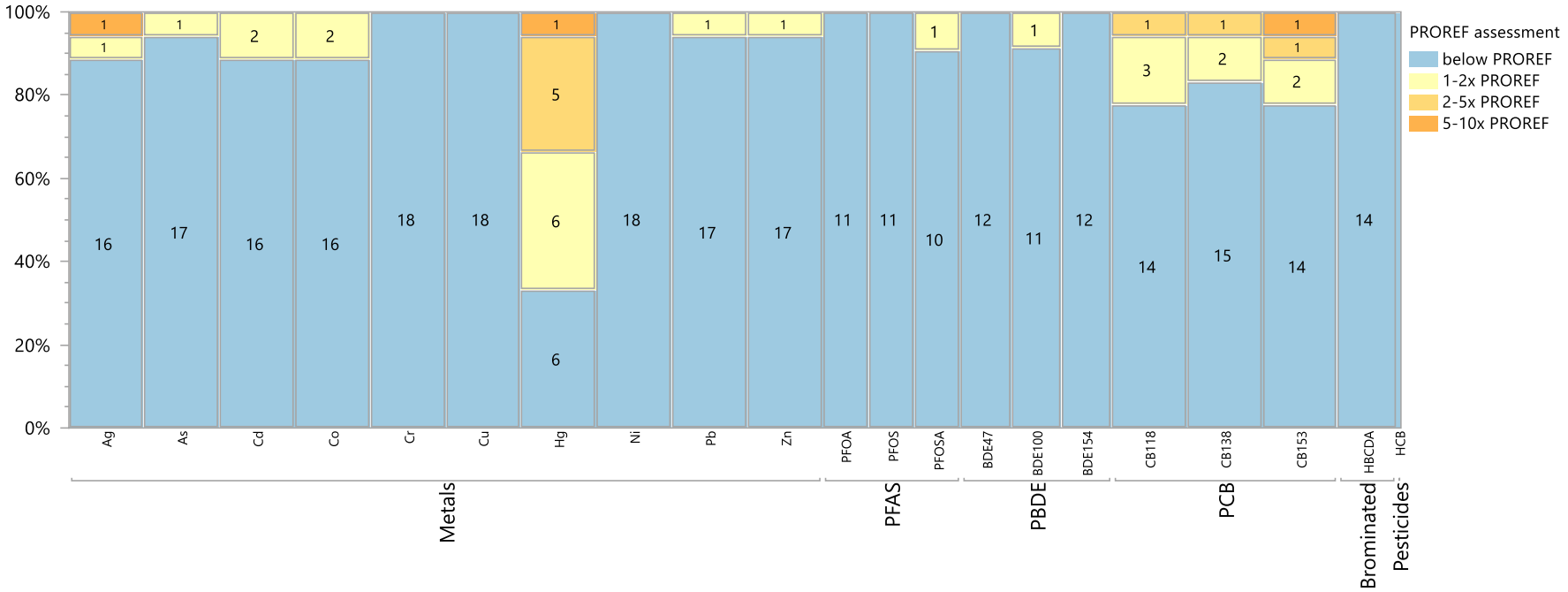


Figure 12. Assessment of PROREF ratios in cod by contaminant and contaminant group. The assessments are considered by the median for each station and are represented by colours in the figure.

3.2.2. Heatmaps for stations

Blue mussel stations in the Inner Oslofjord (**Figure 13**) had several exceedances of PROREFs, and among these, Akershuskaia (I301) had the most exceedances, while Gressholmen (30A) had the highest exceedance (CB118). PCBs had the highest exceedances, which were observed in several urban stations (harbours of Bodø (97A3), Ålesund (28A2), and Bergen (I241)). One of three samples from station Solbergstrand (31A) in the Mid Oslofjord and the only sample from Bjørkøya (71A) in the Langesundfjord were suspected to have been contaminated by nickel and chromium during sample preparation. Results are therefore lacking for Bjørkøya, while assessment at Solbergstrand are based on two, not three samples.

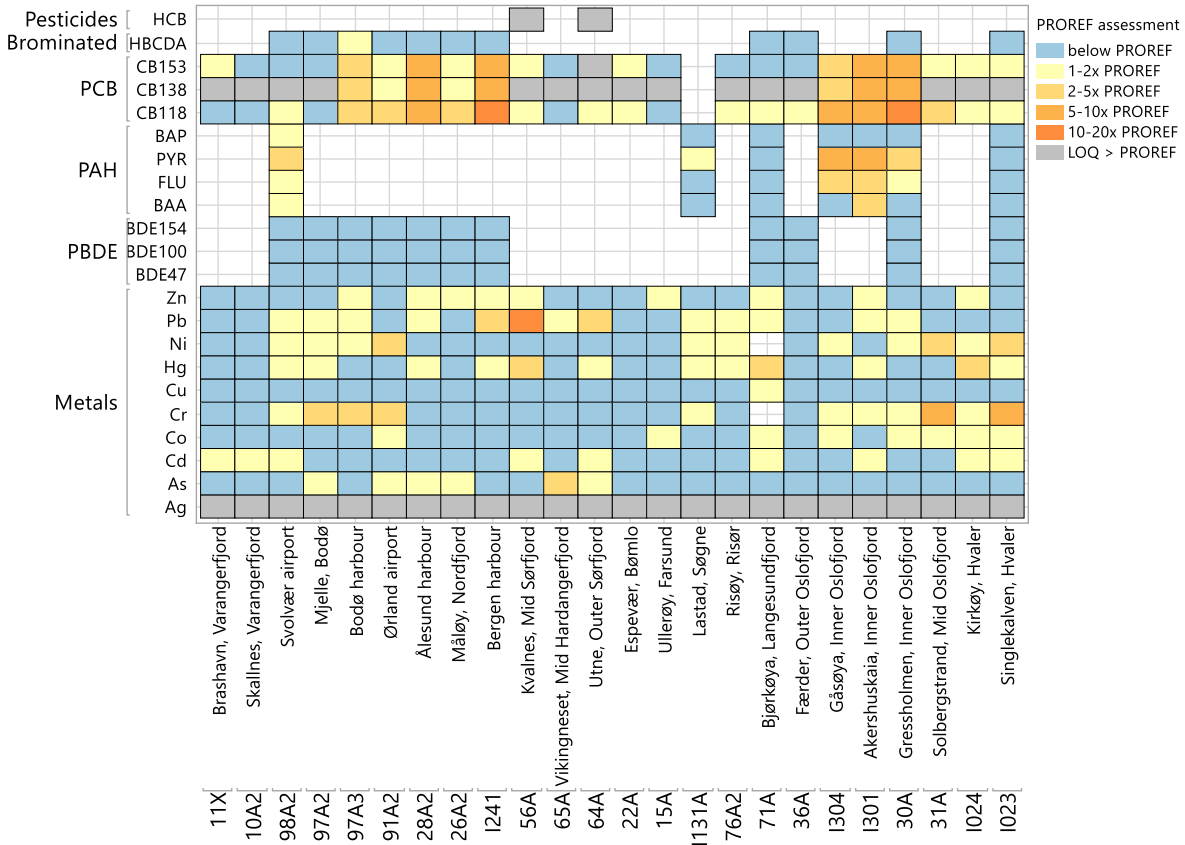


Figure 13. Heatmap of assessment of PROREF ratio in blue mussel. The assessments are considered by the median for each station and are represented by colours in the figure. In cases where LOQs were higher than PROREF (grey) no assessments could be made. Empty "cells" mean that the contaminant was not analysed at the indicated station. Grey lines show the midpoint of each station and contaminant. The stations are ordered along the coastline starting north moving south.

Exceedances of PROREF in cod (**Figure 14**) were most often observed at the stations in the Inner Oslofjord (30B) followed by Langesundfjord (71B), Bergen harbour (24B), and Ålesund (28B). Four stations did not have exceedances of PROREF for any compounds investigated in cod from Hammerfest (45B2), Tromsø harbour (43B2), Isfjorden, Svalbard (19B), and Sandnessjøen (96B).

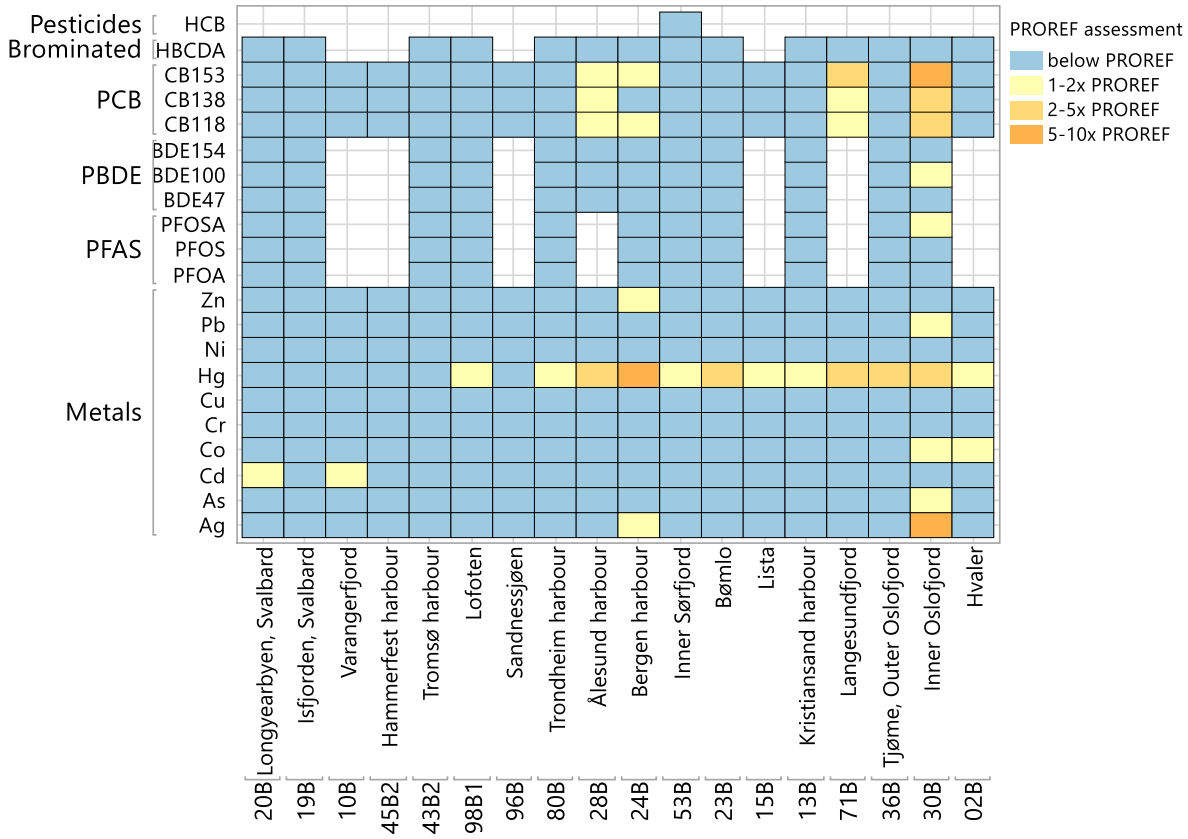


Figure 14. Heatmap of assessment of PROREF ratios in cod. The assessments are considered by the median for each station and are represented by colours in the figure. In cases where LOQs were higher than PROREF (grey) no assessments could be made. Empty "cells" mean that the contaminant was not analysed at the indicated station. Grey lines show the midpoint of each station and contaminant. The stations are ordered along the coastline starting north moving south.

Figure 15 shows PROREF quotients for assessing the contaminants that exceed the PROREFs the most in data from 2024. PCBs were the contaminants that exceeded the PROREFs most, followed by lead (in blue mussels only), and mercury (both cod and blue mussel). Among the PAHs, pyrene exceeded the most, whole PBDEs and PFAS were exceeded only in one station in cod.

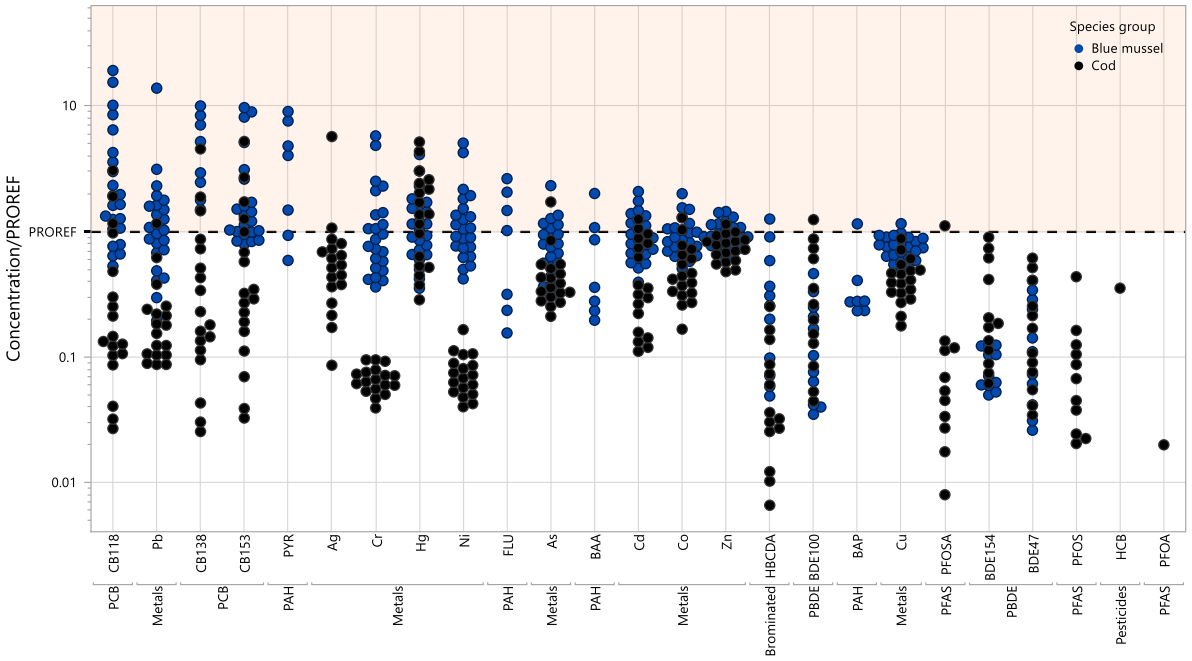


Figure 15. PROREF quotients (concentration/PROREF) for the selected contaminants. Each station is represented with the median concentration. The vertical axis indicates the log10 PROREF quotients and the horizontal axis shows different groups of contaminants. PROREF is indicated with a stippled horizontal line. Data are shown in decreasing order based on the maximum PROREF quotient. Species with PROREF are blue mussel and cod indicated with different colours.

3.3 Time trends

3.3.1. Species and contaminants

In 2024, the OSPAR method of estimating time trends HARSAT, (Arctic Monitoring and Assessment Programme (AMAP) et al., 2022/2025), was implemented for MILKYS (**chapter 7.7**). This means some minor changes to the terms used for time trends, and some changes in the trends themselves compared to the previous method. Originally, OSPAR's method calculates *recent trend* (last 20 years) and *whole trend* (the whole trend period). When implementing the method at NIVA, the recent trend was changed in the method settings to 10 years to align with previous assessments. We have chosen to use the terms (recent and whole) used by OSPAR to differentiate between the two methods (formerly referred to as short and long trends).

For time series that are least 5 years long, the HARSAT method fits a linear time trend to the data, and if the time series is at least 7 years long, it attempts to fit non-linear time trends in addition to the linear trend (OSPAR, 2025a). The final choice of time trend (linear vs. non-linear) depends on model fit (based on AIC_c values, (Akaike Information Criterion for small sample size)). HARSAT also takes into consideration both the uncertainty of the chemical analysis (**chapter 7.2**) and also treats values under LOQ correctly left-censored data, meaning that the true value can be everywhere between zero and LOQ (OSPAR, 2025b) **chapter 7.4**). For more details on the trend analysis, see **chapter 7.7**. Both recent and whole trends are assessed using the same fitted trend (only the start year used for comparison differs). Time trends with shorter or equal span than 10 years have been assigned a status of "data span ≤ 10 years" in the whole trend. Both recent and whole trends can have an assignment of "too few years" indicating that monitoring over more years are needed before a trend can be assigned.

Time trends for selected contaminants (**Table 5**) were assessed. In total >800 time trends in each of two time spans categories (recent and whole) were estimated (combination of selected contaminant ×

station × tissue). Figures for time trends for contaminants not selected for presentation in extended summary are shown (but not commented) in **Supplementary** data.

Time trends for chlorinated paraffins are estimated. The estimations for these groups are challenging since there is varying detection limits and low detection frequency at some stations. When detection frequencies were low in recent years the time trends have been assigned "too few years".

Table 5. Contaminants selected for describing time trends.

Group	Contaminant	Number of stations for which trend is reported here (whole and recent)		
		Blue mussel	Cod	Eider[1]
Metals	Ag	24	18	2
	As	24	18	2
	Cd	24	18	2
	Co	24	18	1[2]
	Cr	23	18	1[2]
	Cu	24	18	2
	Hg	24	18	2
	Ni	23	18	1[2]
	Pb	24	18	2
	Zn	24	18	2
PFAS	PFOA	6	11	2
	PFOS	6	11	2
	PFOSA	6	11	2
PBDE	BDE47	11	12	2
	BDE100	11	12	2
	BDE154	11	12	2
PAH	BAA	7	0	0
	FLU	7	0	0
	PYR	7	0	0
	BAP	7	0	0
PCB	CB118	23	18	2
	CB138	23	18	2
	CB153	23	18	2
Siloxanes	D5	0	13	2
CPs	MCCP	11	14	2
	SCCP	11	14	2
Brominated	HBCDA	11	14	2
Pesticides	HCB	2	1	0
All	All	421	359	43

[1] Eider: one station with trends for two tissues (egg and blood)

[2] Samples were contaminated with during homogenization, and trends were therefore not determined

Time trends (recent (≤ 10 years) and whole period) for species are shown in **Figure 16**. More detailed view of time trends for contaminants in blue mussel, cod, and eider are shown in **Figure 17** to **Figure 19**. Heatmaps of time trends (stations vs. contaminants) are shown in **Figure 20** and **Figure 21**. In this report we report different categories of trends as defined by OSPAR, upward trend, no change, and downward trend. Two categories due to lacks in dataset are also used, either "too few years" or (only for whole trends) "data span ≤ 10 years".

A part (10-25%) of the time trends could not be determined due to lacks in the dataset (too few data). Whole time trends in blue mussel were dominated by no trend followed by downward trends (**Figure 16**). However, also upward trends were observed (5-10%). For blue mussels more upward trends for recent trends than whole trends were observed. Roughly the same picture was observed for cod, with more downward trends and fewer upward trends observed. Eider has not been monitored long enough to observe long time trends, and for recent trends, no trend dominated followed by downward trends where trends could be observed. No upward time trends were observed in eider.

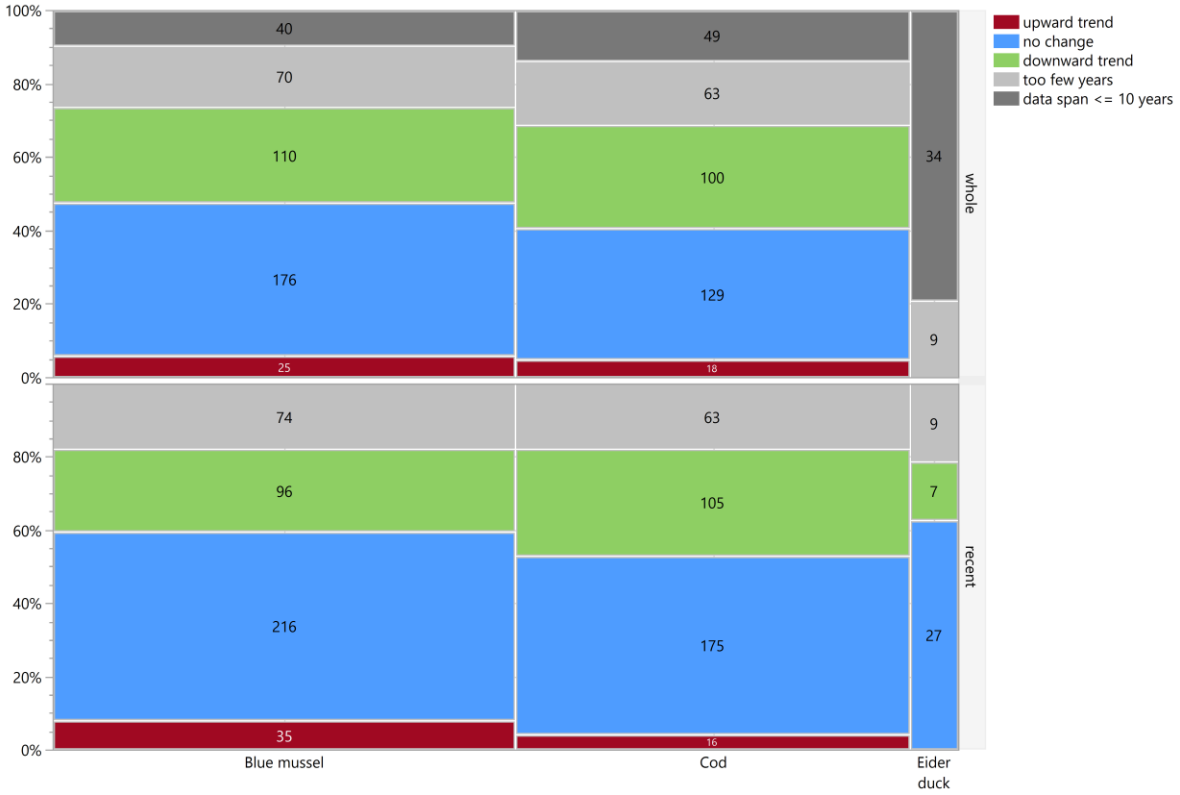


Figure 16. Mosaic plot of time trends for blue mussel, cod and eider. Upper panel shows the whole trends, while lower panel shows recent trends. The number of trends (stations × contaminants) are indicated in the respective cells.

In blue mussel, downward trends in the whole period were more frequent than upward trends, and were found for many contaminants. Upward whole trends were found for all metals except silver, and were also found for PCBs (CB118, CB138, and CB153) and BDE100.

The overall picture was roughly the same for recent trends, but more upward trends for PCBs were found. Fluorene (FLU) had upwards trends in the last 10 years, but not BDE100.

The LOQs of the chemical analyses were increased for PCB and silver (in 2017 and 2019 respectively). Lack of data above LOQ is challenging for time trend methods.

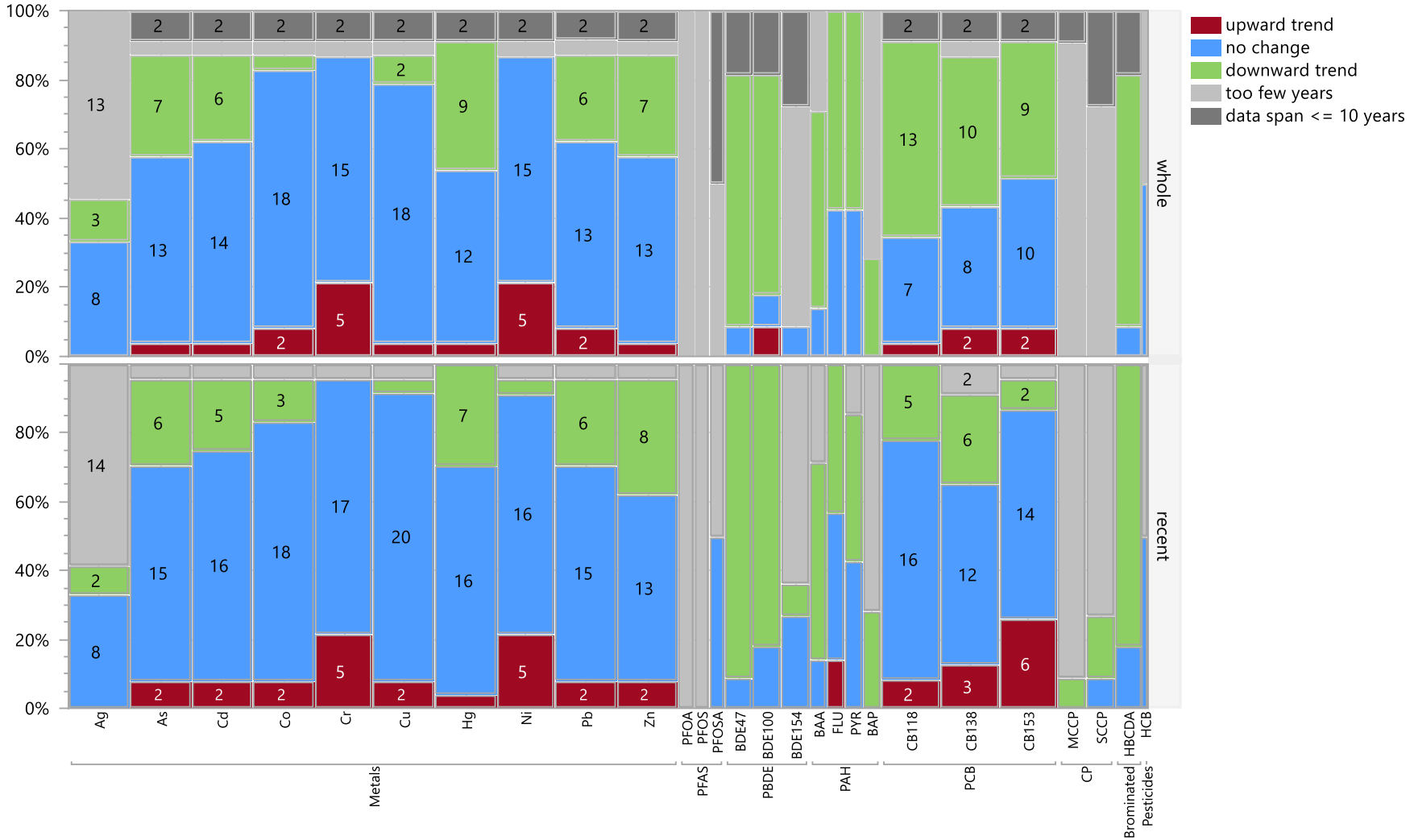


Figure 17. Time trends for blue mussel. Upper panel shows the whole trends, while lower panel shows recent trends. The numbers of stations are indicated in the respective cells.

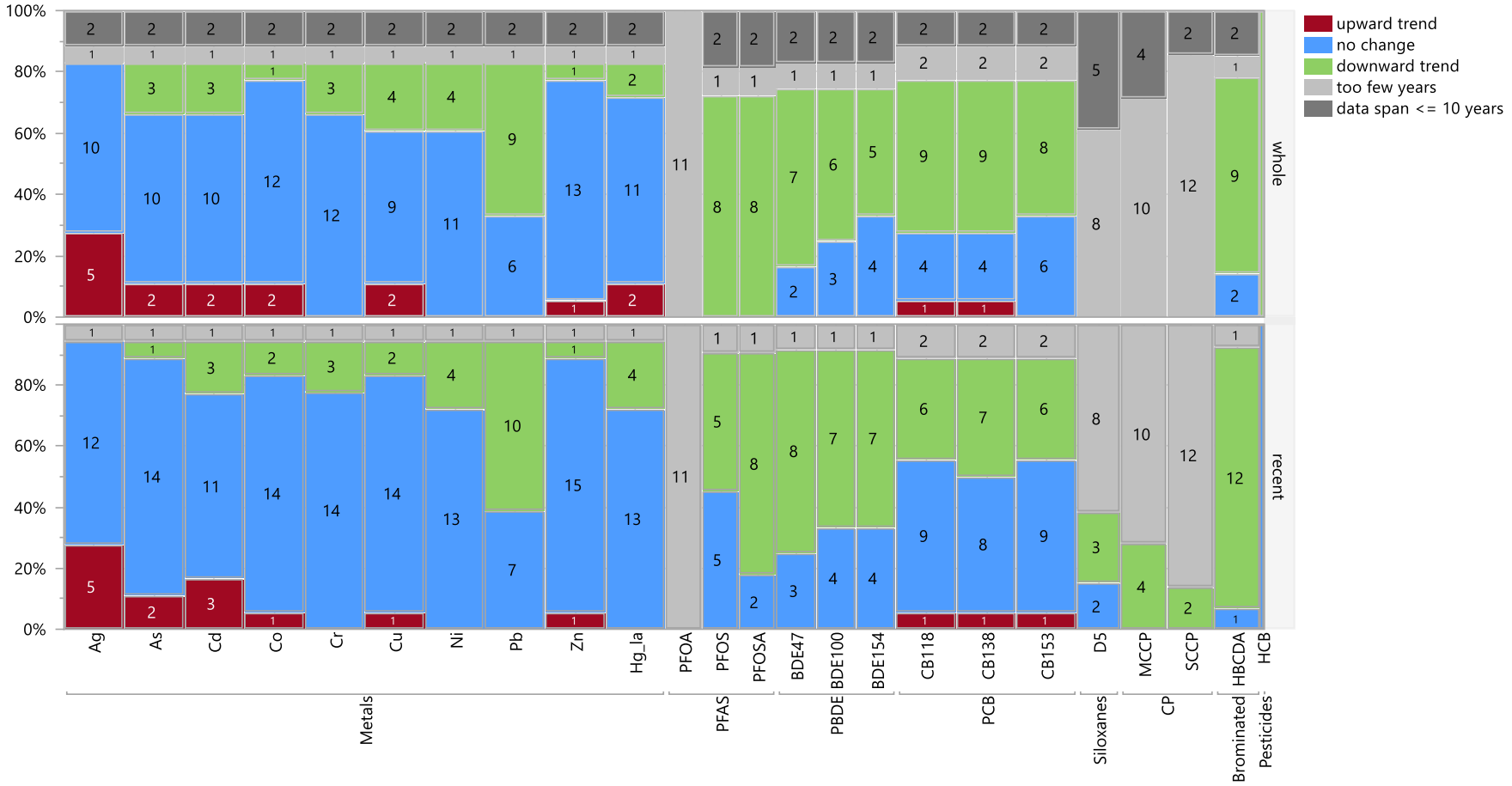


Figure 18. Time trends for cod. Upper panel shows the whole trends, while lower panel shows recent trends. The number of stations is indicated in the respective cells.

Downward time trends for the whole period in cod were more frequent than upward trends (**Figure 18**). Many metals had upwards trends, most were observed for silver. No upward time trend for length adjusted mercury in recent period was observed, but two stations had increasing trends for the whole period. A few stations had upward time trends for PCBs.

Time trends for eider are shown in **Figure 19**. A few downward recent time trends were observed in blood and eggs. CB138 had downward trends in both blood and eggs, otherwise the downward trends differed between eggs and blood. Eggs were contaminated during homogenisation (Cr, Co, and Ni) which are therefore not shown for recent trends.

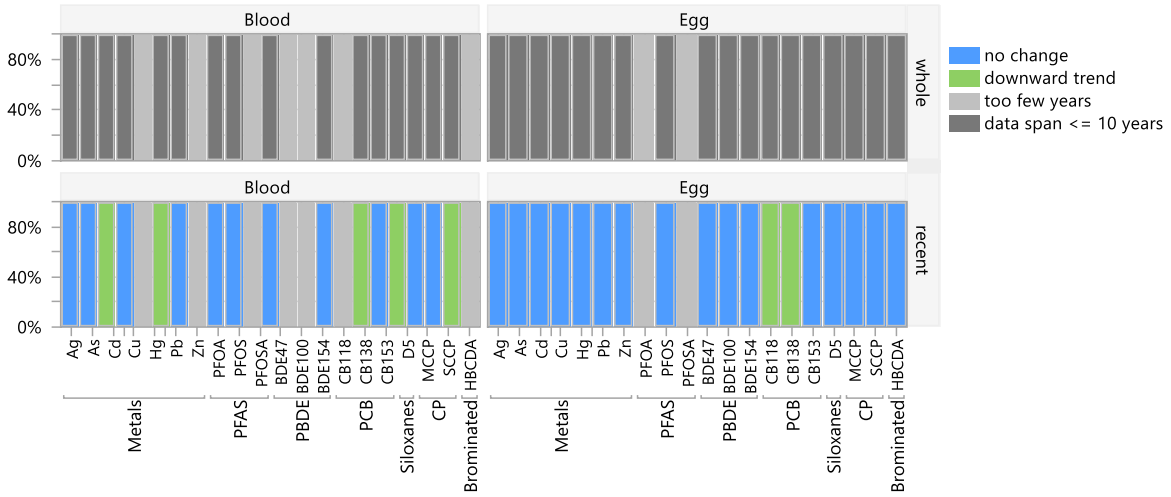


Figure 19. Time trends for eider. Upper panel shows the whole trends, while lower panel shows recent trends.

3.3.2. Heatmaps for stations

The upward whole and recent trends for metals in blue mussel (**Figure 20**) were mostly found at stations in the Oslofjord, but also at other stations. Mercury had an upward time trend only at Akershuskaia (both recent and whole trends). Several stations had upward recent time trends for PCBs, while only two had upward time trends for the whole period.

Also in cod, a few upward recent and whole trends for metals were observed **(Figure 21**). Lista (15B), Sandnessjøen (96B), and Varangerfjord (10B) had the most upward time trends. Time trends at Svalbard (19B) could also be estimated, and a single upward recent trend was found for silver. A few upward trends for PCBs were also observed, Ålesund had upwards trends for both whole and recent periods and Hammerfest for recent period.

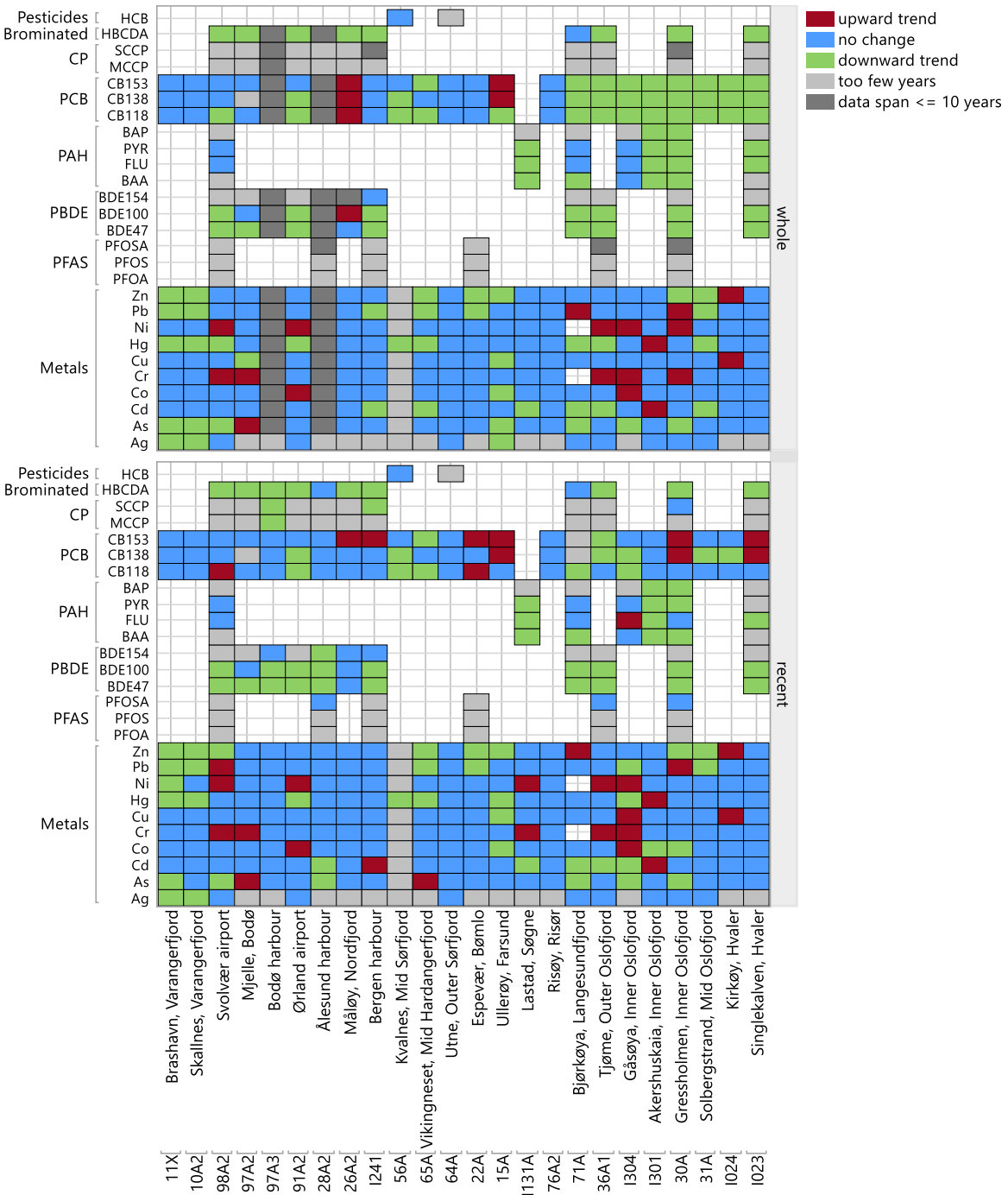


Figure 20. Heatmap of the whole trend and recent time trends in blue mussel. The colours represent time trends observed at stations. Empty "cells" mean that the contaminant was not analysed. Grey lines show the midpoint of each station and contaminant. The stations are ordered along the coastline starting north moving south. Time trends for chromium and nickel for Bjørkøya (71A) are not shown since 2024 data were suspected to be contaminated during sample preparation.

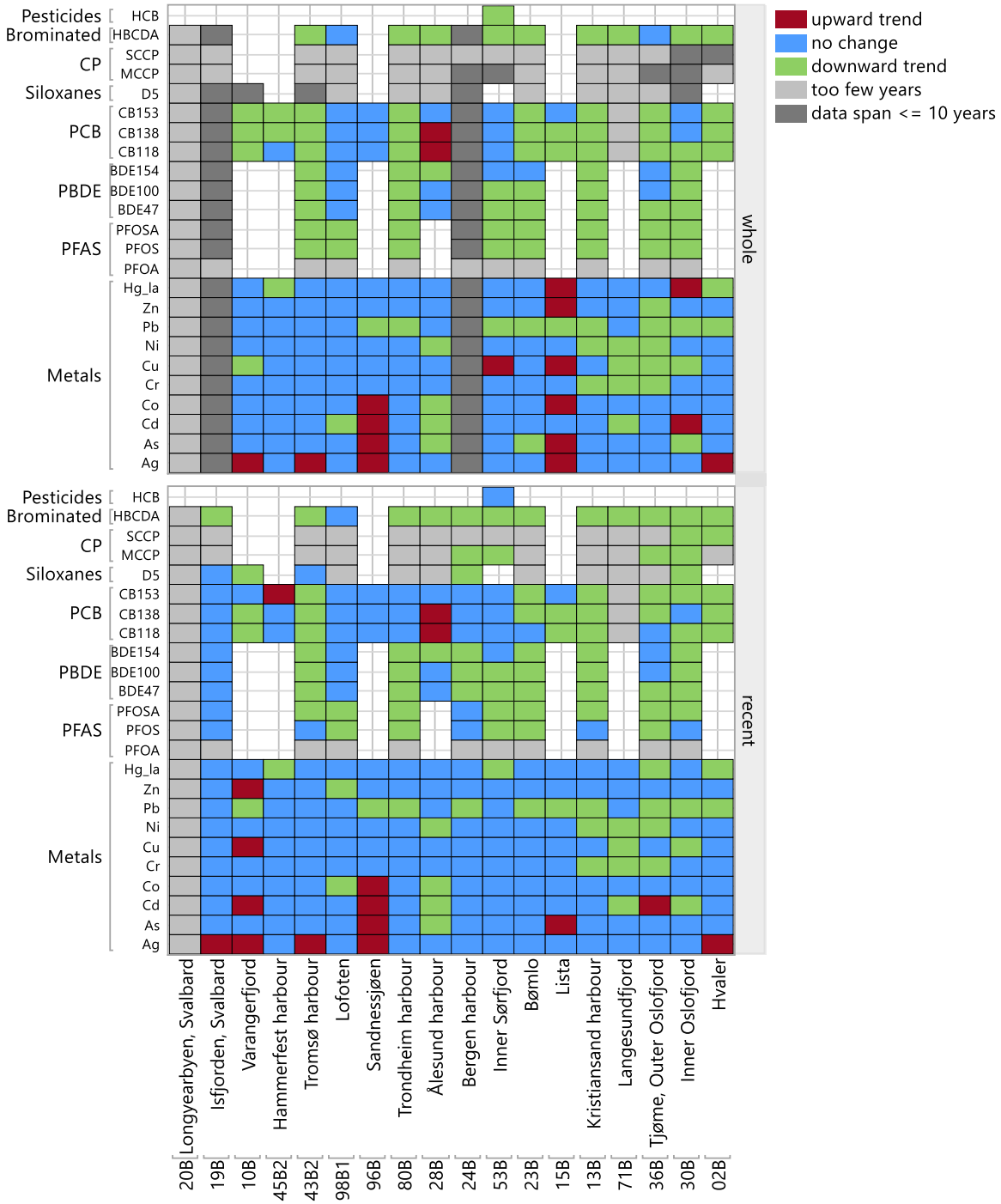


Figure 21. Heatmap of the whole trend and recent time trends in cod. The colours represent time trends observed at stations. Empty "cells" mean that the contaminant was not analysed. Grey lines show the midpoint of each station and contaminant. For mercury, cod have been length adjusted. The stations are ordered along the coastline starting north moving south.

The number of increasing trends for selected compounds (both whole and recent period) are summarized in **Figure 22**. Of the 24 blue mussel stations, 16 had one or more upward trends. Gåsøya (I304) (a total of 8 increasing trends) followed by Svolvær airport (98A2), and Gressholmen (30A) had the most increasing trends. For the cod stations, 11 of the 18 stations had upward trends, most at Sandnessjøen (96B) (8 trends), followed by Lista (15B) and Varangerfjord (10B).

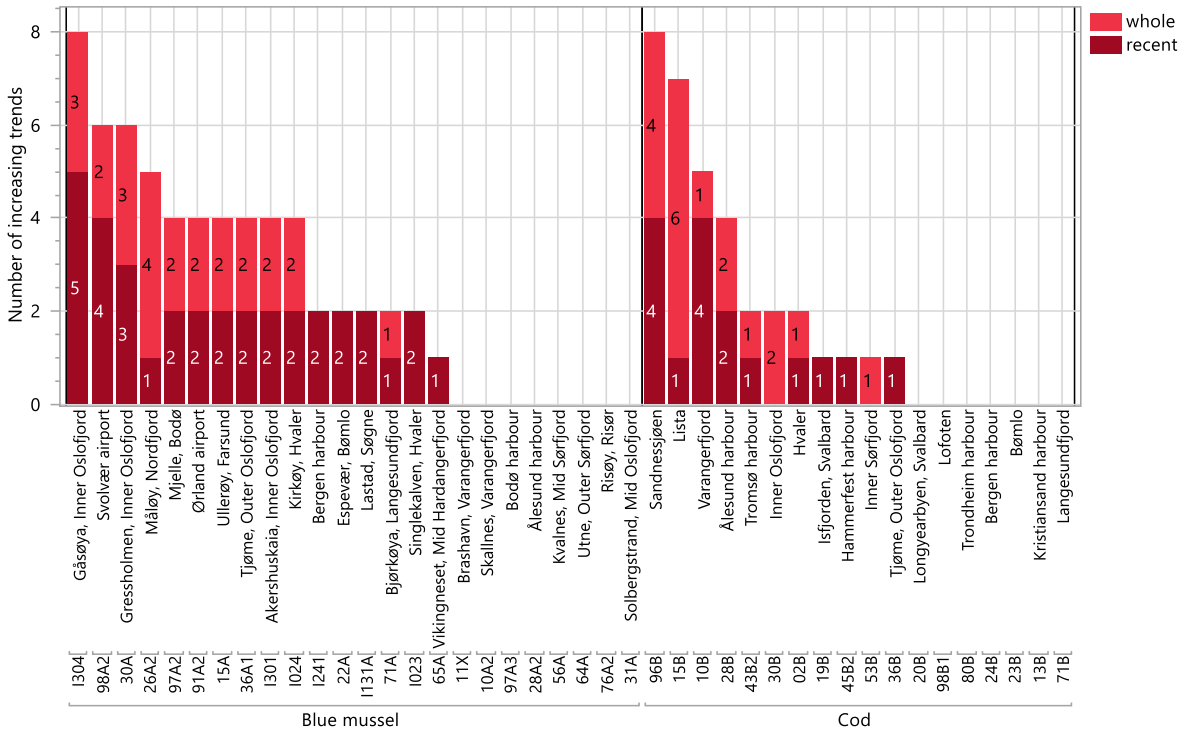


Figure 22. Number of upward time trends for blue mussel and cod stations. Recent and whole trends are shown in different red colours, and the number of contaminants for the two types of time trends are shown. If a contaminant has increasing time trends for both recent and whole period, it is not counted twice since the underlying data are different. Please refer to the heatmaps for time trends for specific contaminants overview (**Figure 19**-**Figure 21**).

4 Effect parameters and stable isotopes

4.1 Biological effect parameters

4.1.1. Dogwhelk and common periwinkle

Tributyltin (TBT) and imposex/intersex

Tributyltin (TBT) is an organic compound of tin that was used as a biocide especially in marine antifouling paints until 2008, when it was banned globally. TBT is toxic to marine life and was first known to be used in the 1960s. Masculinized female marine snails were first described in the late sixties (Blaber, 1970). Gender disruption was found in several hundred neogastropod species worldwide.

Female sexual abnormalities were monitored as biomarkers of TBT effects. TBT induces male sex characters onto females, such as imposex in dogwhelk and intersex in common periwinkle. In female dogwhelk, the TBT effect causes a vas deference and a pseudopenis that are superimposed onto female genital structures. Sterility and even death of individuals occur in the most advanced stages. In female

common periwinkle, the TBT effect causes a pathological alteration in the oviduct, development of spermatocytes in ovary or oocytes in the testis and/or penis. Sterility occurs in the most advanced stages. Common periwinkle is less sensitive to TBT than dogwhelk and may act as an alternative sentinel when dogwhelk is not found.

In the present study, TBT was quantified in dogwhelk at eight stations and common periwinkle at one station (Fugløyskjær in Langesund (71G)). Imposex (Vas Deferens Sequence Index, VDSI) was investigated in dogwhelk and intersex (Intersex Stage Index, ISI) in common periwinkle.

EQS

When applying the EQS for TBT (150 µg/kg ww, **Table 3**) in biota ("for fish") on dogwhelk (<2.3 µg/kg ww) and common periwinkle (<1.2 µg/kg ww), all TBT-concentrations were below EQS. When applying the EQS for triphenyltin (TPhT) (150 µg/kg ww, **Table 3**) in biota on dogwhelk (<0.55 µg/kg ww) and common periwinkle (<0.5 µg/kg ww), all TPhT-concentrations were below EQS.

PROREF

In the post-ban period since 2008, the VDSI levels have been below PROREF (3.68) at all stations.

Time trends of TBT

There were significant downward whole trends for TBT in dogwhelk at Færder (36G) in the Outer Oslofjord, Risøya (76G) at Risør, in the Mid Karmsund (227G), Espevær (22G) by Bømlo, and Svolvær (98G) in Lofoten (**Figure S13**).

There was a significant downward recent trend for TBT in common periwinkle at Fugløyskjær (71G) (**Figure S13**).

Biological effects of TBT (imposex/VDSI) in dogwhelk

The effects of TBT measured by the imposex parameter VDSI were zero at all eight stations. All results were below the OSPARs Background Assessment Criteria (BAC=0.3) (OSPAR, 2008) and the OSPARs Ecotoxicological Assessment Criteria (EAC=2) (OSPAR, 2013a, 2013b).

Time trends of VDSI

In dogwhelk, both significant downward whole and recent trends for VDSI were observed in the Mid Karmsund (227G) (**Figure 23** and **Figure S13**). Significant downward whole trends were found at Færder (36G) in the Outer Oslofjord (**Figure 23**), Risøya (76G) at Risør, Lastad (131G) at Søgne, Ullerøy at Farsund (15G), Espevær (22G) by Bømlo, and at Svolvær in Lofoten (98G).

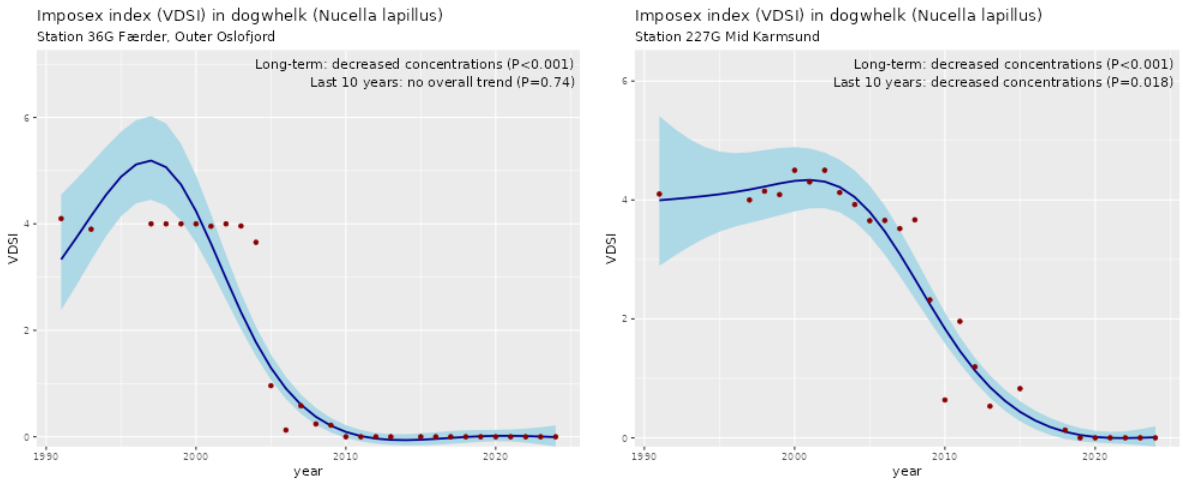


Figure 23. VDSI from 1991 to 2024 for dogwhelk from Færder (36G) in the Outer Oslofjord (left) and in the Mid Karmsund (227G) (right). Measurements are shown as red circles. The model for the time trend is shown as a blue line with the 95 % confidence band in blue surrounding it. In the upper right corner, the interpretations of the trends (Long-term=whole and Last 10 years=recent) are given with significance details.

Selected time trends

Two time trends for VDSI in dogwhelk are shown in **Figure 23**. VDSI in dogwhelk at Færder (36G) showed downward whole trend. In the Mid Karmsund (227G), there were both downward whole and recent trends. The apparent turning points correspond well with the TBT bans in 2003 for vessels longer than 25 m, and the global ban in 2008.

The 2024 data confirmed the results since 2017 of no effects of TBT on dogwhelk (VDSI=0) (Schøyen et al., 2019). These results from the Norwegian coast in general, show that the TBT bans have been effective.

Biological effects of TBT (intersex/ISI) in common periwinkle

The effect of TBT in common periwinkle, ISI, was zero at Fugløyskjær (71G) in the Langesundfjord. ISI in common periwinkle is too sensitive for application of BAC and EAC (OSPAR, 2013a).

Time trends of ISI

The data of ISI in common periwinkle at Fugløyskjær (71G) showed no significant recent trend (**Figure 24**).

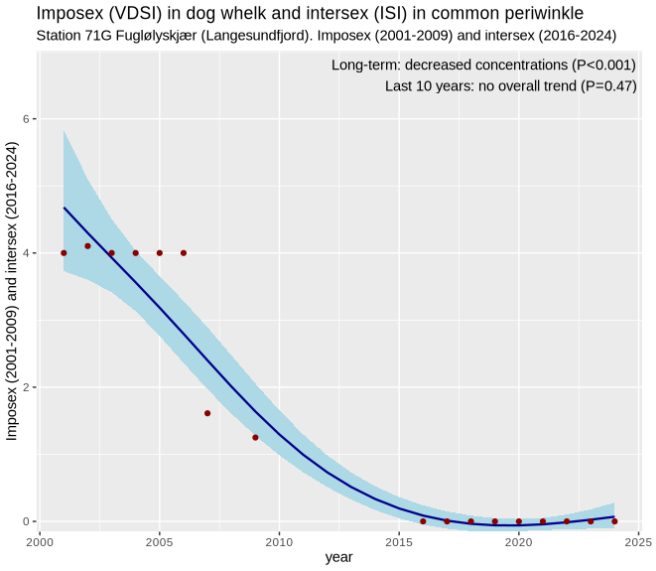


Figure 24. ISI from 2001 to 2024 for common periwinkle from Fugløyskjær in the Langesundfjord (71G).

In the TBT contaminated fjord Vikkilen, close to Grimstad in southern Norway, intersex in common periwinkle (*L. littorea*) also showed a significant long-term decline, with no cases observed since 2018, while imposex in netted dog whelk (*Tritia reticulata*) persisted in both inner (TBT-hotspot) and outer fjord sites in 2024 (Schøyen et al. in prep).

4.1.2. Cod

Biological effect methods (BEM) are included in the monitoring programme to further assess the potential pollution effects on organisms. There are three BEM applied to cod (including determination of degradation products of PAH in bile). Each method is in theory specific to individual or groups of chemicals. One of the advantages of these methods used at the individual level is the ability to integrate biological and chemical endpoints, since both approaches are performed on the same specimens. The results can be interpreted in relation to established reference values (OSPAR, 2013a).

The programme comprises quantification of OH-pyrene metabolites in bile of cod from 4 stations (15B, 23B, 30B, and 53B), as well as ALA-D activity in blood cells and hepatic cytochrome P450 1A-activity (EROD activity) in cod from 3 stations (23B, 30B, and 53B).

OH-pyrene metabolites in bile

Determination of OH-pyrene in bile is not a measurement of biological effects, *per se*. It is included here, however, since it is a result of biological transformation (biotransformation) of PAHs and is thus a marker of exposure.

In 2024 the median (non-normalised [4]) concentrations of OH-pyrene metabolites in bile from cod at Lista (15B) and Bømlo (23B) were below the ICES/OSPAR assessment criterion (background assessment criteria, BAC; 21 ng/ml), however, with large variation, especially at Lista (range: <0.5 – 347 ng/g). Among the four stations, OH-pyrene concentrations were highest in the Inner Oslofjord (30B) and Sørfjord (53B), where concentrations were significantly different from those at Lista (15B) and Bømlo (23B; Tukey-Kramer HSD).

[4] *Not normalised to absorbance at 380 nm*

ALA-D in blood cells

Inhibited activity of ALA-D indicates exposure to lead. Although ALA-D inhibition is lead-specific, it is not possible to rule out interference by other metals or organic contaminants.

The median ALA-D activity in cod at the reference station (Bømlo; 23B) in 2024 appeared similar as in as most years, since 2013. The median activity in the Inner Oslofjord (30B) and the Inner Sørfjord (53B), were both significantly lower than at Bømlo (Tukey-Kramer HSD). The largest variation in ALA-D activity was observed in the Inner Sørfjord (53B). Earlier frequent lower activities of ALA-D in cod from the Inner Sørfjord (53B; as well as the Inner Oslofjord, 30B), have been attributed to lead contamination. In 2024, higher hepatic concentrations of lead were found in cod from the Inner Oslofjord (30B) and Inner Sørfjord (53B), than at Bømlo (23B; Tukey-Kramer HSD).

EROD activity

High activity of hepatic cytochrome P450 1A activity (EROD activity) normally occurs as a response to planar compounds such as dioxins, certain PCBs, PCNs (polychlorinated naphthalenes), or PAHs. In 2024, the median EROD activity appeared lower at Bømlo (23B, reference station), than in the Inner Oslofjord (30B) and Inner Sørfjord (53B), however the differences were not statistically significant (Tukey-Kramer HSD). The highest variability was observed in the Inner Oslofjord (30B). Median EROD activities were below the ICES/OSPAR assessment criterion (background assessment criteria, BAC; 145 pmol/min/mg microsomal protein), at all stations.

4.2 Analysis of stable isotopes

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 of 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) than the autochthonous. 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 ($\delta^{15}N$) is 3-5 ‰ per trophic level (Layman et al., 2012; Post, 2002). It thus offers a continuous descriptor of trophic position. As such, it is also the basis for Trophic Magnification Factors (TMFs). TMFs give the factor of increase in concentrations of contaminants per trophic level. If the concentration increases per trophic level can be expressed as:

Log_{10} Concentration = $a + b *$ (Trophic Level)

Then:

TMF = 10^b

The TMF has 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.

The results of the stable isotope analysis in 2024 generally show the same pattern as observed in previous years i.e., a continual geographical pattern, indicating a spatial trend persistent in time (**Figure 25**).

As previously, cod from the Sørfjord (53B) and (partly also) Bergen harbour (24B; both in Vestland County) stand out with low δ^{15}N signature (**Figure 25**). The same is shown for mussels from the Sørfjord (56A) and Bergen harbour (I241), indicating that the δ^{15}N baseline of the food web in these parts of Norway is lower. Likewise, isotope signatures of both cod (30B) and mussels (stations 30A and I304) from the Inner Oslofjord are among the highest observed (**Figure 25**) indicating a high baseline.

The isotopic signatures in cod from Svalbard appear similar at the two stations (19B and 20B; **Figure 25**), and those are among the stations with the lowest cod δ^{13}C-values.

In 2019, the δ^{15}N data from the whole Norwegian coast were scrutinized further by deducing the trophic position of cod, based on a known baseline in the same area, given by the isotopic profile in blue mussel, inhabiting trophic position 2 (primary consumer, feeding on particulate matter; (N. W. Green et al., 2020).This study showed that baseline adjusted trophic position of cod differed between stations along the Norwegian coast, suggesting that parts of the spatial differences in cod contaminant concentrations may be attributed to different trophic positions of the cod at the different stations, and not merely differences in environmental concentrations between stations.

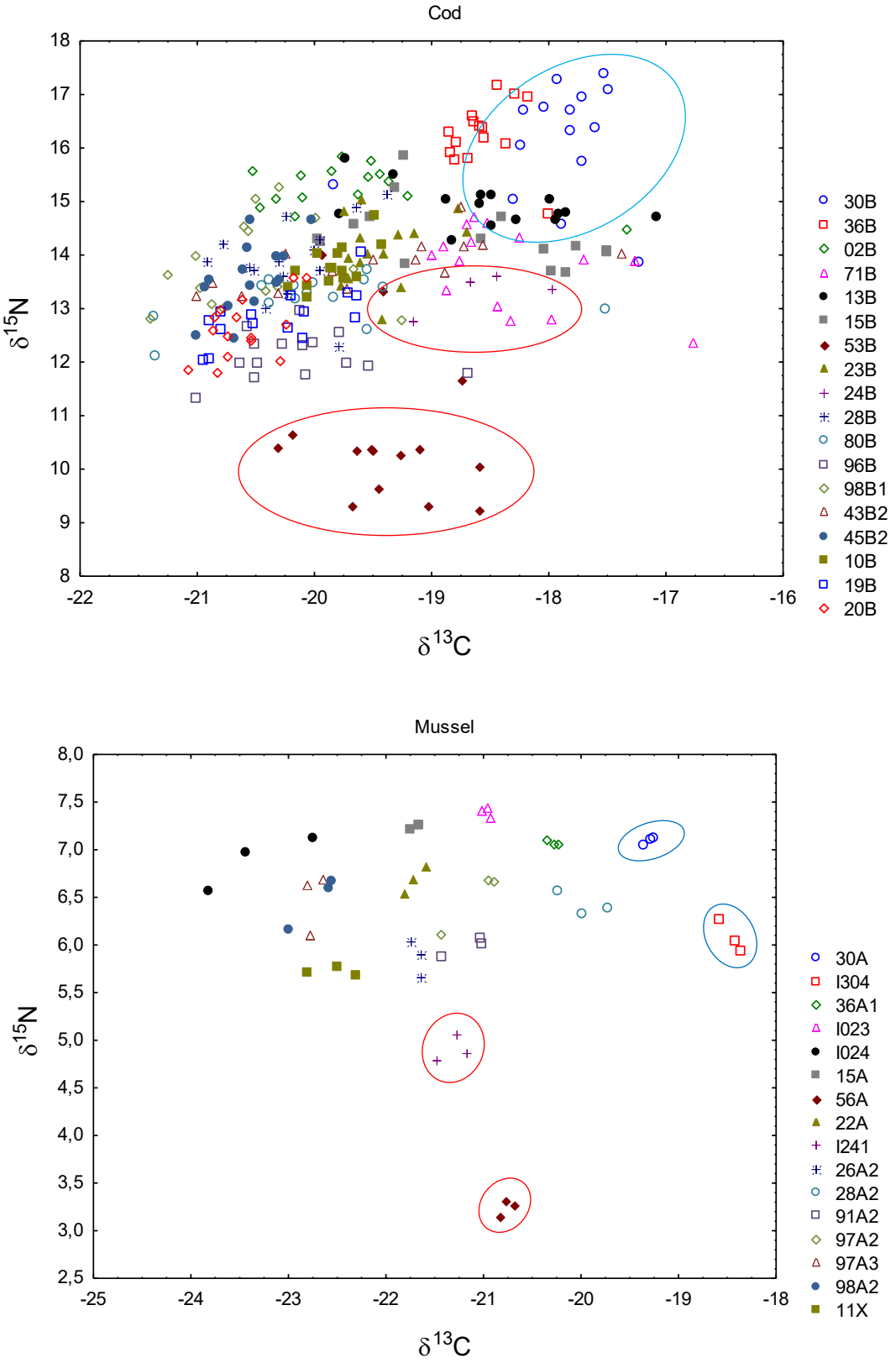


Figure 25. $\delta^{13}C$ plotted against $\delta^{15}N$ for cod (top) and blue mussel (bottom). Blue ellipses indicate the position of (most of) the samples of cod and blue mussel from the Inner Oslofjord, while red ellipses indicate the position of the samples of (most of) the cod and blue mussel from the Sørfjord and Bergen harbour.

The $\delta^{15}N$ values in eiders from Svalbard (blood and egg) resembled those previously observed (Schøyen, Grung, Lund, Hjermann, Ruus, Øxnevad, Christensen, Beylich, Jenssen, Tveiten, Håvardstun, Sagerup, et al., 2024) with approximately the same $\delta^{15}N$-signatures in the two matrices, and higher $\delta^{13}C$ values in blood than in eggs (**Figure 26).** This is likely related to different lipid content (also recognized by a higher C:N weight ratio in eggs), as lipids are $\delta^{13}C$-depleted relative to proteins (Sweeting et al., 2006). Samples were not treated to remove carbonates or lipid prior to stable isotope analysis.

In 2024, eggs and bird blood samples were collected from the same nest, and the $\delta^{13}C$ signatures were correlated; significant linear regressions were found between isotopic signatures in blood and eggs (R^2=0.64).

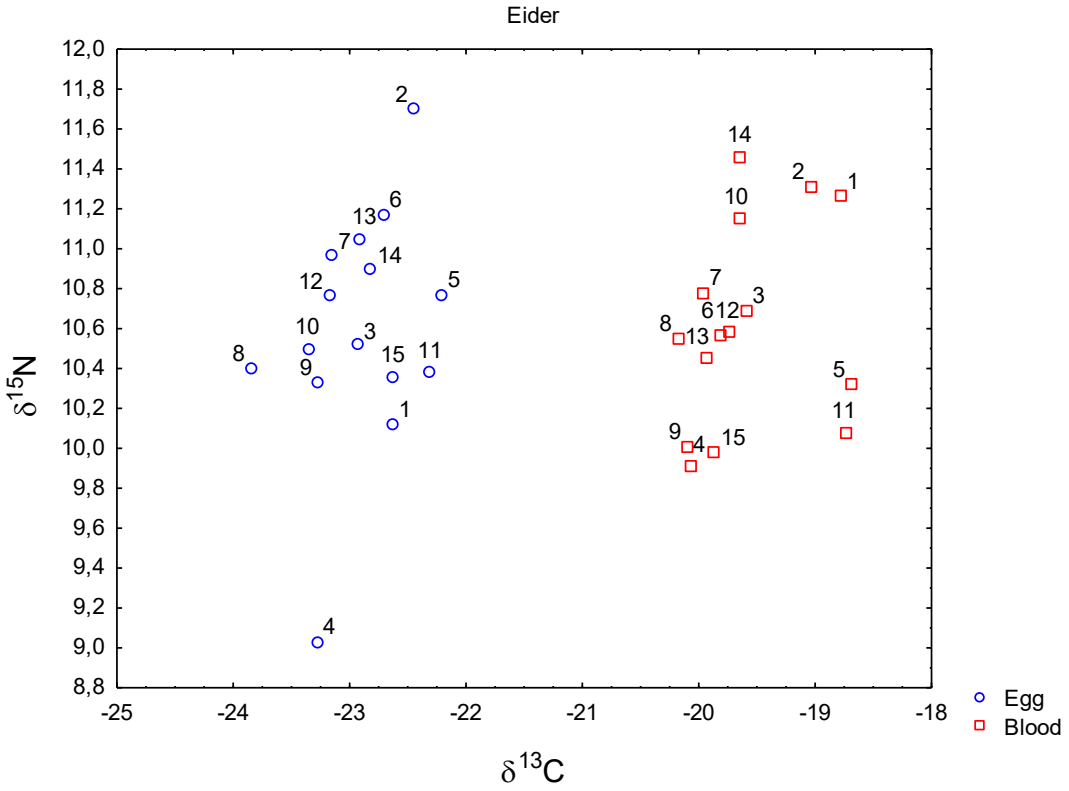


Figure 26. $\delta^{15}N$ plotted against $\delta^{13}C$ in blood and egg of eider from Svalbard (19N), 2024. Sample numbers are superimposed.

5 Sediments (Option 3)

5.1 Dating

The chronological data obtained are presented in **Figure 27**. The results for dating sediment core analyses collected in the Inner Oslofjord (Steilene), Raunefjord near Bergen, and Nordbotn in Tromsø are shown. The samples have been analysed for the activity of ^{210}Pb, ^{226}Ra and ^{137}Cs via gammaspectrometry, and the sediments have been dated by using the lead-210 method. This method can date deposits younger than about 150 years and is widely used in studies of pollution history and climate history. The method is based on the fact that radon gas (^{222}Rn) escapes into the atmosphere. It has a half-life of only 3.8 days and therefore quickly decays into other nuclides. These are not gaseous and fall to the ground or onto water surfaces, where they continue to decay. At this stage, the lead isotope ^{210}Pb becomes concentrated because it has the longest half-life. It is then deposited on the bottom of oceans and lakes and subsequently covered by new layers. ^{210}Pb is a radioactive nuclide that will disappear after roughly 200 years. By measuring the decrease in ^{210}Pb down through the sediment layers, one can determine the age of the very youngest layers.

The station in the Inner Oslofjord-Steilene had the highest sedimentation rate. The 12-14 cm layer for the Inner Oslofjord-Steilene station was dated to be 24 years old (from the year 2000). The Bergen and Tromsø stations had lower sedimentation rates. Fairly uniform content of unsupported ^{210}Pb in the upper 10 cm layer of the sediment from the Inner Oslofjord-Steilene and Tromsø-Nordbotn indicates that bioturbation is significant. The sediment from Bergen-Raunefjord had exponential decline in the content of unsupported ^{210}Pb. This is an indication of constant sedimentation during the last ≈100 years, and chronology is believed to do be reliable. Traces of ^{137}Cs were found in layers dated to well before the initial release of the isotope into nature (mid 1950´s) and slight sediment mixing is therefore indicated. Bioturbation affects the sediments to some extent and may blur or smooth the chemical signals, making them less distinct or sharp. However, it does not alter the overall chemical signal from one layer to another.

Calculated flux of unsupported ^{210}Pb was higher than the expected flux for all three sediment stations. This indicates that the stations are subject to sediment focusing (the process where water turbulence redistributes sediment, leading to a higher concentration of sediment in deeper areas than would be expected from simple vertical settling alone). So, both bioturbation and sediment focusing are sources of error to the dating of the sediment cores. More detailed information of the dating of sediment cores can be found in **Supplementary** data. The *median timespan* for each figure is shown in text below the figures in this chapter. A comparison of the real timespan is shown in **Figure 31**.

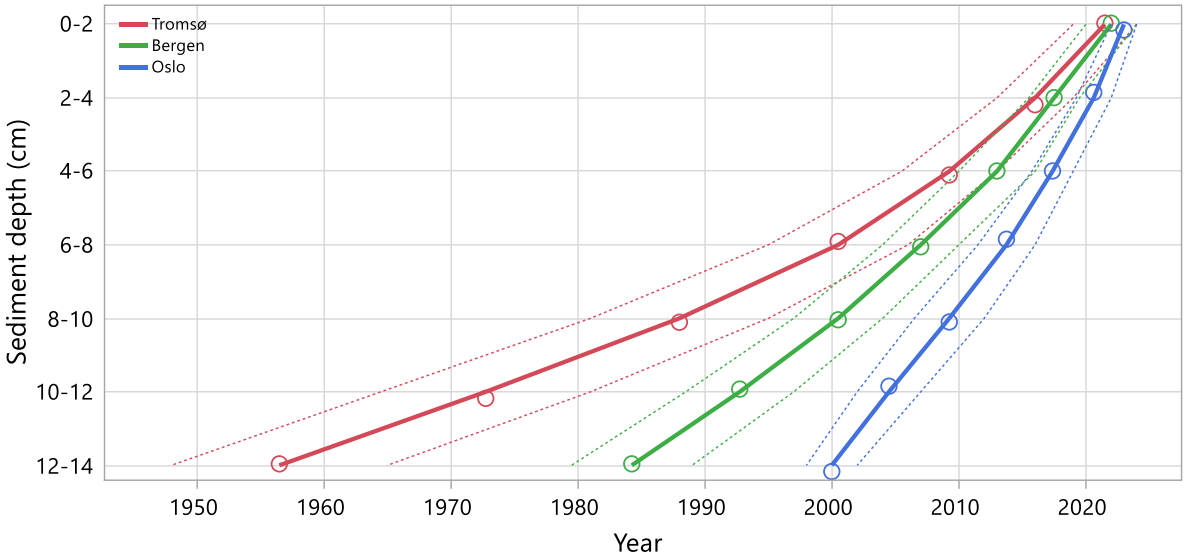


Figure 27. Presentation of the chronological data obtained from sediment core analyses collected in the Inner Oslofjord (Steilene), Raunefjord near Bergen, and Nordbotn in Tromsø. The median year of the sediment layer is shown with open circles, and the max and min year of the dating is shown with dotted lines. Results for dating of the deeper layers of the sediment cores are shown in Supplementary data.

5.2 Contaminants

The sediment from Tromsø-Nordbotn had higher concentration of TOC than the sediment from Bergen-Raunefjord, and the Inner Oslofjord-Steilene (**Figure 28**). The sediment core from the Inner Oslofjord had lower fraction of sediment grain size less than 63 µm (silt-sand boundary). The sediment from Bergen-Raunefjord had highest fraction of sediment grain size less than 63 µm.

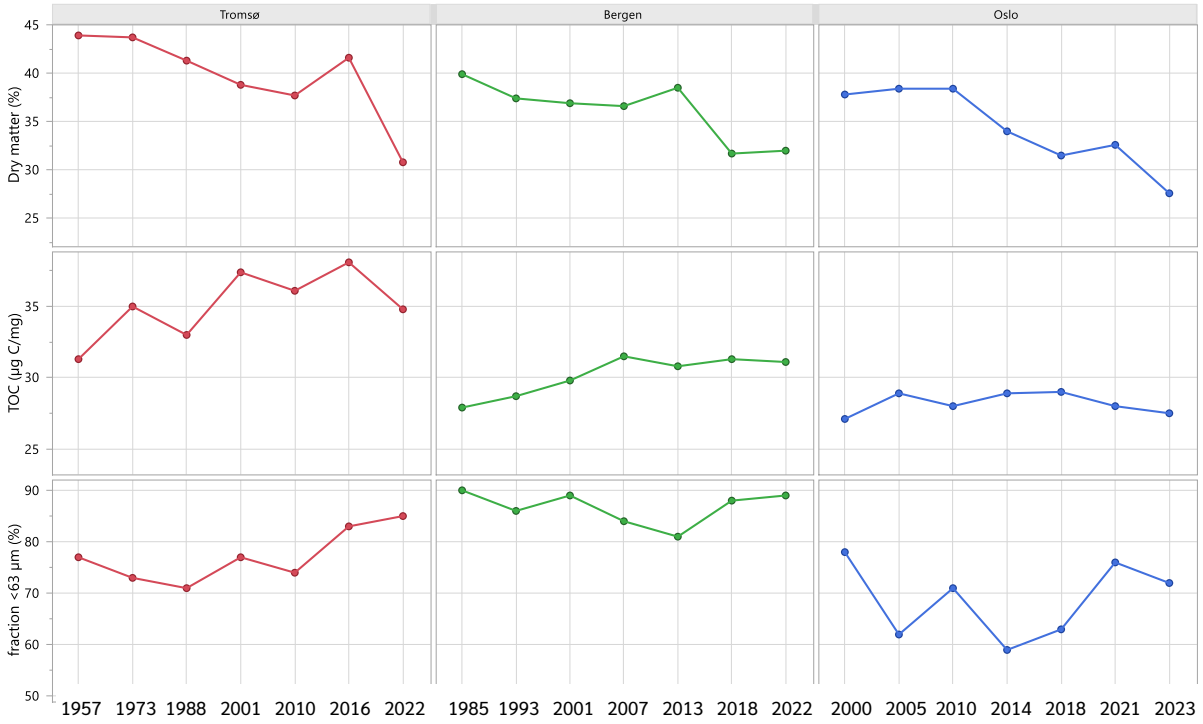


Figure 28. Sediment properties vs. sediment sample (cm) (% dry matter, total organic carbon (TOC)) and sediment grain size fraction less than 63 µm for sediment cores from Inner Oslofjord-Steilene, Bergen-Raunefjord, and Tromsø-Nordbotn.

The sediment samples from the Inner Oslofjord-Steilene core had higher frequency of exceedance of EQS than the sediment samples from Bergen-Raunefjord and Tromsø-Nordbotn (**Figure 29**). For the sediment core from Bergen-Raunefjord, all concentrations were below EQS. The Tromsø sediment had only exceedance of EQS for PFOS. Please refer to **Figure 31**-**Figure 41** for an overview of which specific sediment core sample that exceeded EQS.

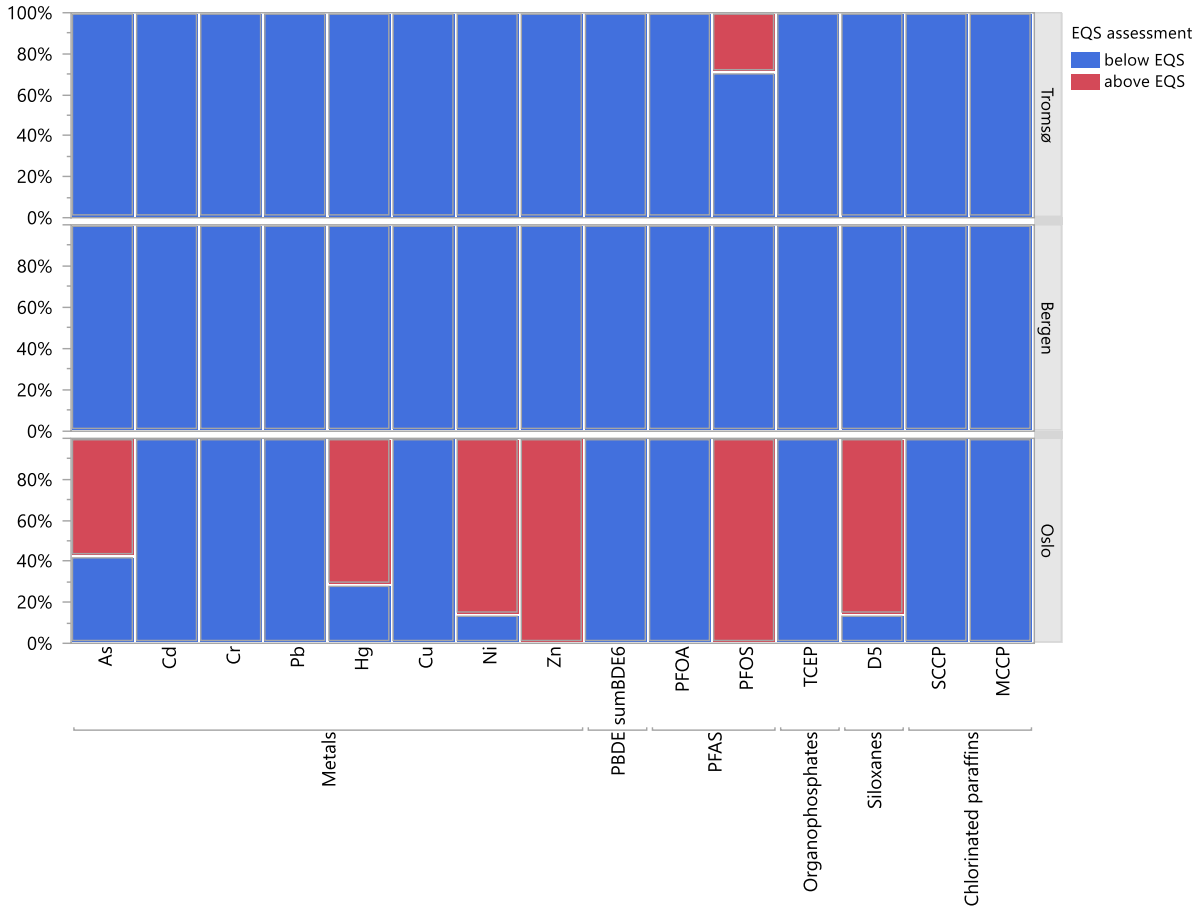


Figure 29. EQS assessment of sediment concentrations. Each sediment sample was assessed vs. EQS, where one core sample represent 1/7 (14 %) of the total samples from the station.

Risk quotients (RQ) (sediment concentrations divided by EQS) for the sediment samples are shown in **Figure 30**. The sediment from the Inner Oslofjord-Steilene had the highest frequency of exceeding EQS.

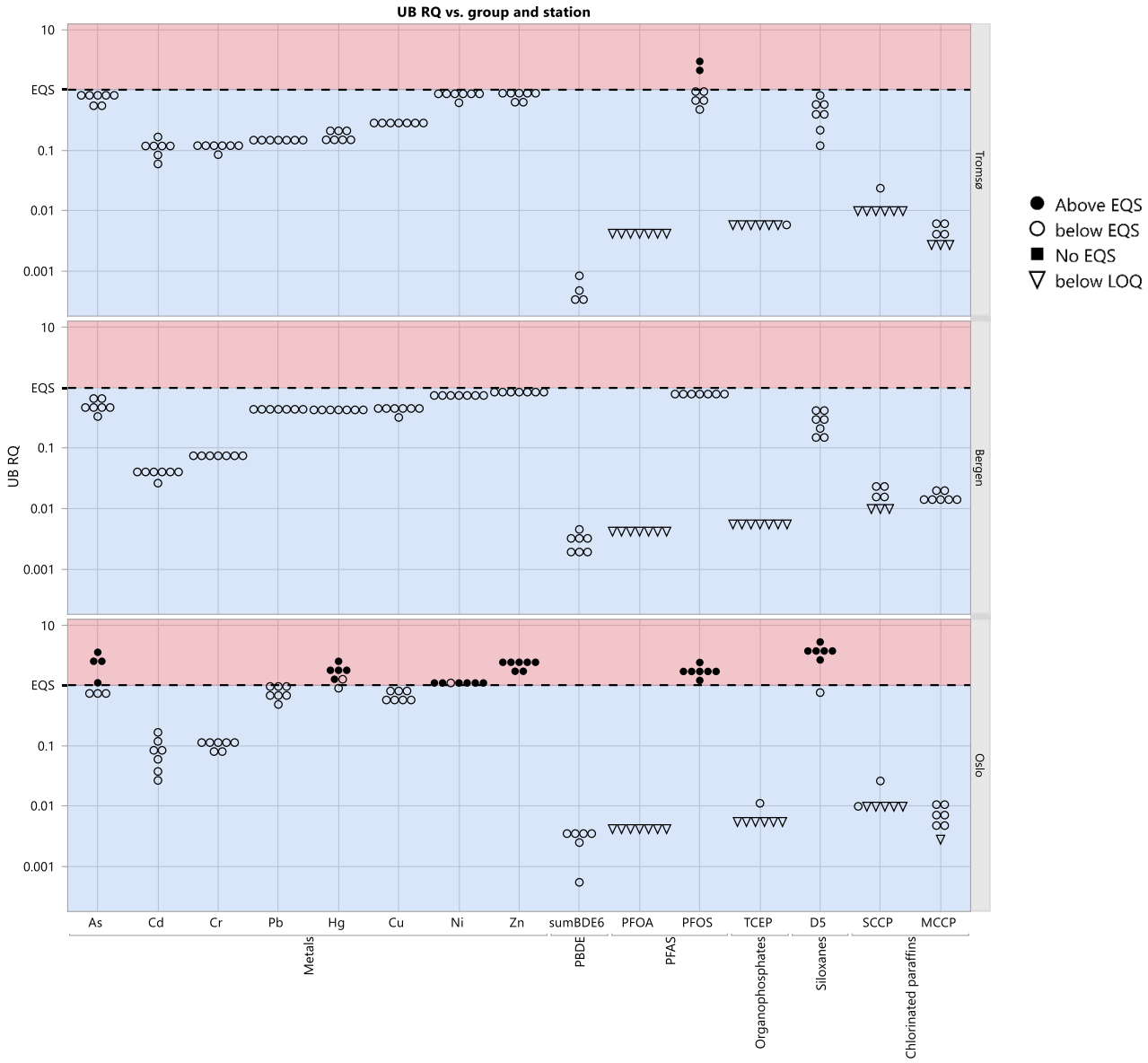


Figure 30. Risk quotients (RQ) (sediment concentrations divided by EQS) vs. contaminants and groups of contaminants for sediments from the three station (city is identified on the right vertical axis). EQS is marked with a stippled line, and area above EQS is in red, area below EQS is in blue and signify no exceedance of EQS. Upper bound values were used for the sediment concentrations. The markers show assessment vs. EQS (filled circle exceeds EQS, open circles do not). Concentrations showed as triangles were below LOQ, and are placed at LOQ. The vertical axis is on a log10-scale.

The concentration of mercury and cadmium have decreased in the sediment from the Inner Oslofjord-Steilene (**Figure 31**) from 2000 to 2024. The top sedimentlayer (0-2 cm) had much lower concentration of mercury than the sediment from the 12-14 cm layer (from year 2000). The concentration of mercury in the top 4 cm layer was below the EQS. The concentration of arsenic in sediment from the Inner Oslofjord-Steilene has increased since 2010, and increased to concentrations above EQS. The concentrations of toxic metals in sediment from Tromsø-Nordbotn and Bergen-Raunefjord have been quite stable.

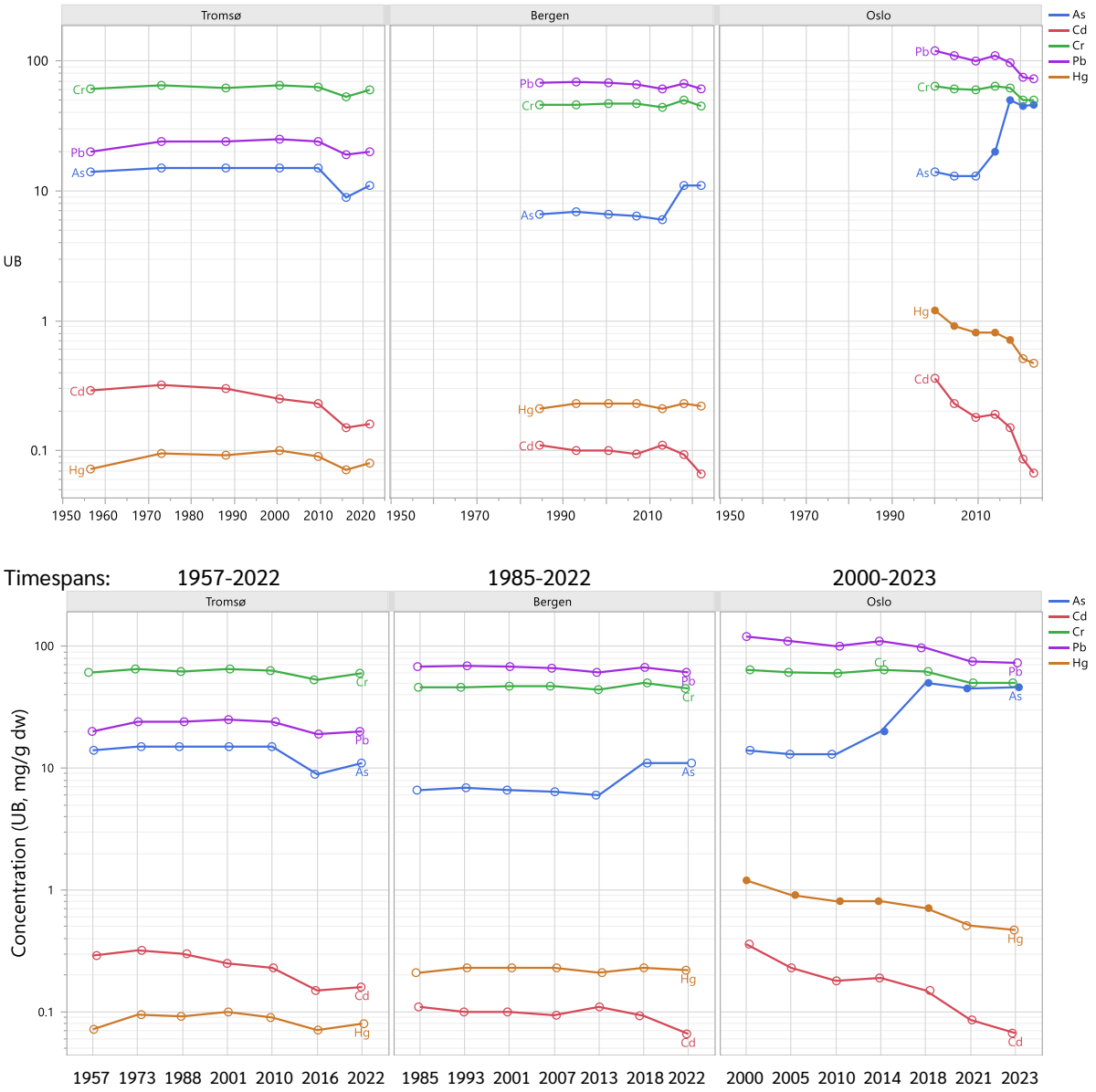


Figure 31. Timeline of toxic metals. Timelines in both interpolated dating (upper graph) and the sediment cores sampled (lower figure) are shown. The vertical axis is on a log10-scale. Upper bound (UB) data are used (i.e. data below LOQ are shown at LOQ). Only contaminants that were quantified in at least one sample pr. site is included in the figures. Keep in mind that the timescale for sediments from Bergen-Raunefjord is shorter than Tromsø-Nordbotn, and the time-scale of sediments from the Inner Oslofjord-Steilene is even shorter than those from Bergen-Raunefjord. The timespan for each site is indicated above each figure.
Filled circle: EQS is exceeded; **open circles**: EQS not exceeded; **triangles**: below LOQ and placed at LOQ. *The median timespans* for the sediment cores are indicated above all following figures in this chapter. Please refer to **Figure 27** to see the time spans for the different stations.

The concentrations of zinc, copper, nickel and cobalt was higher in sediment from the Inner Oslofjord-Steilene than in sediment cores from Bergen-Raunefjord and Tromsø-Nordbotn (**Figure 32**). Decreasing concentrations of zinc, copper, and tin can be seen in the Oslofjord sediments, with lower concentrations in the top sediment layer. The sediment layers in the core samples from Bergen-Raunefjord showed little variation in concentration of metals.

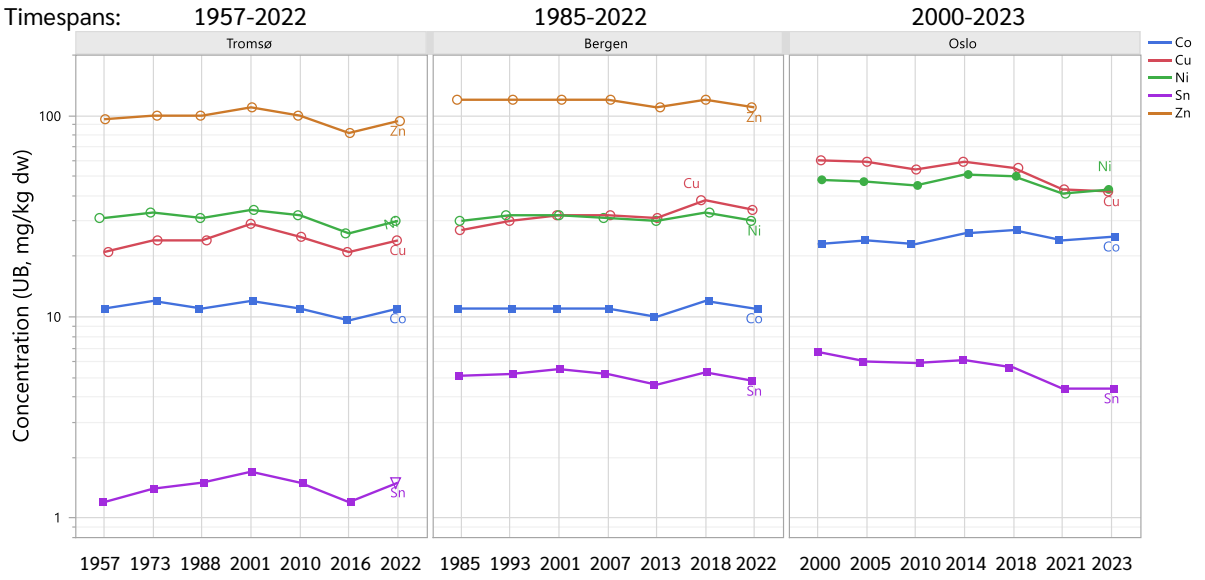


Figure 32. Timeline of other metals from the Inner Oslofjord-Steilene, Bergen-Raunefjord and Tromsø-Nordbotn. Concentrations are shown as mg/kg dry weight. The vertical axis is on a log10-scale. Filled circle means that EQS is exceeded, open circles: EQS is not exceeded. Concentrations showed as triangles were below LOQs and are placed at LOQ. Squares indicate that EQS does not exist.

For the sediment from Tromsø-Nordbotn, there were increasing concentrations of PFOS from sediment layer 12-14 cm (from 1956) to sediment layer 6-8 cm (from 2001). The concentration of PFOS was higher than the EQS at 4-8 cm. The following sediment layers up to the sediment surface had decreasing concentrations of PFOS and below EQS (**Figure 33**). Several PFASs were detected in samples from the Inner Oslofjord. For the sediment core from the Inner Oslofjord there were increasing concentrations for PFOS and PFUnDA and decreasing concentrations for N-EtFOSAA and 12:2 FTS. The concentration of PFOS was above the EQS in all layers. The sediment core from Bergen-Raunefjord had low concentrations of PFOS, with little variation in the sediment layers. PFOA was not detected.

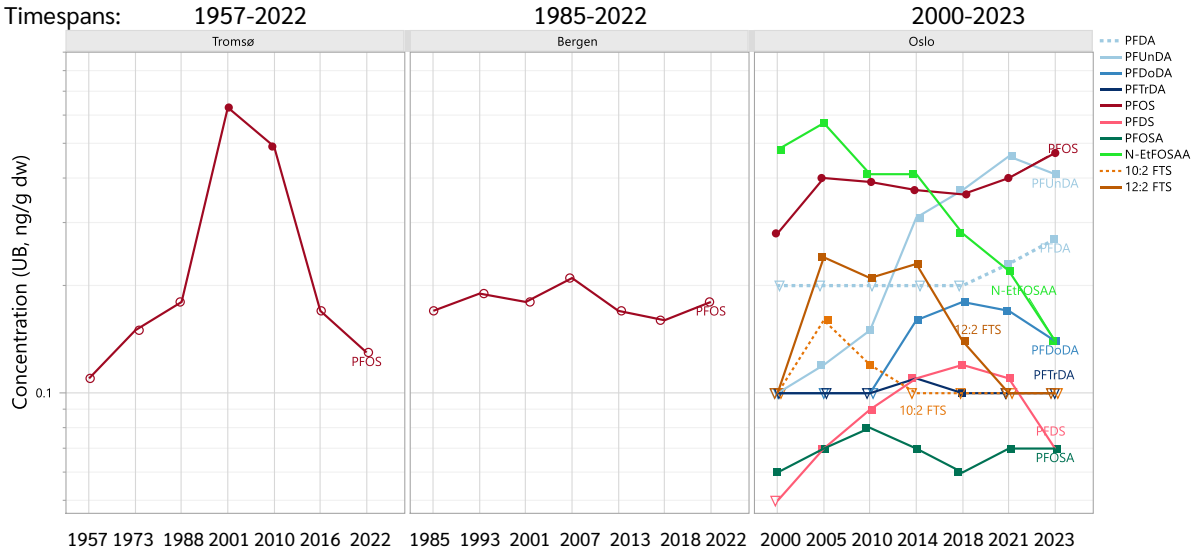


Figure 33. Timeline for PFAS in sediment cores from the Inner Oslofjord-Steilene, Bergen-Raunefjord and Tromsø-Nordbotn. Concentrations are given in ng/g (µg/kg). The vertical axis is on a log10-scale. Filled circle means that EQS for PFOS is exceeded, open circles: EQS is not exceeded. Concentrations showed as triangles were below LOQ and are placed at LOQ. Squares indicate that EQS does not exist.

Quaternary ammonium compounds (QACs), ATAC (alkyltrimethylammonium chlorides, C16-C22) were found in increasing concentrations from deeper sediment layers (12-14 cm) to the surface sediment layer (0-2 cm) (**Figure 34**). Highest concentrations were found for ATAC-C22. This was found in sediment cores from all three sites. The very strong sorption properties and resistance to desorption of even the most soluble QACs gives an explanation to that these compounds are found in sediments downstream WWTPs in appreciable quantities. The finding implies that QACs can be relatively persistent in receiving waters (Lara-Martín et al., 2010; Li & Brownawell, 2010; Martínez-Carballo et al., 2007).

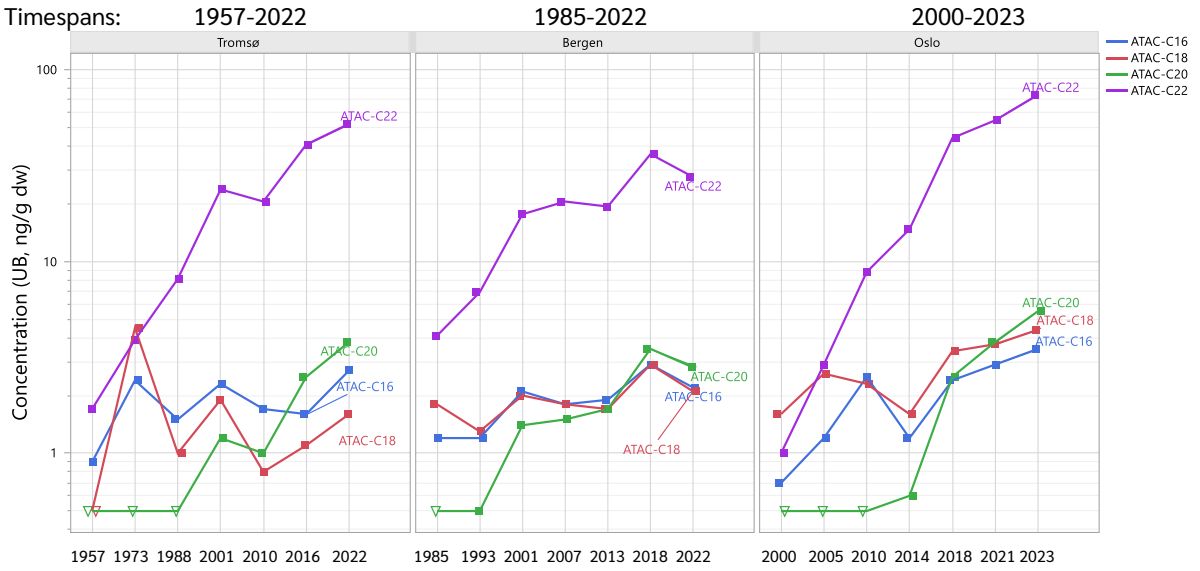


Figure 34. Quaternary ammonium compounds (ATAC C16-C22) analysed in sediment cores from the Inner Oslofjord-Steilene, Bergen-Raunefjord, and Tromsø-Nordbotn. The vertical axis is on a log10-scale. Concentrations are given in µg/kg dry weight. Concentrations showed as triangles were below LOQ and are placed at LOQ. Squares indicate that EQS does not exist.

For quaternary ammonium compounds BAC (benzalkonium chloride, C12-C18), there were increasing concentrations from the deeper sediments to the surface sediment layer. This was most evident for the sediment core from the Inner Oslofjord (**Figure 35**). For the sediment cores from Tromsø-Nordbotn and Bergen-Raunefjord there were also concetration peaks in the 8-10 cm sediment layer. Highest concentrations of BAC-C12 and BAC-C18 was found in the Tromsø-Nordbotn sediment.

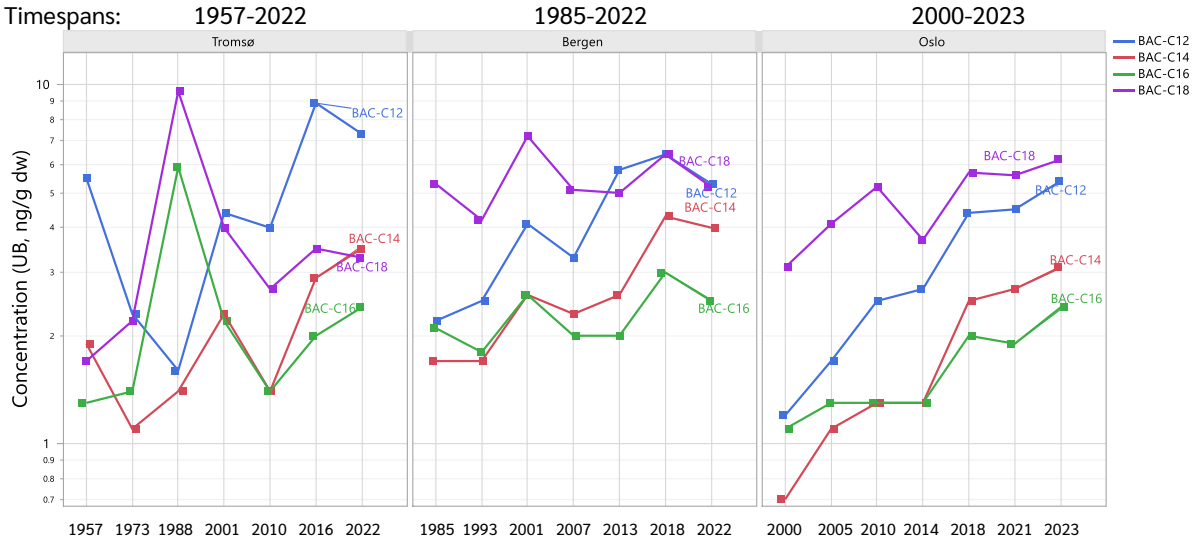


Figure 35. Quaternary ammonium compounds (BAC C12-C18) in sediment cores from the Inner Oslofjord-Steilene, Bergen-Raunefjord and Tromsø-Nordbotn. The vertical axis is on a log10-scale. Concentrations are given in µg/kg dry weight. Concentrations showed as triangles were below LOQ and are placed at LOQ. Squares indicate that EQS does not exist.

For quaternary ammonium compounds DADMAC (diallyldimethylammonium chloride, C8-C18), highest concentrations were found for DADMAC-C18 and DADMAC-C16 (**Figure 36**). Highest concentrations were found for the sediment core from Inner Oslofjord-Steilene. For DADMAC-C14, DADMAC-C16 and DADMAC-C18 there were decreasing concentrations from sediment layer 8-10 cm to the surface sediment layer. This was the case also for the Bergen-Raunefjord and Tromsø-Nordbotn sites. Many quaternary ammonium compound have negative effects on human health and are slowly degraded (Miljødirektoratet, 2015). The quaternary ammounium compounds are therefore importand to follow the trends an environmental compounds. Predicted no-effect concentrations (PNEC) for several are developed (Arnold et al., 2023).

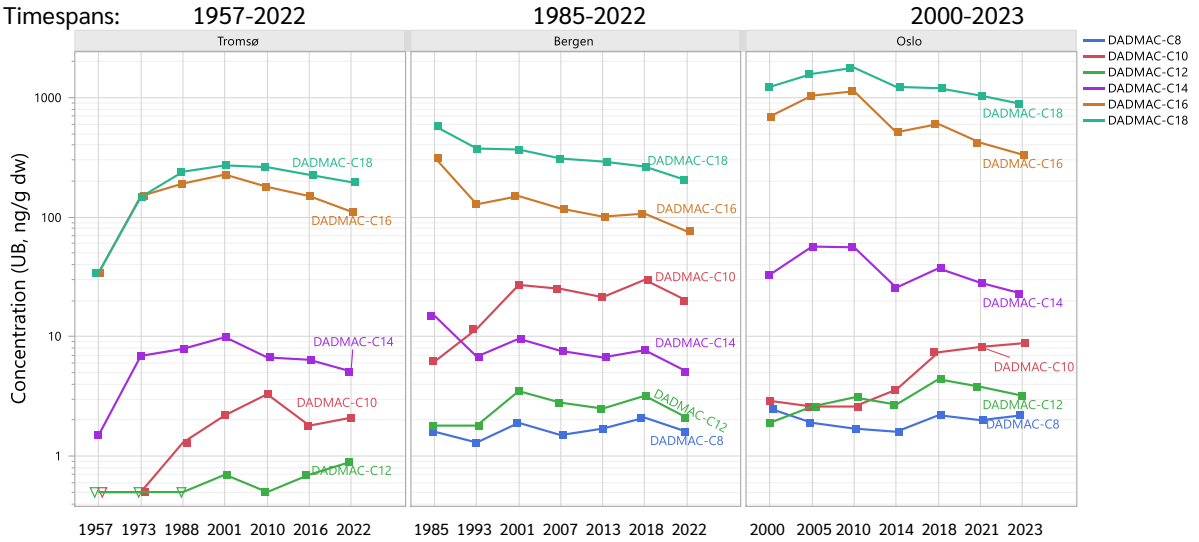


Figure 36. Quaternary ammonium compounds (DADMAC C8-C18) in sediment cores from the Inner Oslofjord-Steilene, Bergen-Raunefjord and Tromsø-Nordbotn. The vertical axis is on a log10-scale. Concentrations are given in µg/kg dry weight. Concentrations showed as triangles were below LOQ and are placed at LOQ. Squares indicate that EQS does not exist.

Concentrations of BDEs inlcuded in sumBDE6 are shown in **Figure 37**. The sediment core from Inner Oslofjord-Steilene had increasing concentrations of BDE47, BDE99, and BDE100 from de deeper sediment layer to the surface sediment layer. Highest concentrations were found for BDE47 in the Oslofjord sediments. Decreasing concentrations were found in the sediment core from Bergen-Raunefjord, with lower concentrations in the surface sediment. The Bergen-Raunefjord sediment core had concentration peak in the 6-8 cm layer.

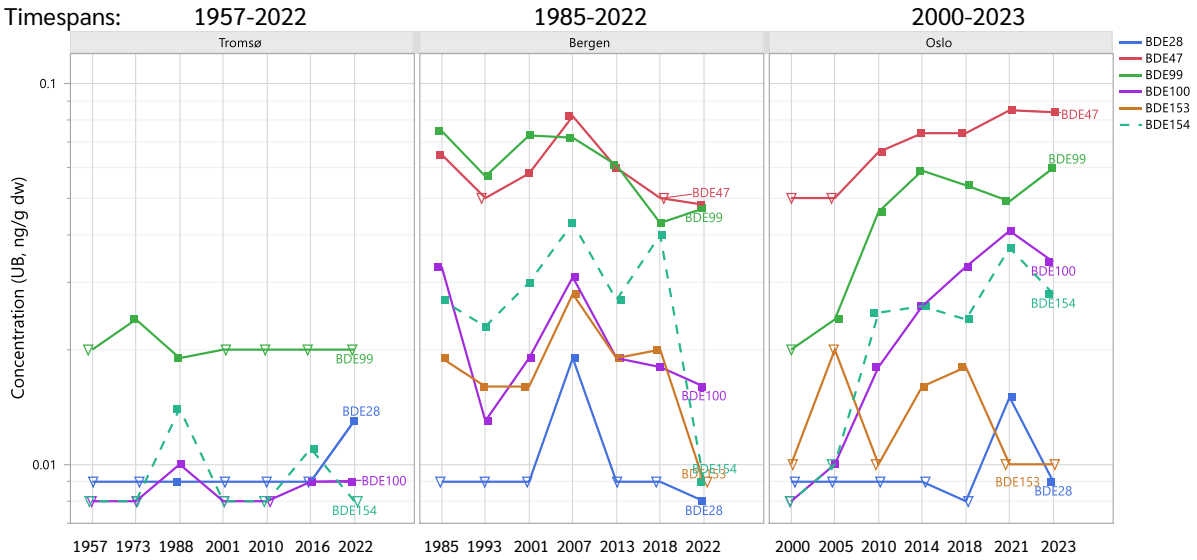


Figure 37. BDE included in sumBDE6 in sediment cores from the Inner Oslofjord-Steilene, Bergen-Raunefjord and Tromsø-Nordbotn. Concentrations are given in µg/kg dry weight. Filled circle means that EQS is exceeded, open circles: EQS is not exceeded. Concentrations showed as triangles were below LOQ and are placed at LOQ. Squares indicate that EQS does not exist.

Of the PBDEs, BDE209 was found in highest concentrations, and the Bergen sediment had higher concentrations than the sediment cores from Tromsø-Nordbotn and Inner Oslofjord-Steilene (**Figure 38**). There were increasing concentrations from the deeper sediment layers to the top sediment layers. For the Tromsø-Nordbotn sediment core, there were concentrations peaks in 8-10 cm and 2-4 cm layers. The other PBDEs were found in much lower concentrations.

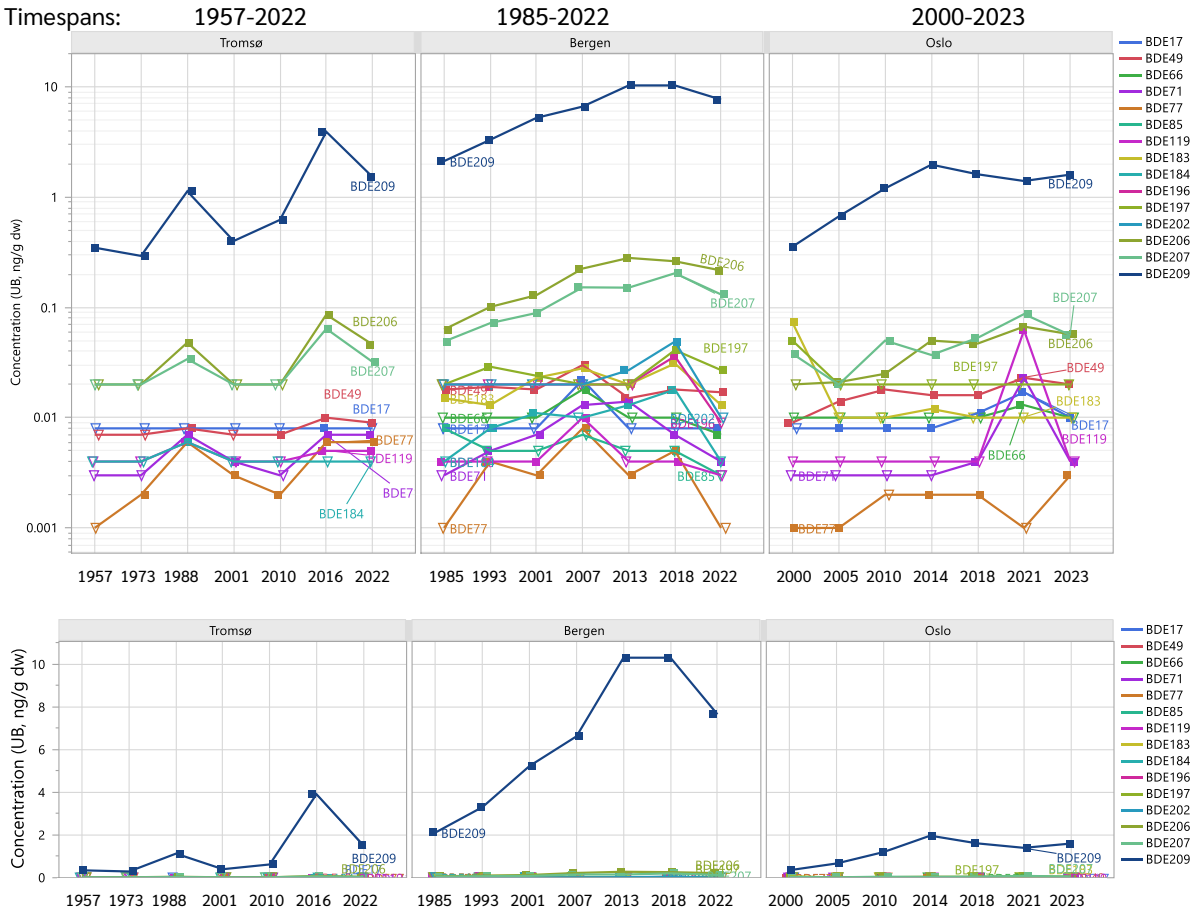


Figure 38. PBDEs in sediment cores from the Inner Oslofjord-Steilene, Bergen-Raunefjord, and Tromsø-Nordbotn. Concentrations are given in µg/kg dry weight. The figures show PBDEs not included in sumBDE6. The two graphs are shown with log10-scale (upper figure) and linear scale to illustrate the difference in scales. Concentrations showed as triangles were below LOQ and are placed at LOQ. Squares indicate that EQS does not exist.

Of other brominated compounds, tricresyl phosphate (TXP) was found at highest concentration in the sediment core from the Inner Oslofjord-Steilene, with decreasing consentrations towards the surface sediment (**Figure 39**). The other brominated compounds were found at considerably lower concentrations in the sediments from Tromsø and Bergen.

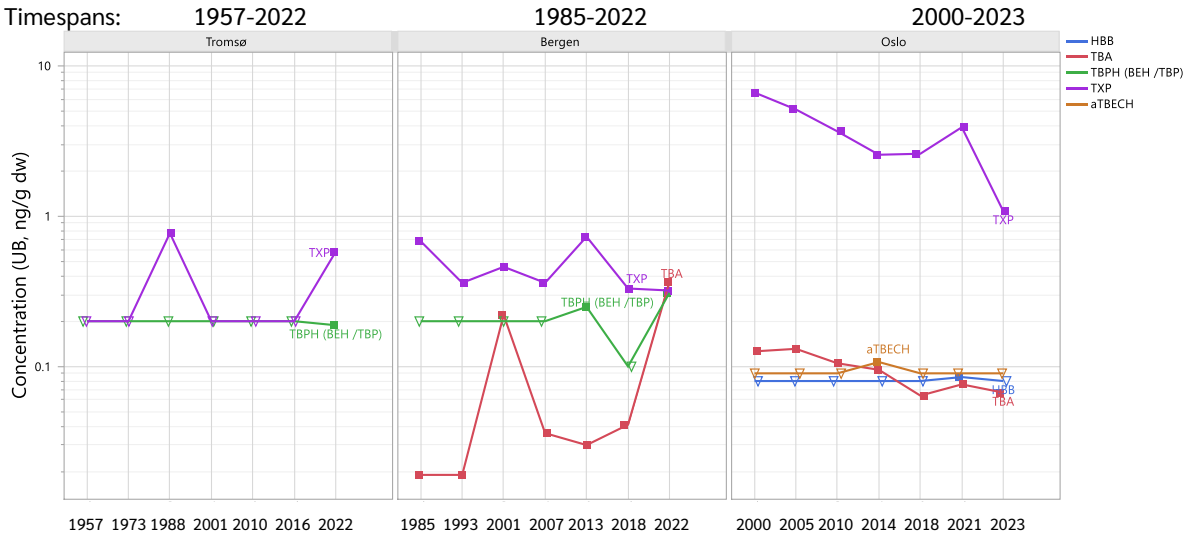


Figure 39. Other brominated compounds in sediment cores from the Inner Oslofjord-Steilene, Bergen-Raunefjord, and Tromsø-Nordbotn. The vertical axis is on a log10-scale. Concentrations are given in µg/kg dry weight. Concentrations showed as triangles were below LOQ and are placed at LOQ. Squares indicate that EQS does not exist.

Siloxanes were found in higher concentrations in the sediment from Inner Oslofjord-Steilene, than in the sediment from Bergen-Raunefjord and Tromsø-Nordbotn (**Figure 40**). For the Inner Oslofjord-Steilene sediment core there were increasing concentrations from the 12-14 cm sediment layer to 4-6 cm sediment layer. Then there were lower concentrations in the surface sediment layer. In Bergen-Raunefjord, there were increasing concentrations from the 12-14 cm sediment layer to 8-10 cm sediment layer. Then, there were lower concentrations in the 4-6 cm sediment layer, higher in the 2-4 cm sediment layer, and a drop to the surface sediment. In the Tromsø-Nordbotn sediment core there were increasing concentrations of D4 and D6 from the 12-14 cm layer to the surface layer (0-2 cm). For D5 there was an increase in concentration from the 12-14 cm layer to the 6-8 cm layer, and from there a concentration drop to the surface sediment.

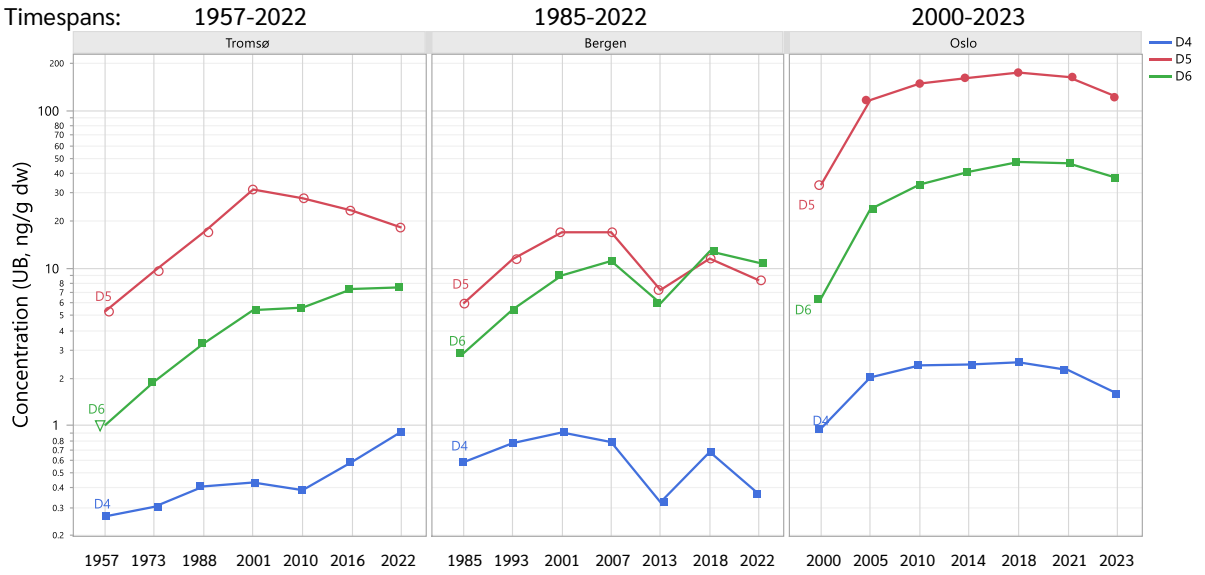


Figure 40. Siloxanes in sediment cores from the Inner Oslofjord-Steilene, Bergen-Raunefjord and Tromsø-Nordbotn. The vertical axis is on a log10-scale. Concentrations are given in µg/kg dry weight. Filled circle means that EQS is exceeded, open circles: EQS is not exceeded. Concentrations showed as triangles were below LOQ and are placed at LOQ. Squares indicate that EQS does not exist.

Long chain chlorinated paraffins (LCCPs) was found in highest concentrations at the three sites (**Figure 41**). In the Inner Oslofjord-Steilene sediment core, there was a concentration peak of LCCP in the 6-8 cm layer. For the Tromsø-Nordbotn sediment core, there was increasing concentrations of LCCP from the 12-14 cm layer to the surface sediment layer.

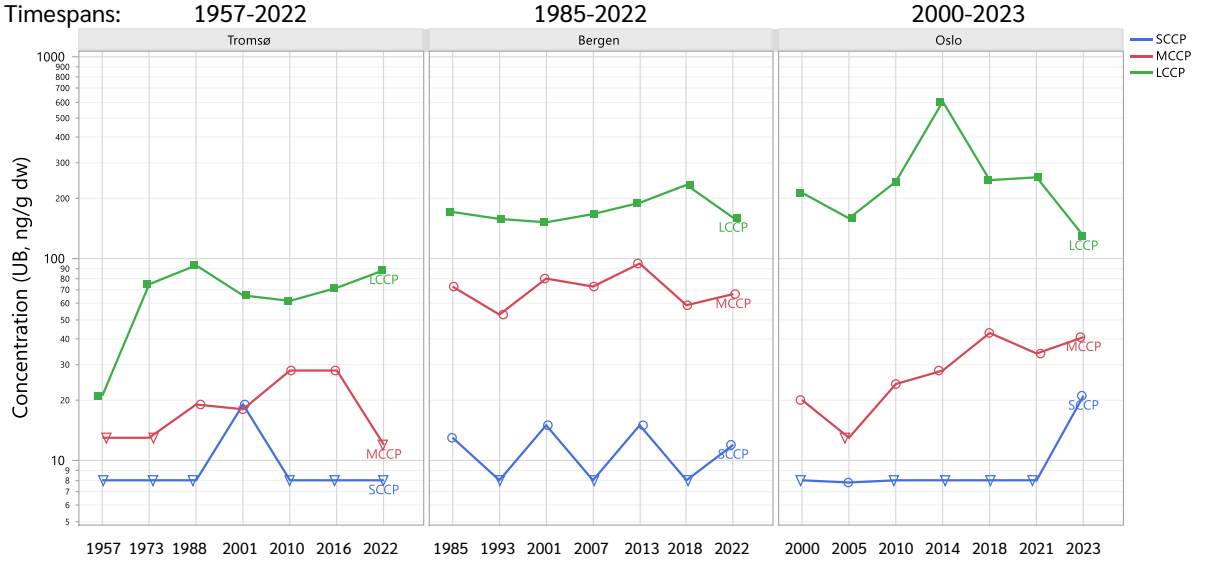


Figure 41. Chlorinated paraffins (CPs) in sediment cores from the Inner Oslofjord-Steilene, Bergen-Raunefjord, and Tromsø-Nordbotn. The vertical axis is on a log10-scale. Concentrations are given in µg/kg dry weight. Filled circle means that EQS is exceeded, open circles: EQS is not exceeded. Concentrations showed as triangles were below LOQ and are placed at LOQ. Squares indicate that EQS does not exist.

5.3 Timetrends and comparison of trends to biota trends

The Inner Oslofjord-Steilene sediment core had the highest number of significant increasing time trends, and also highest number of significant decreasing time trends. (**Figure 42**). **Figure 43** shows more details of time trends for the contaminants groups. The Inner Oslofjord-Steilene sediment core had the highest number of significant increasing time trends.

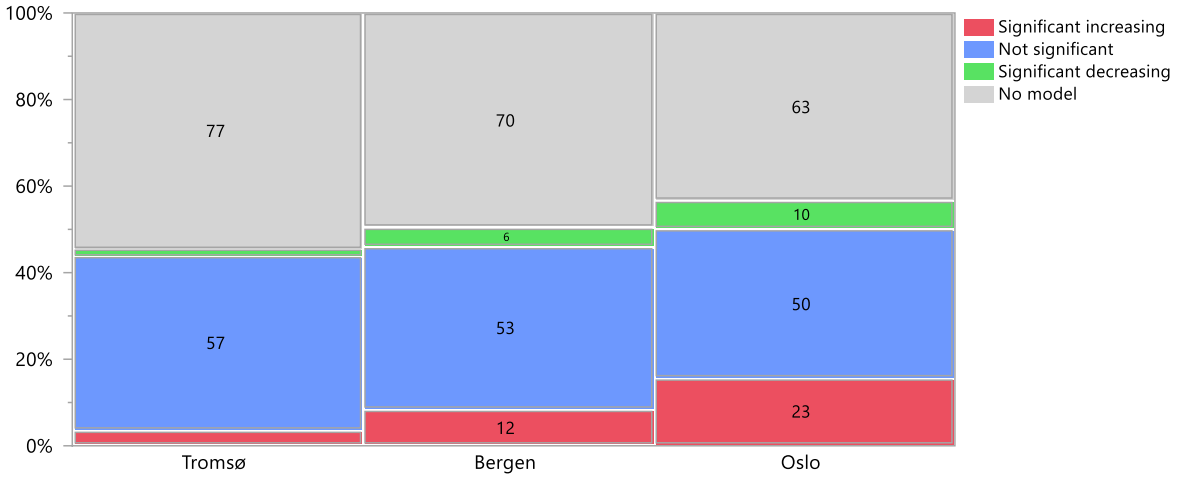


Figure 42. Time-trends for each station as assessed by linear regression model. No model is when no time trend could be assigned, usually because many or all concentrations were below LOQ.

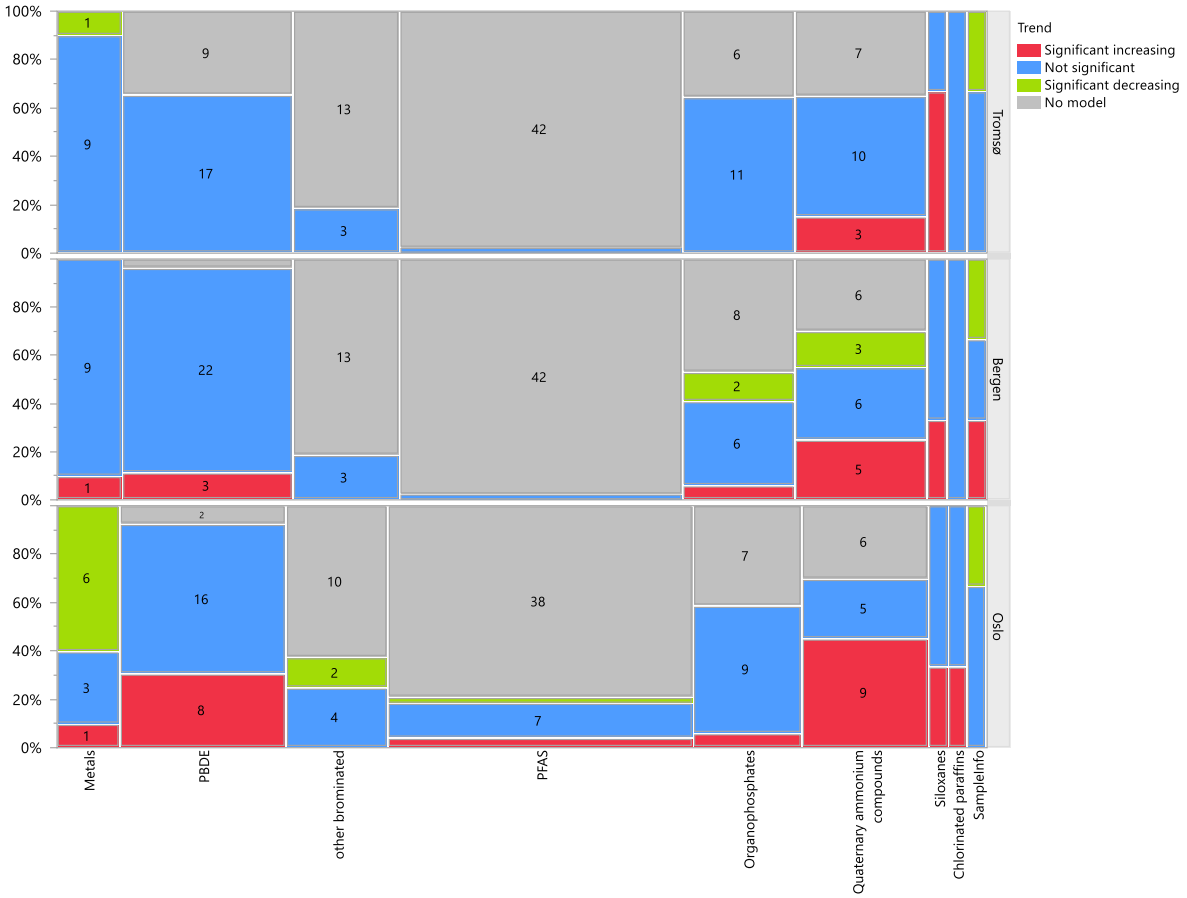


Figure 43. Time trends in sediment cores by main group of contaminants.

Significantly increasing time trends (p<0.0.5) are shown in **Figure 44**, with the highest number of increasing time trends for the sediment core from the Inner Oslofjord-Steilene. We want to comment that in general also the TOC-content of the sediments also increase with time for the sediment cores (see **Figure 28**). We have however, not corrected for TOC in the timetrends

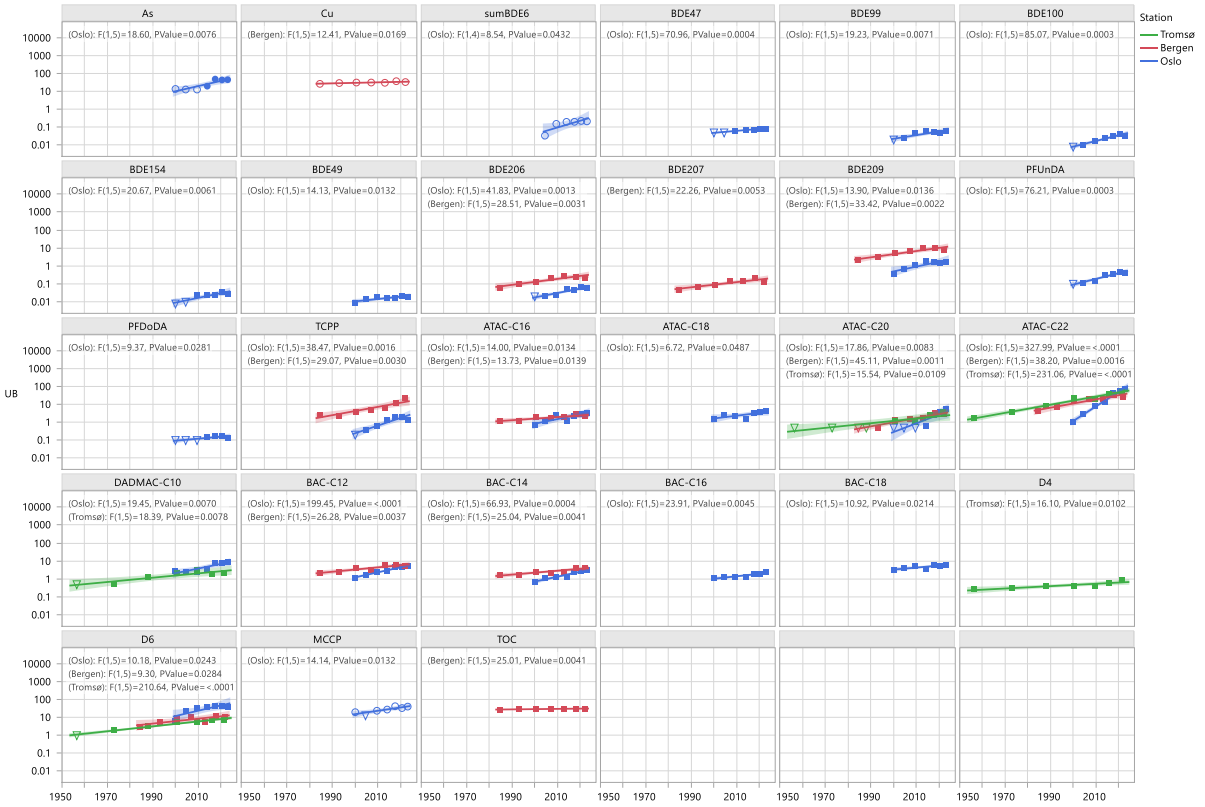


Figure 44. The time trends (assessed only by linear regression) for significantly increasing trends in sediment cores. The sediments from different cities are indicated with colours, and each contaminant/sediment info have a separate box. p-values are shown at the top of each figure.

Significantly (p<0.05) decreasing time trends are shown in **Figure 45**, whith the highest number of trends for the sediment core from the Inner Oslofjord-Steilene.

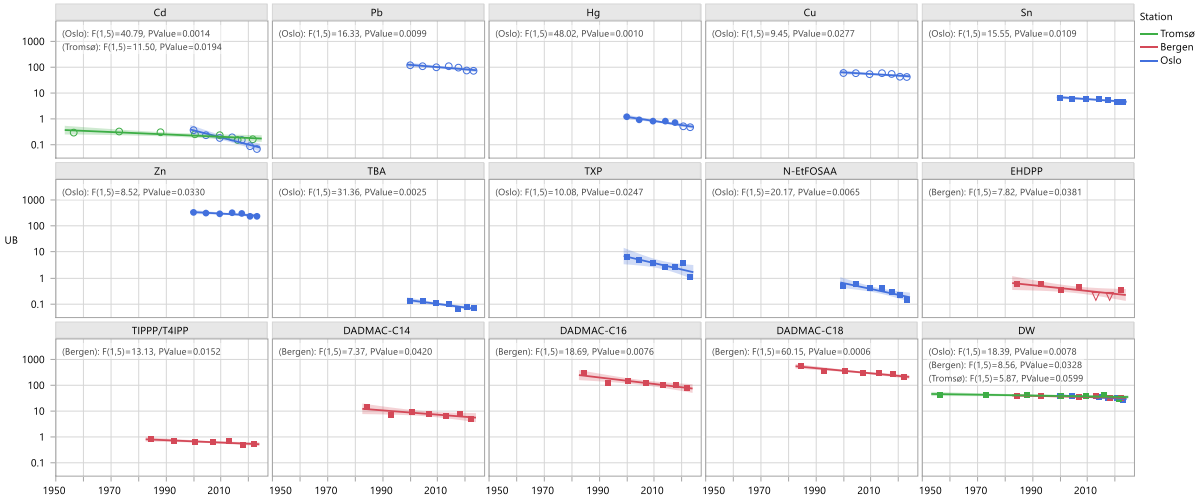


Figure 45. The time trends (assessed only by linear regression) for significantly decreasing trends in sediment cores. The sediments from different cities are indicated with colours, and each contaminant/sediment info have a separate box. p-values are shown at the top of each figure.

In many cases there were significant time trends in both sediment and cod (data from cod sampled in 2023) from the same stations (**Table 6** and **Figure 46**).

Table 6. Overview of contaminants that had significant (p<0.05) time trends in sediment core samples and in cod at the tree sediment stations. The sediment cores were compared to cod samples in the following stations: Oslo, 30B; Bergen, 24B, and Tromsø, 43B2. Time trends for sediment were compared to cod 2023-time trends, both recent and whole time trends.

Group	Contaminant
Metals	As, Cd, Co, Cr, Cu, Hg, Ni, Pb, Sn, Zn
PBDE	BDE28, BDE47, BDE99, BDE100, BDE126, BDE153, BDE154
PFAS	PFOS, PFOS
Siloxanes	D4, D5, D6
CP	MCCP, SCCP

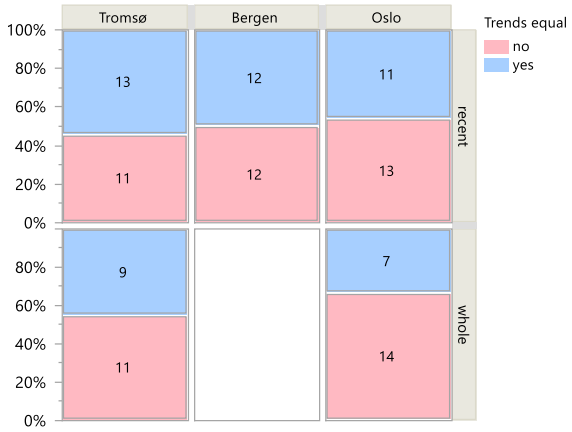


Figure 46. Comparison of sediment core time trends with time trend in cod (data from 2023) for compounds that have results both in sediment cores and in cod.

In **Figure 47** sediment core time trends are matched with time trends for cod. For several of the heavy metals there are matching time trends for cod and sediments, but also for PFASs there were matching time trends. **Table 7** shows the number of sediment core trends that are the same as recent time trends in cod, and also the number of trends that are different.

Table 7. Number of matching sediment trends in sediment cores with recent time trends in cod.

Sediment trend same as in cod	Station	N
yes	Tromsø	26
	Bergen	24
	Oslo	22
no	Tromsø	22
	Bergen	24
	Oslo	26

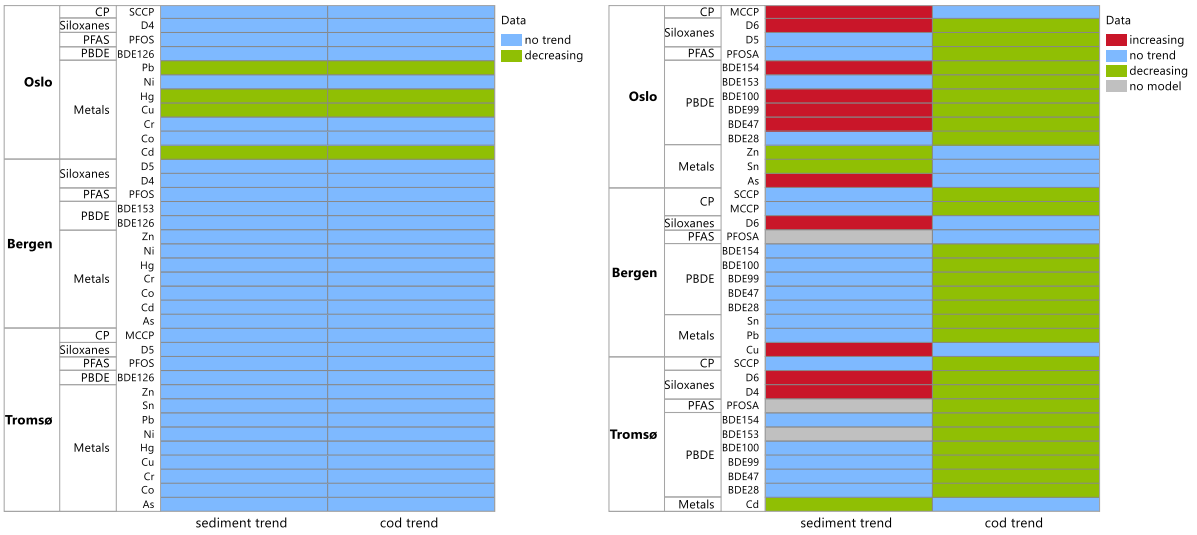


Figure 47. Comparison of sediment core time trends with cod time trends for *recent* time trends for cod. To the left, trends that were the same in cod and sediment. To the right, trends that were different in cod and sediment.

5.4 X-ray radiographic imaging (XRI)

The X-ray radiographic imaging (XRI) is used to examine the structure of sediment cores and can show layering and homogeneity, bioturbation, trawling impacts, compaction, shell, and coarse particles. See **Supplementary** data for XRI.

The three cores were very well suited for both chemical analyses and X-ray imaging, although they all showed signs of trawling activity and bioturbation on the surface. The bioturbation does not appear to have significantly displaced the chemical signals, and the age dating of the cores as well as the chemical results from the different sections seem therefore to be reliable.

The Inner Oslofjord

The sediments from the Inner Oslofjord were sampled at Steilene at 100 m water depth. The core shows that the sediments were totally bioturbated. This indicates oxygenated conditions and active benthic fauna over time. Almost all structures in the core consisted of burrows of various sizes and orientations; horizontal, oblique, and vertical. Two shells can be seen.

Bergen

The sediments from Bergen were sampled at Raunefjord at 244 m water depth. The core shows that the sediments were bioturbated with many burrows, but not as clear as in the Oslo core. Some intervals appeared to show more distinct burrow traces then others (darker intervals vs. lighter intervals). The darker intervals were totally bioturbated.

Tromsø

The sediments from Tromsø were sampled at Nordbotn at 44 m water depth. The core shows that the sediments were bioturbated. Several larger shells can be seen. The sediments were more homogeneous than both the Oslo and Bergen cores, with fewer distinct burrows. The presence of shells indicate that the sediments have been reworked by benthic biota. There are no primary sedimentary structures, which means that the original layering patterns and depositional structures formed during sedimentation have been completely destroyed or erased.

6 Alternative species to cod (Option 11)

There are valid arguments to consider finding alternatives to cod in the monitoring. At some locations it may be difficult to obtain sufficient material for analysis, and it may be advantageous to avoid sampling cod from an environmental point of view, because of the population size.

Challenges of comparing contaminants in different species include that the species may have different behaviour, they may occupy different trophic levels, or the fat content of their liver and muscle may differ, all of which may influence the contaminant concentrations in the tissues.

Comparison of contaminant level between species (cod, haddock, whiting and pollack) was done on wet weight (ww) basis and fat-normalized basis (**Table 10**, materials and methods section). Contaminants that accumulate in lipids were normalized to lipid weight basis in the sample while other data were compared on a ww basis. However, for siloxanes it was not possible to normalize to lipid weight basis, and samples were therefore compared on a ww basis (see chapter 7.1.8). Boxplot of two influential parameters for the accumulation of contaminants is shown in **Figure 48**. The results show that $\delta^{15}N$ is higher in cod than in whiting (*Merlangius merlangus*), haddock (*Melanogrammus aeglefinus*), and pollack (*Pollachius pollachius*), but the difference is not statistically different ($p>0.05$ see details chapter 6.2) and html of the Dunnet statistics. The fat content is lower in cod liver than in haddock, pollack and whiting, but not statistically significant ($p>0.05$).

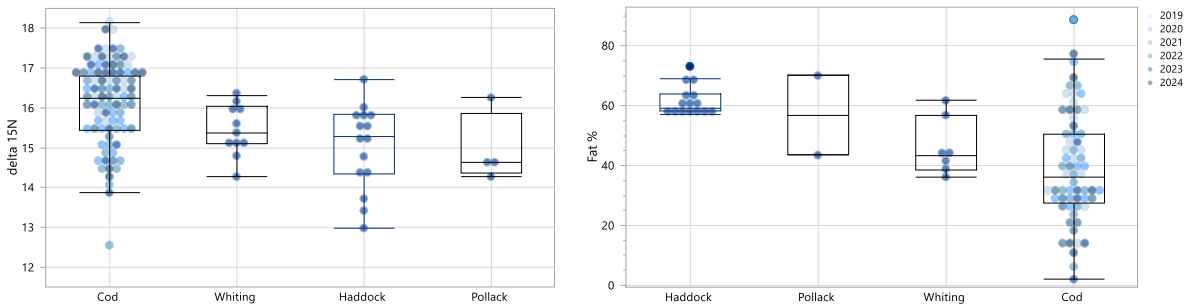


Figure 48. Boxplot of the delta 15N in muscle (left) and %fat in liver (right) of the species of fish caught in Inner Oslofjord (shown in decreasing order based on the median). The year the fish were caught are indicated with different colours.

6.1 Results from matched pairs statistics

Results from matched pairs statistics of haddock, whiting, and pollack compared to cod are shown in **Figure 49**. The data for difference between haddock and cod shows that on average, the concentrations in cod are higher (difference (haddock-cod) is negative). All points above zero indicate higher levels in haddock than cod, all points below zero indicate higher concentrations in cod. Both the mean difference and the confidence intervals are below zero, meaning that on average concentrations in haddock are lower than in cod ($p<0.0001$). The concentrations in haddock and cod were correlated (0.94) indicating that the data can be used if properly corrected for. However, we don't know how the levels of contaminants that were not determined in haddock were in comparison to cod.

The difference between pollack and cod was not statistically significant for the two-sided test ($p=0.056$), but the one-sided test (that cod is significantly higher than pollack) was significant ($p=0.028$). **Figure 49** shows that the upper confidence interval is very close to zero (0.0025). The correlation between pollack and cod was good (0.97).

The normalized contaminants (see chapter 7.1.8 for normalization procedure) in whiting were not statistically different from those in cod (p=0.27), and the correlation between the contaminants in the species were high (0.98). From **Figure 49** it can be seen that zero difference is between the confidence interval lines and that the mean difference (-0,042 on a log10 scale) is close to zero. However, also for whiting there are some contaminants that have different levels than in cod. Figures for each contaminant group labelled with abbreviations are shown in supporting information, **Figure S 17** - **Figure S 22**.

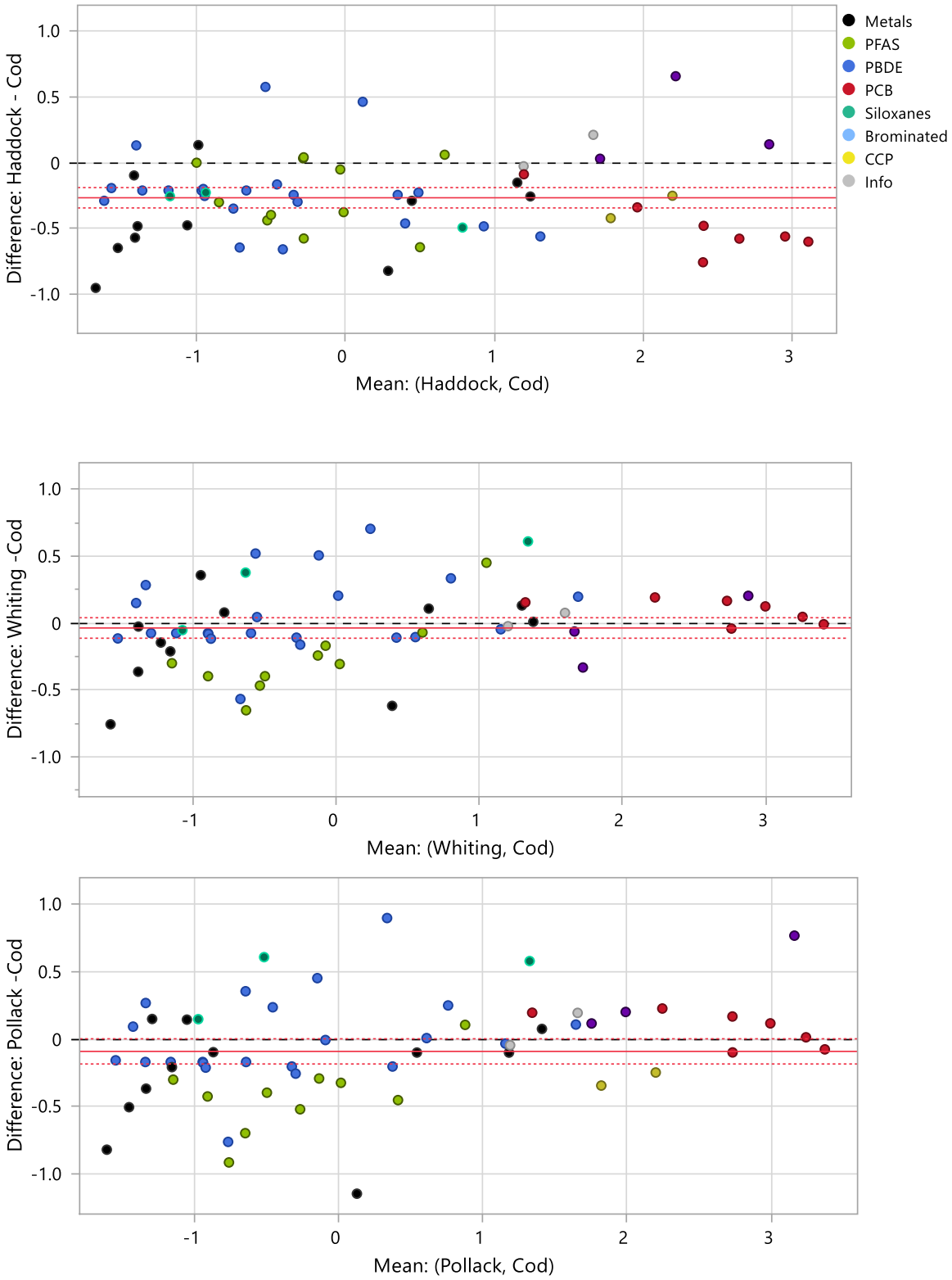


Figure 49. Matched pairs statistics of haddock and cod (upper figure), whiting and cod (middle), and pollack and cod (lower figure). All data from liver, except of Hg where muscle was used. Zero difference is indicated with a dotted black line. The mean difference is indicated with a red line and the 95% confidence interval is indicated with dotted red lines. Significant differences between species occur when zero is outside the confidence interval (CI). Groups of contaminants are indicated by colour.

The conclusion from these contaminants is that whiting seems to be the most appropriate species as an alternative to cod. However, as seen from **Figure 49**, there are some contaminants that have different levels in the two species. Whiting is common along the coast of Norway up to Stadt, but not equally common further north. It can be found, however, up to the South-Eastern Barents sea. As such, it may be challenging also to catch whiting at some locations. Both species are demersal but may also swim more pelagically. They both feed on fish and crustaceans, however the cod is considered more of a generalist. They may both live shallow and down to greater depths (whiting to ~200 m, and cod even deeper).

6.2 Results from Dunnet statistics

Dunnet statistics investigate contaminant levels in cod relative to the other species. The statistics do not investigate differences between other species, e.g. difference between whiting and haddock. We have chosen to present whether normalized concentrations in cod were higher or lower than in the three other species (see chapter 7.1.8 for normalization procedure). This is represented by the colours in **Figure 50**. The levels should ideally be balanced so that 50% of concentrations are higher and 50% is lower. Furthermore, this balance should also be by the contaminant group as well. We have also indicated which of the data shows statistically significant differences between the contaminants in the different species. However, since the number of samples for the species is different, it must be kept in mind that since the data were not balanced (see **Table 10** for number of analyses for each species), it is more difficult to find a statistical difference between cod and pollack than between cod and haddock (more haddock were sampled than pollack).

Looking only at the statistical differences presented in **Figure 50**, most differences were found between cod and haddock, and fewest between cod and pollack.

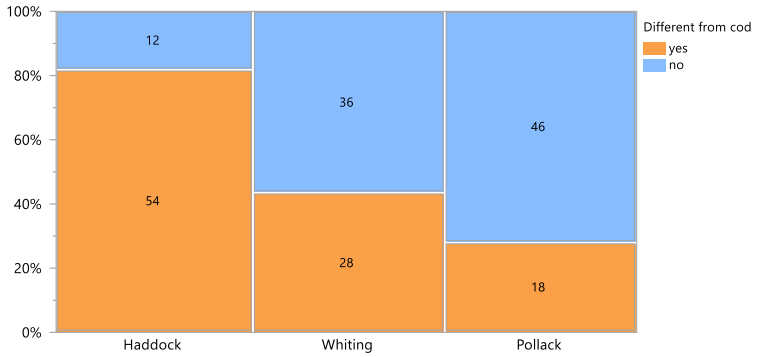


Figure 50. Number of statistical differenced in Dunnet statistics between cod and three other species. The numbers indicate the count of contaminants/information investigated for each species.

Because of the imbalanced number of samples from the different species we also have chosen to present the differences between species by the mean concentration (on log10 basis) versus cod and the statistical difference indicated. This is presented in **Figure 51**, where the mean concentration (on log10 basis) is compared to cod. The figure indicates whether the mean concentration is higher or lower than cod (colour). At the same time, the shaded area shows which of these concentrations that are statistically significant ($p<0.05$).

The results of the Dunnet statistics (both mean comparison and statistics) indicate that haddock is not a suitable species for comparison since the levels are more unbalanced than whiting and pollack. For all species there is an imbalance between groups of contaminants. For example, cod has higher PFAS mean concentrations for the majority of PFAS (on log10-scale) than all the other species. For PCBs, they have

lower concentrations in whiting and pollack, but higher concentrations in haddock. This is even though the PCB-concentrations have been normalized to the lipid content of the sample.

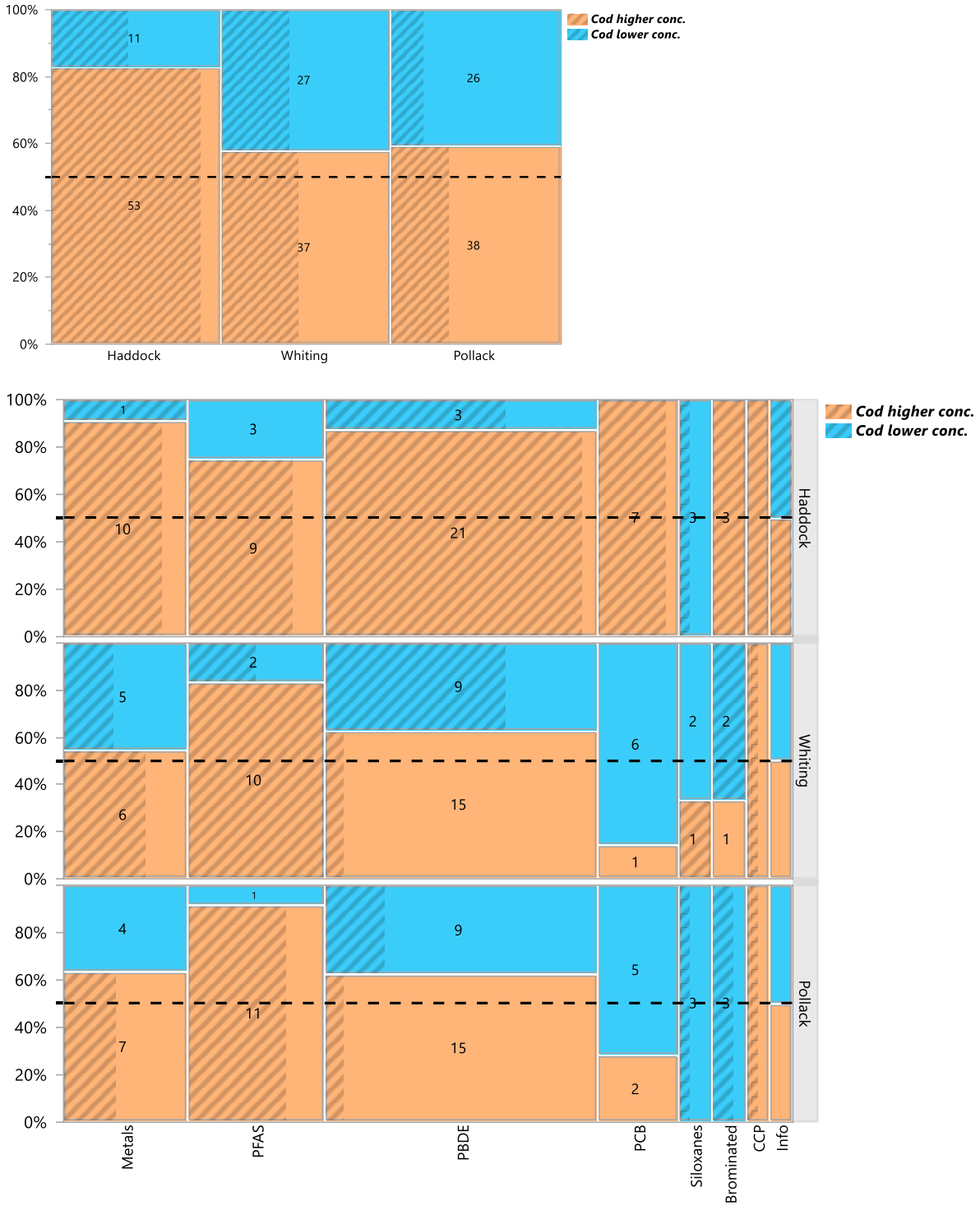


Figure 51. Results from the Dunnet statistics where levels of contaminants (and fat/delta N15) in three species were compared to levels in cod. The upper figure shows the total data for the three species, while the lower figure shows the groups of contaminants. Orange colour indicates that cod had higher mean (log10-transformed UB) concentrations than the other species, blue that cod had lower mean concentrations. Significant differences between species are indicated with a shaded area. 50% are indicated with a dotted black line.

7 Materials and methods appendix

Large parts of this chapter reuse text from our previous reports (Schøyen et al., 2022; Schøyen, Grung, Lund, Hjermann, Ruus, Øxnevad, Christensen, Beylich, Jenssen, Tveiten, Håvardstun, Eftevåg, et al., 2024; Schøyen, Grung, Lund, Hjermann, Ruus, Øxnevad, Christensen, Beylich, Jenssen, Tveiten, Håvardstun, Sagerup, et al., 2024).

7.1 Sampling and matrices

7.1.1. Stations

Samples for the investigation of contaminants were collected along the Norwegian coast, from the Swedish border in the south and to the Russian border in the north, as well as Svalbard (**Figure 1**). The sampling involved blue mussel at 24 stations, dogwhelk at eight stations, common periwinkle at one station, cod at 18 stations, and the common eider at one station (**Table 1**).

In addition in 2024, sediment cores were sampled from three areas; Oslo, Bergen, and Tromsø (Option 3), and alternative species to cod (whiting, pollack, and haddock) in the Inner Oslofjord (Option 11).

Samples were collected during 2024 and analysed according to OSPAR guidelines (OSPAR, 2021)[5] where these could be applied. The data was screened and submitted to ICES by agreed procedures (ICES, 1996) as well as to the national database Vannmiljø. Blue mussel (*Mytilus edulis*), dogwhelk (*Nucella lapillus*), common periwinkle (*Littorina littorea*), and Atlantic cod (*Gadus morhua*) are the target species selected for MILKYS to indicate the degree of contamination in the sea. Blue mussel is attached to shallow-water surfaces, thus reflecting exposure at a fixed point (local pollution). Mussels and snails are usually abundant, robust, and widely monitored in a comparable way. The species are, however, restricted to the shallow waters of the shoreline. Cod is widely distributed and commercially important fish species. It is a predator and, as such, will for hydrophobic compounds mainly reflect contamination levels in their prey. Recently, however, it has become increasingly difficult to catch sufficient numbers of adequate size of both blue mussel and cod. The 2024 programme also included investigation of contaminants in the common eider (*Somateria mollissima*).

Some details on methods applied in previous years of monitoring are provided in earlier reports (N. W. Green et al., 2008; Schøyen, Grung, Lund, Hjermann, Ruus, Øxnevad, Christensen, Beylich, Jenssen, Tveiten, Håvardstun, Sagerup, et al., 2024; Schøyen, Lund, et al., 2024).

Sample material is also collected for other projects at some of the stations, such as blue mussels for the Monitoring of microplastics in the Norwegian environment (MIKRONOR)[6] and cod for The Environmental Specimen Bank[7] (ESB Norway, Miljøprøvebanken).

7.1.2. Blue mussel

Blue mussel has been proven as a promising indicator organism for contaminants (Beyer et al., 2017). In general, blue mussel is widely used for monitoring in controlled field studies (Schøyen et al., 2017).

A sufficient number of individuals for three pooled samples of blue mussel were found at nearly all the 24 stations (**Table 1**, **Figure 52**). The stations were chosen to represent either highly polluted areas or reference stations distributed along the Norwegian coast. It has been shown that the collected

[5] *See also* http://www.ospar.org/work-areas/hasec

[6] Mikroplast i kystområder, elver og innsjøer (Mikronor) - miljodirektoratet.no

[7] The Environmental Specimen Bank « Miljøprøvebanken

individuals are not all necessarily *Mytilus edulis* (Brooks & Farmen, 2013), but may be other Mytilus species (*M. trossulus* and *M. galloprovincialis*). Possible differences in contaminant uptake between *Mytilus* species were assumed to be small and they were not taken into account in the interpretations of the results for this investigation.

Figure 52. Blue mussel (photo: Janne Gitmark, NIVA, right) and blue mussel sampling at st. I301 Akershuskaia in the Oslo harbour area (photo: Marijana Stenrud Brkljacic, NIVA, centre and left).

The blue mussel samples were collected from 22th August to 15th December 2024. This is within the OSPAR guidelines and considered to be outside the mainly mussel spawning season.

Generally, blue mussel was not abundant on the exposed coastline from Lista (southern Norway) to the north of Norway. The mussel was more abundant in more protected areas and were collected from dock areas, buoys, or anchor lines. All blue mussels were collected by NIVA, except for some blue mussel stations collected by local contacts.

The method for collecting and preparing blue mussel was based on the National Standard for mussel collection (Norwegian Standard, 2017). Three pooled samples of approximately 50 individuals (size range of 3-5 cm) were collected at each station and kept frozen until later treatment. Shell length was measured by slide callipers. The blue mussel was scraped clean on the outside by using knives or scalpels before taking out the tissue for the analysis. Mussel samples were frozen (-20°C) for later analyses.

7.1.3. Dogwhelk and common periwinkle

Concentrations and effects of organotin on dogwhelk were investigated at eight stations and one station for common periwinkle (**Table 1**, **Figure 53**). TBT-induced development of irreversible male sex-characters in female dogwhelk, known as imposex, was quantified by the Vas Deferens Sequence Index (VDSI) analysed according to OSPAR-CEMP guidelines. The VDSI ranges from zero (no effect) to six (maximum imposex effect) (Gibbs et al., 1987). Detailed information about the chemical analyses of the animals is previously described (Følsvik et al., 1999).

Figure 53. Dogwhelk (photos: Lise Tveiten, left, and Jarle Håvardstun, NIVA, centre) and common periwinkle (photo: Lise Tveiten, NIVA, right).

Dogwhelk lives on wave-exposed hard bottom areas in the tidal zone. Effects (imposex, (Gibbs, 1999)) and concentrations of organotin in dogwhelk were investigated using 50 individuals from each station. Individuals were kept alive in a refrigerator (at +4°C) until possible effects (imposex) were quantified, and about 25 females were analysed. The snail samples were collected from 3rd September to 23th October 2024.

TBT-induced development of male sex-characters in female common periwinkle, known as intersex, was quantified by the intersex stage index (ISI) analysed according to guidelines (Bauer et al., 1995). The ISI ranges from zero (no effect) to four (maximum intersex effect).

7.1.4. Atlantic cod

Atlantic cod was caught from 18 stations (**Table 1**, **Figure 54**). The goal was to get a minimum of 15 cod from each station, but for some stations that was not possible. The cod was sampled from 15th August to 1st December 2024, except for cod collected until 10th February 2025 in Bergen (24B). Cod was caught by Akvaplan-niva and local fishermen, except for the cod in the Inner Oslofjord (30B) which was collected by NIVA by trawling from the research vessel F/F Trygve Braarud owned and operated by the University of Oslo (UiO) (**Figure 54**). Instructions were given to the fishermen to catch coastal cod. Coastal cod is more attached to one place than open ocean cod which migrate considerably farther than coastal cod. Some spot checks were taken looking at the cross-section pattern of the otoliths. The otoliths are stored for further verification if necessary (Stransky et al., 2008). Tissue samples from each fish were prepared in the field and stored frozen (-20 °C) until analysis or the fish was frozen directly and prepared later at NIVA.

Figure 54. Trawling for cod in the Inner Oslofjord (30B). The cod population in the Oslofjord has been at a historically low level the recent years. NIVA has permission from the Norwegian Directorate of Fisheries to trawl for cod for research (photos: Merete Schøyen, NIVA, left and centre and Marthe T. S. Jenssen, NIVA, right).

The general lack of material was partially compensated for by making pooled samples of livers. The concerns using pooled samples or small sample size in cod are discussed in an earlier report (N. W. Green et al., 2015).

The age of the fish was determined by noting the number opaque and hyaline zones in otoliths (Vitale et al., 2019). These results, along with results from some other parameters (e.g., liver weight) are publicly available but not necessarily used for this report.

7.1.5. Common eider

Contaminants in the common eider were investigated at one station in the Kongsfjord at Svalbard (19N), which the present study is considered as a reference station (**Table 1**, **Figure 55**). Blood samples were collected from 15 individuals (two subsamples from each) and eggs from 15 other individual's 6th-10th June 2024. All samples are from adult nesting females. Starting in 2022, samples of blood were taken from an adult female from the nest for which eggs were sampled. Thus, a maternal relationship is expected between the egg and the female from which the blood was sampled. This relationship is not expected for eggs and blood sampled prior to 2022.

Figure 55. Common eider at Svalbard (photos: Kjetil Sagerup, NINA, top left and bottom left Oddgeir Sagerup).

7.1.6. Flat fish

Flatfish (*Platichthys flesus*) was sampled at Sande (33F). The samples from 2021 (sampled 15Th September to 20th October), 2022 (sampled 19th August to 23th October), 2023 (sampled 3rd to 10th October), and 2024 (sampled 17th September to 15th October) are recently analysed, but the results are not included in this report.

7.1.7. Sediments, Option 3

The fieldwork for sediment core sampling was conducted in the Inner Oslofjord (25.06.2024), the Bergen area (19.06.2024), and the Tromsø area (11.06.2024) (**Table 8)**. A Gemini corer was used for core

sampling. Separate sediment cores were collected for chemical analyses (**Table 9**), dating, X-ray imaging (XRI) and microplastic analyses from each of the three areas. The cores for chemical analyses were sliced into 2 cm sections from the upper 0–14 cm sediment length. This resulted in seven samples from each core for chemical analyses, and by comparing these with the dating of the various sections, a historical development of the analysed compounds was demonstrated for each site. The cores for microplastic analyses were in addition to the seven samples from 0-14 cm, analysed on a 0-2 cm section from the bottom of each core, so a total of eight samples were analysed for microplastic.

Table 8. Sediment stations close to Oslo, Bergen, and Tromsø.

Area	Station number	Database name	Station name	Coordinates		Water depth (m)	Total core length (cm)
Oslo	30S2	Steilene2	Inner Oslofjord-Steilene	59.819051˚	10.567270˚	100	48
Bergen	24S2	Bergen-Raunefjord	Bergen-Raunefjord	60.273867˚	5.144783˚	244	35
Tromsø	42S2	Tromsø-Nordbotn	Tromsø-Nordbotn	69.675650˚	18.801383˚	44	26

Table 9. Contaminants determined in sediment samples from Oslo, Bergen, and Tromsø.

Group	Parameters
Sample Info	<63 µm, TOC (total organic carbon), DW (dry weight)
Metals	As, Cd, Cr, Pb, Hg, Co, Cu, Ni, Sn, Zn
PBDE	sumBDE6, BDE28, BDE47, BDE99, BDE100, BDE153, BDE154, BDE17, BDE49, BDE66, BDE71, BDE77, BDE85, BDE119, BDE126, BDE138, BDE156, BDE183, BDE184, BDE191, BDE196, BDE197, BDE202, BDE206, BDE207, BDE209
Other brominated	ATE (TBP-AE), BATE, BTBPE, DBDPE, DPTE, EHTBB, HBB, PBBZ, PBEB, PBT, TBA, TBPH (BEH /TBP), TXP, aTBECH, bTBECH, γ/δ-TBECH
PFAS	EOF, TFA, PFPrA, PFBA, PFPA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnDA, PFDoDA, PFTrDA, PFTeDA, PFHxDA, PFOcDA, PMeS, PFEtS, PFPrS, PFBS, PFPS, PFHxS, PFHpS, PFOS, brPFOS, PFNS, PFDS, PFUnDS, PFDoDS, PFTrDS, PFTeDS, PFBSA, N-MeFBSA, N-EtFBSA, PFOSA, N-MeFOSA, N-EtFOSA, N-MeFOSE, N-EtFOSE, N-EtFOSAA, 4:2 FTS, 6:2 FTS, 8:2 FTS, 10:2 FTS, 12:2 FTS, ADONA, PFECHS, HFPO-DA (Gen-X)
Quaternary ammonium compounds	ATAC-C8, ATAC-C10, ATAC-C12, ATAC-C14, ATAC-C16, ATAC-C18, ATAC-C20, ATAC-C22, DADMAC-C8, DADMAC-C10, DADMAC-C12, DADMAC-C14, DADMAC-C16, DADMAC-C18, BAC-C8, BAC-C10, BAC-C12, BAC-C14, BAC-C16, BAC-C18
Siloxanes	D4, D5, D6
Chlorinated paraffins	SCCP, MCCP, LCCP

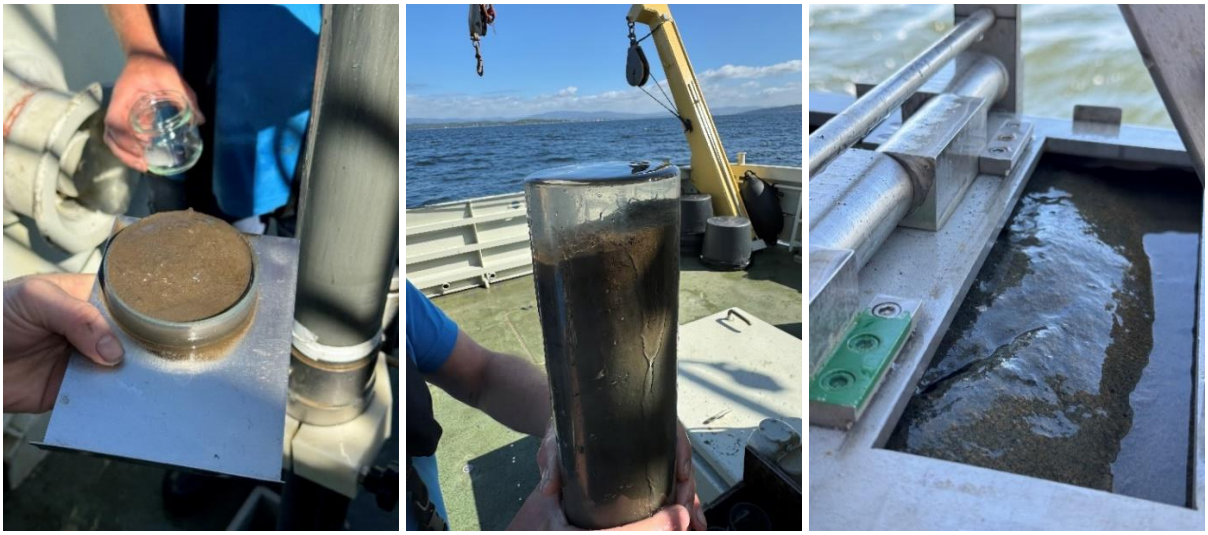


Figure 56. Sediment sampling in the Inner Oslofjord (30S2) (photos: Merete Schøyen, NIVA).

Figure 57. Sediment sampling in Bergen-Raunefjord (24S2) (photos: Jarle Håvardstun, NIVA).

Figure 58. Sediment sampling in Tromsø-Nordbotn (42S2) (photos: Jarle Håvardstun, NIVA).

The results for microplastics in the sediments from the same stations have been reported for Monitoring of microplastics in the Norwegian environment (MIKRONOR) (Alling et al., 2025).

X-ray radiographic imaging (XRI)

X-ray radiographic imaging (XRI) of sediment cores is a non-destructive method applied to whole sediment cores in order to visualize and interpret structures and layering in the cores. It provides a detailed image of density differences within the sediments, which can reveal anything from bioturbation (mixing of sediments by organisms) to volcanic ash layers or ice-rafted debris. The image can show layering and variations in the sediments, presence of shell, stones, or other objects, and change in density, that may indicate environmental shifts over time. See XRI from the Inner Oslofjord, Bergen, and Tromsø in **Supplementary data**.

MAREANO (Marine area database for Norwegian waters) also uses XRI to analyse sediment cores from several regions along the Norwegian coast and offshore areas (Jensen et al., 2024).

7.1.8. Alternative species to cod, Option 11

Option 11 involved testing whether fish species other than cod may be suitable for monitoring environmental contaminants. This is highly relevant since the cod population has declined, especially in the Oslofjord. Contaminants were determined in pollack (4 fish), haddock (15 fish), and whiting (11 fish) from the Inner Oslofjord (30B) caught as bycatch when trawling for cod at R/V Trygve Braarud (UiO) 12th November 2024. The number of fish liver samples was fewer, a total of 2, 15, and 7 samples respectively. The samples were analysed for metals, PFAS, PBDE, brominated pesticides, CPs, and siloxanes **(Table 10)**. Cod analyses during the last five years was included to make statistics stronger and less dependent on the few fish sampled in 2024. The samples of cod each year were 14, 12, 15, 11, 8, and 4 for the years 2019-2024. For analytes determined in muscle tissues (e.g. mercury, isotopes), the number of samples was 15 every year. Quantifications of siloxanes were also more numerous.

Table 10. Overview of analytes determined for comparison of species and number of samples. Depending on the properties of the group of contaminants, the comparison of contaminants was done on a wet weight (ww) basis (for water soluble compounds) or on fat normalised basis (FB, fat soluble compounds). Information about the basis used for comparison is given in the table below, which also include the number of samples.

Group	Basis	Parameters	Number of samples			
			Cod	Haddock	Pollack	Whiting
Info	WW	lipid%	64	15	2	7
		Delta 15N	90	15	4	11
Metals	WW	Ag, As, Cd, Co, Cr, Cu, Ni, Pb, Pb, Zn	62	15	2	7
		Hg	90	15	4	11
PFAS	WW	PFOA, PFOS, PFOSA, PFBS, PFDA, PFDS, PFHpA, PFHxA, PFHxS, PFNS, PFTrDA, PFUnDA	55	15	2	7
PBDE	FB	BDE17, BDE28, BDE47, BDE49, BDE66, BDE71, BDE77, BDE85, BDE99, BDE100, BDE119, BDE126, BDE138, BDE153, BDE154, BDE156, BDE183, BDE184, BDE191, BDE196, BDE197, BDE206, BDE207, BDE209	63	15	2	7
PCB	FB	CB28, CB52, CB101, CB118, CB138, CB153, CB180	64	15	2	7
CP	FB	MCCP, SCCP	61	15	2	7
Brominated	FB	HBCDA, HBCDB, HBCDG	64	15	2	7
Siloxanes	WW*	D4, D5, D6	89	15	4	11

* Siloxanes were determined in liver samples prior to making samples for other analyses (liver from a small fish is not sufficient material for analysing all contaminants). Therefore, the siloxane concentrations were not determined in the same sample as the lipid content (see difference in numbers of samples of the two analyses). Therefore, it was not possible to normalise the siloxane concentrations to the lipid percentage as we would have done if possible.

Matched pairs statistic (also called Bland-Altman analysis) was used to compare concentrations in the different species. The method was developed to test whether two different methods can be used for measuring clinical data in medicine (e.g. oxygen saturation in blood) (Bland & Altman, 1986; Tim, 2016). However, the method can also be more widely used since the analysis answers two questions; do the

methods agree, and can they be used interchangeably. Instead of just comparing the average values from the two methods, Bland-Altman looks at how much they differ for each measurement. For these statistics, we used the median concentration of each contaminant for each species. The comparison is done in different steps:

- Take each pair of measurements (one from each species).
- Calculate the average of the two values.
- Calculate the difference between the two values.
- Plot the difference against the average.

The resulting plot has a middle line indicating the *average difference* (called the bias). If it's close to zero, the two methods are similar on average. The top and bottom lines show the limits of agreement with a 95% confidence interval of the differences. This tells you how much the two methods might differ in practice. The plot's usefulness lies in its ability to help you see:

- if one species consistently gives higher or lower concentrations
- shows whether the difference between species changes depending on the size of the measurement (e.g. when concentrations increase)
- if the species are close enough to be used interchangeably

The drawback of the matched pairs statistics is that the variability of contaminants within each species is not taken into account in the statistics. Only the median results are compared.

In addition, more traditional statistics were used, the Dunnet test. The Dunnett test is a statistical test that answers if the species have significantly higher (or lower) contaminant levels compared to cod. However, the test will not give differences between other species (haddock vs. whiting) for example. The drawback of the Dunnet test vs. the matched pairs test is that the Dunnet test is repeated for each contaminant, running into the chance of false positives. In addition, since the number of data for each species was not balanced (**Table 10**), it is easier to detect a statistical difference between cod and haddock (15 samples) than whiting and pollack. Differences between cod and pollack are especially difficult to determine due to the few samples of pollack (2 or 4 depending on matrix analysed). The samples were considered statistically difference at $p<0.05$.

7.1.9. Storage of samples

Samples that have not been analysed are kept in an external freezer for long-term storage together with residual samples.

7.2 Analytical procedures and information on quality assurance

The laboratories (NIVA, subcontractors EF, and NILU) have participated in the Quality Assurance of Information for Marine Environmental Monitoring in Europe (QUASIMEME), International Food Analysis Proficiency Testing Services (FAPAS, BIPEA), international intercalibration exercises (EURL, JRC), and other proficiency testing relevant to chemical and imposex analyses. The results are acceptable. The quality assurance programme is similar to previous years.

NIVA participated in the QUASIMEME Laboratory Performance Studies “imposex and intersex in Marine Snails BE1” in 2021. Females with imposex, penis-length-male, penis-length-female, average-shell-height, female-male-ratio, and VDSI were measured in two tests containing 40 samples. NIVA got the score satisfactory for all parameters except females with imposex, penis-length-female and VDSI in one test, which got the score questionable. This was due to lack of imposex-females in one of the tests.

In addition to the QUASIMEME exercises, certified reference materials (CRM) and in-house reference materials are analysed routinely with the MILKYS samples. It should be noted that for biota, the type of tissues used in the CRMs does not always match the target tissue for analysis. The Standard Reference Material (SRM) was ZRM 81 in mussel tissue. The in-house reference materials were apple juice, spiked fish oil, spiked fish meal, and spiked fish liver.

The results are also quality checked before import to the database at NIVA, and reported to Vannmiljø, OSPAR/ICES using an interactive tool. In this tool, the new results are plotted together with the time series of the same contaminant from the previous years, making it easier to pick out suspicious values. In addition, there is an automatic check of new values by comparison with previous year's values, so that stations/substances with values or LOQs that differ greatly from previous years are automatically highlighted.

The laboratories used for the chemical testing are accredited according to ISO 17025 [8].

Summary of quality control results

Standard Reference Materials (SRM) as well as in-house reference materials were analysed regularly (**Table 11**). In-house references (fish oil, liver, and fillet) were used for PCB, BDE, PAH, and PFAS; apple juice for metals; and ZRM 81 (mussel tissue) as SRM for organotin compounds.

[8] *ISO/IEC 17025. General requirements for the competence of testing and calibration laboratories*

Table 11. Summary of the quality control of results for the 2024 biota samples analysed in 2024-2025. The SRM, in-house reference materials and quality assurance standards were analysed in series with the MILKYS samples and measured several times (N) over several weeks (W). The values are reported in the following units (in ww): metals (µg/kg), BDEs (pg/g), PCBs (ng/kg), DDTs (ng/kg), SCCPs and MCCPs (ng/sample), HBCDDs (ng/g), PAH (ng/kg), tin organic compounds (mg/kg) and PFAS (% recovery).Tissue types were: mussel soft body, snail (SB), fish liver (LI), and fish fillet (MU).

Code	Contaminant	Tissue type	SRM type	SRM value confidence interval	N	W	Mean value	Standard deviation
As	Arsenic	SB/LI	Apple juice	109 ± 22	45	8	108	9,8
Cd	Cadmium	SB/LI	Apple juice	95 ± 29	45	8	94	5,4
Cr	Chromium	SB/LI	Apple juice	103 ± 30	45	8	107	8,0
Cu	Copper	SB/LI	Apple juice	4796 ± 1439	45	8	4716	259
Hg	Mercury	SB/MU	Apple juice	18.4 ± 4.8	45	8	17	1,1
Ni	Nickel	SB/LI	Apple juice	112 ± 34	45	8	108	11
Pb	Lead	SB/LI	Apple juice	95 ± 20	45	12	98	6,2
Zn	Zinc	SB/LI	Apple juice	5163 ± 1549	45	8	5160	299
Sn	Tin	-	-	-	-	-		-
BDE28	2,2,4' Tribromodiphenylether	SB	Internal RM (fish oil)	43 ± 13	66	15	43	6,3
BDE47	2,2,4,4',- Tetrabromodiphenylether	SB	Internal RM (fish oil)	832 ± 249	66	15	832	105
BDE100	2,2',4,4',6- Pentabromodiphenylether	SB	Internal RM (fish oil)	1513 ± 454	66	15	1513	107
BDE99	2,2',4,4',5- Pentabromodiphenylether	SB	Internal RM (fish oil)	771 ± 231	66	15	771	54
BDE154	2,2',4,4',5,6'- Hexabromodiphenylether	SB	Internal RM (fish oil)	197 ± 59	66	15	197	31
BDE153	2,2',4,4'5,5'- Hexabromodiphenylether	SB	Internal RM (fish oil)	46 ± 13	66	15	46	8,3
BDE49	2,2',4,5'- tetrabromodiphenyleter	SB	Internal RM (fish oil)	336 ± 100	66	15	336	47
BDE66	2,3',4,4'- Tetrabromodiphenyleter	-	Internal RM (fish oil	29 ± 11	66	15	37	6,2
CB52	PCB congener CB52	SB/LI	Internal RM (fish)	144 ± 43	34	23	139	7,2
CB28	PCB congener CB28	SB/LI	Internal RM (fish)	49 ± 15	34	23	46	9,2
CB180	PCB congener CB180	SB/LI	Internal RM (fish)	308 ± 92	34	23	305	30
CB153	PCB congener CB153	SB/LI	Internal RM (fish)	1180 ± 354	34	23	1171	110
CB138	PCB congener CB138	SB/LI	Internal RM (fish)	786 ± 236	34	23	777	75
CB118	PCB congener CB118	SB/LI	Internal RM (fish)	379 ± 114	34	23	377	23
CB101	PCB congener CB101	SB/LI	Internal RM (fish)	379 ± 114	34	23	380	30
DDEPP	p,p'-DDE	SB/LI	Internal RM (feed)	2,5 ± 0,75	14	4	2,5	0,33
TDEPP	p,p'-DDD	SB/LI	Internal RM (feed)	0,456 ± 0.137	14	4	0,46	0.07
DDTPP	p,p'-DDT	SB/LI	Internal RM (feed)	0,27 ± 0.08	14	4	0,27	0.03
SCCP	Short-chain chlorinated Paraffins (C10-C13)	SB/LI	Internal RM (spiked fish)	10000 (spike)	21	34	10448	845
MCCP	Medium-chain chlorinated Paraffins (C14-C17)	SB/LI	Internal RM (spiked fish)	10000 (spike)	21	34	11238	1030
α-HBCDD	α-Hexabromocyclododecane	SB	Internal RM (fish oil)	0,619 ± 0,0387	27	15	0,62	0,039
β-HBCDD	β-Hexabromocyclododecane	SB	Internal RM (fish oil)	0,0133 ± 0,00219	27	15	0,01	0,002
γ-HBCDD	γ-Hexabromocyclododecane	SB	Internal RM (fish oil)	0,0324 ± 0,00464	27	15	0,03	0,005
BGHIP	Benzo[ghi]perylene	SB	Internal RM (fish oil)	46 ± 23	17	15	40	4.8
ICDP	Indeno[1,2,3-cd]pyrene	SB	Internal RM (fish)	53 ± 64	17	15	33	0.9
BBJF	Benzo[b+j]fluoranthene	SB	Internal RM (fish)	93 ± 65	17	15	79	13

Code	Contaminant	Tissue type	SRM type	SRM value confidence interval	N	W	Mean value	Standard deviation
DBA3A	Dibenzo[ac,ah]anthracene	-	Internal RM (fish)	61 ± 38	17	15	61	24
BKF	Benzo[k]fluoranthene	SB	Internal RM (fish)	54 ± 50	17	15	48	12
ACNLE	Acenaphthylene	SB	Internal RM (fish)	38 ± 11	17	15	29	4.7
ANT	Anthracene	SB	Internal RM (fish)	49 ± 26	17	15	34	3.3
BAA	Benzo[a]anthracene	SB	Internal RM (fish)	49 ± 15	17	15	50	13
BAP	Benzo[a]pyrene	SB	Internal RM (fish)	42 ± 23	17	15	40	14
CHR	Chrysene	SB	Internal RM (fish)	49 ± 23	17	15	48	6.3
FLU	Fluoranthene	SB	Internal RM (fish)	42 ± 13	17	15	42	3.1
FLE	Fluorene	SB	Internal RM (fish)	58 ± 38	17	15	53	14
NAP	Naphthalene	SB	Internal RM (fish)	61 ±32	17	15	34	6.6
PA	Phenanthrene	SB	Internal RM (fish)	47 ± 21	17	15	44	6.2
PYR	Pyrene	SB	Internal RM (fish)	42 ± 12	17	15	41	5.2
ACNE	Acenaphthene	SB	Internal RM (fish)	41 ± 14	17	15	31	2.1
MBT	Monobutyltin (MBT)	SB	ZRM 81 (mussel)	2,03 ± 0.61	1	1	2,1	-
DBT	Dibutyltin (DBT)	SB	ZRM 81 (mussel)	1,27 ± 0,38	1	1	1.3	-
TBT	Tributyltin (TBT)	SB	ZRM 81 (mussel)	2.1 ± 0.12	1	1	1.6	-
TPhT	Triphenyltin (TPhT)	SB	ZRM 81 (mussel)	1,4 ± 0.42	1	1	1,2	-
PFHxA	Perfluorohexane acid	LI	In-house spiked liver	100 %[1)]	9	20	87	9,1 %
PFHpA	Perfluoroheptane acid	LI	In-house spiked liver	100 %[1)]	9	20	90	7,8 %
PFOA	Perfluorooctane acid	LI	In-house spiked liver	100 %[1)]	9	20	91	4,6 %
PFNA	Perfluorononane acid	LI	In-house spiked liver	100 %[1)]	9	20	92	9,7 %
PFOS	Perfluorooctane sulphonate	LI	In-house spiked liver	100 %[1)]	9	20	97	8,4 %
PFOSA	Perfluorooctane sulphone amide	LI	In-house spiked liver	100 %[1)]	9	20	99	4,7 %
PFHxS	Perfluorohexane sulphonate	LI	In-house spiked liver	100 %[1)]	9	20	86	4,3 %
PFDA	Perfluorodecanoic acid	LI	In-house spiked liver	100 %[1)]	9	20	94	6,8 %
PFUDA	Perfluoroundecanoic acid	LI	In-house spiked liver	100 %[1)]	9	20	97	8,0 %
PFTrDA	Perfluorotridecanoic acid	LI	In-house spiked liver	100 %[1)]	9	20	95	14 %
PFDS	Perfluorodecanesulphonate	LI	In-house spiked liver	100 %[1)]	9	20	78	5,5 %

1) Recovery of spiked control sample.

Subcontractor NILU has analysed fish liver from Atlantic cod (*Gadus morhua*) in this programme (siloxanes) and egg and blood samples from eider. The laboratory has participated in Quality Assurance of Information for Marine Environmental Monitoring in Europe (QUASIMEME, 2024) and Food Analysis Proficiency Testing Services (FOOD 2024) for the testing of PCBs. The Standard Reference Materials (SRM) in these tests were EDF-2525 in blue mussel, fish liver and fish fillet. For the quality assurance of chlorinated paraffines the reference material was certified through the European Commission Joint Research Centre (JRC, 2022).

A priority list of chemical analysis (**Table 12**) has been prepared by NEA, indicating which analyses should be prioritized if there is insufficient sample material to perform all analyses.

Table 12. Priority list of chemical analysis.

Priority	Parameters
1	Siloxanes
2	PCB
3	DDT
4	Lipid%
5	Metals
6	Dry content
7	SCCP/MCCP
8	PFAS
9	PAH
10	PBDE
11	HBCD

7.3 QA/QC

Additional to the general quality assurance (QA) done by the individual laboratories, all the results from EF, NILU, and NIVA are transferred into NIVAs laboratory information management system (LIMS). An extra quality control is then performed by trained NIVA personnel. In this quality assurance, trends and variations within the different stations are also considered. NIVA has developed an app in R (R Statistical Software **7.7**) to make this control easier and more efficient. Here trends from the last years will appear and deviating results are marked (example in **Figure 60**). A manual assessment is then performed before the results are validated and reported to the project manager and automatically imported into NIVAs database for further treatment. When the results are questionable, a deviation is registered to NIVAs internal control system, and a complaint are reported to the relevant laboratory.

For the 2024 data, it was a deviation for siloxanes levels in three different cod liver stations: Kristiansand (13B), Bømlo (23B) and Bergen (24B). The deviation was reported duo to low levels in general and compared with earlier years. The lab did an extra check, and it was not found any mistakes in the analysis or calculations. Data for the three stations are shown in (**Figure 59**). For station Bergen (24B) there was a decreasing time trend which probably explains the lower concentrations observed in 2024. For the two other stations, there is not enough data yet for a time trend to be assigned. But the lower concentrations may well be the start of a downward trend. Where trends could be detected for D5, downward trends were more frequent than no trend (**Figure 18**).

For three blue mussel stations: Bergen (I241), Ålesund (28A2), and Svolvær (98A2), the lipid content was a bit high. Unfortunately, there were not sample material left for reanalysis. For Bergen, the results have been deleted, but for the two other stations the results are reported. Measures have been taken in the lab to avoid this to happen again.

Also, some PCB results for station Langesundfjord (71B), and one cobalt result for station Tromsø harbour (43B2) where higher than expected. Due to lack for sample material for reanalysis, the results were kept, but a deviation were made and information given to carefully consider the results when trend analysis were done.

Two deviations were also made due to suspected high levels of chromium and nickel in a total of five blue mussel samples. No reanalysis was performed as the suspected reason was most probably due to contamination of the sample during sample preparation. The results have been removed from the dataset. All eider egg samples were also contaminated during homogenisation at a subcontractor for the metal's chromium, nickel and cobalt, and are therefore also not reported.

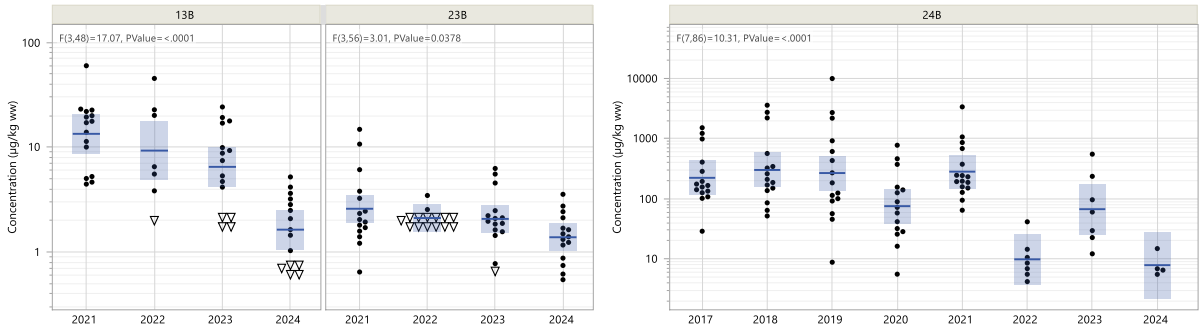


Figure 59. Siloxane concentrations at the stations were the QA/QC indicated lower concentrations found in 2024. Individual concentrations (on a log10 scale) for each sample are shown, as well as mean and confidence interval (blue line and shaded blue area respectively). Data below LOQ are indicated with a triangle at LOQ. The ANOVA test is shown in the upper left corner.

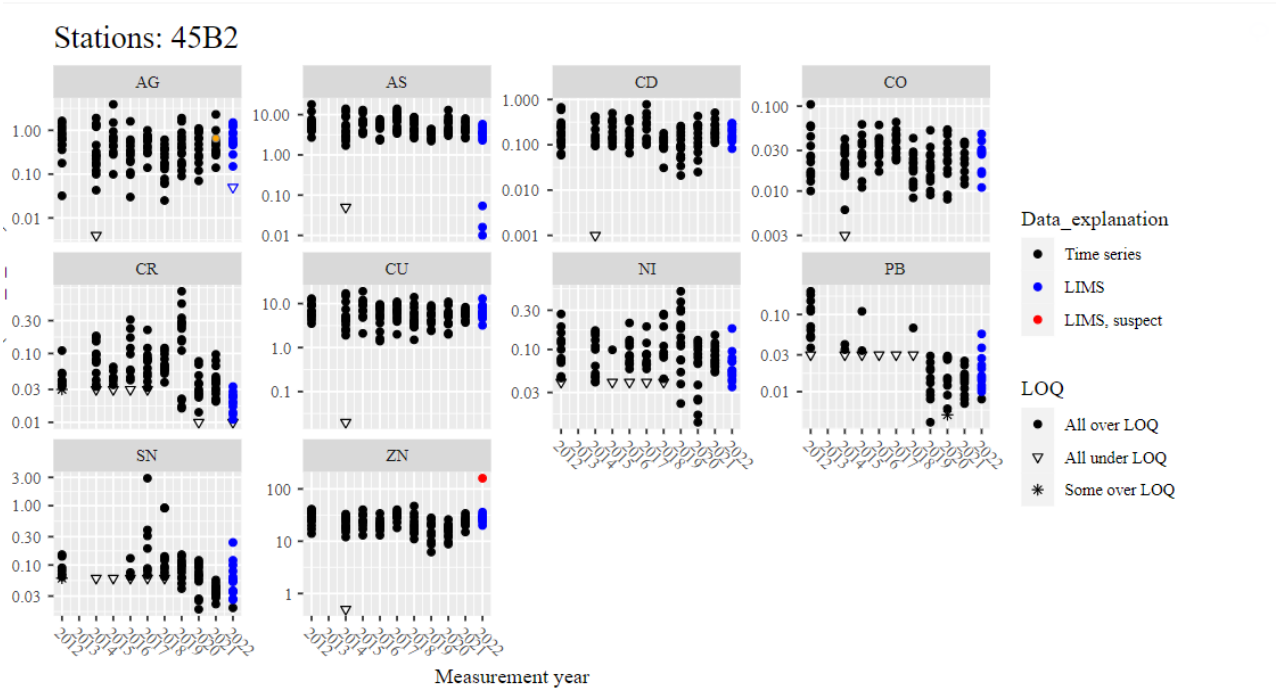


Figure 60. Screenshot of QA app used for manual assessment of chemical concentrations every year. The screenshot shows the results for a single station and for one substance group. The concentrations to perform QA on (last year's results, red, and blue dots) are shown together with previous year's results (black dots) to facilitate the identification of suspect data. In addition, the app aids manual QA by automatically "flagging" possibly suspect data (red dots, zinc) following a set of rules, comparing using both this year's data as well as previous year's data. The person performing the QA can then decide whether the flagged results should be treated as a deviation and a complaint should be sent to the relevant laboratory.

7.4 Detection frequencies of contaminants and history of limit of quantification (LOQ)

Since the start of this programme, there have been changes in laboratories and methods. In the program period from 2012, the analytical provider was changed from NIVA to Eurofins (EF) Moss. However, the methods were mainly the same, and only minor changes of the limit of quantification (LOQ) occurred. From 2017, the organic pollutants were analysed at EF GFA, leading to discrepancies in both methods employed and LOQs. For PCBs, the LOQs increased somewhat (except CB118 which was lowered), and LOQ increased from 0.05 to 0.3 µg/kg. For cod liver with a high percentage of fat, the LOQ is higher with this method, compared to the old, and LOQs from 0.3 to 3 ng/g have been obtained. For PBDE, the LOQs were mainly lowered somewhat, while PAHs were increased for some of the congeners. Metal analyses were moved to EF WEJ in 2019 and a different method was applied [9] (N. W. Green et al., 2020). The changed method had the same or lowered LOQs, except for Ag which had increased LOQ (0.004 mg/kg ww before and 0.05 mg/kg ww with the new methods)

The proportion over LOQ (detection frequency, in %) of the various compounds for each tissue is given in **Figure 61**. **Figure 62** gives the observed LOQ (median values) in blue mussel in the various compounds since 2002.

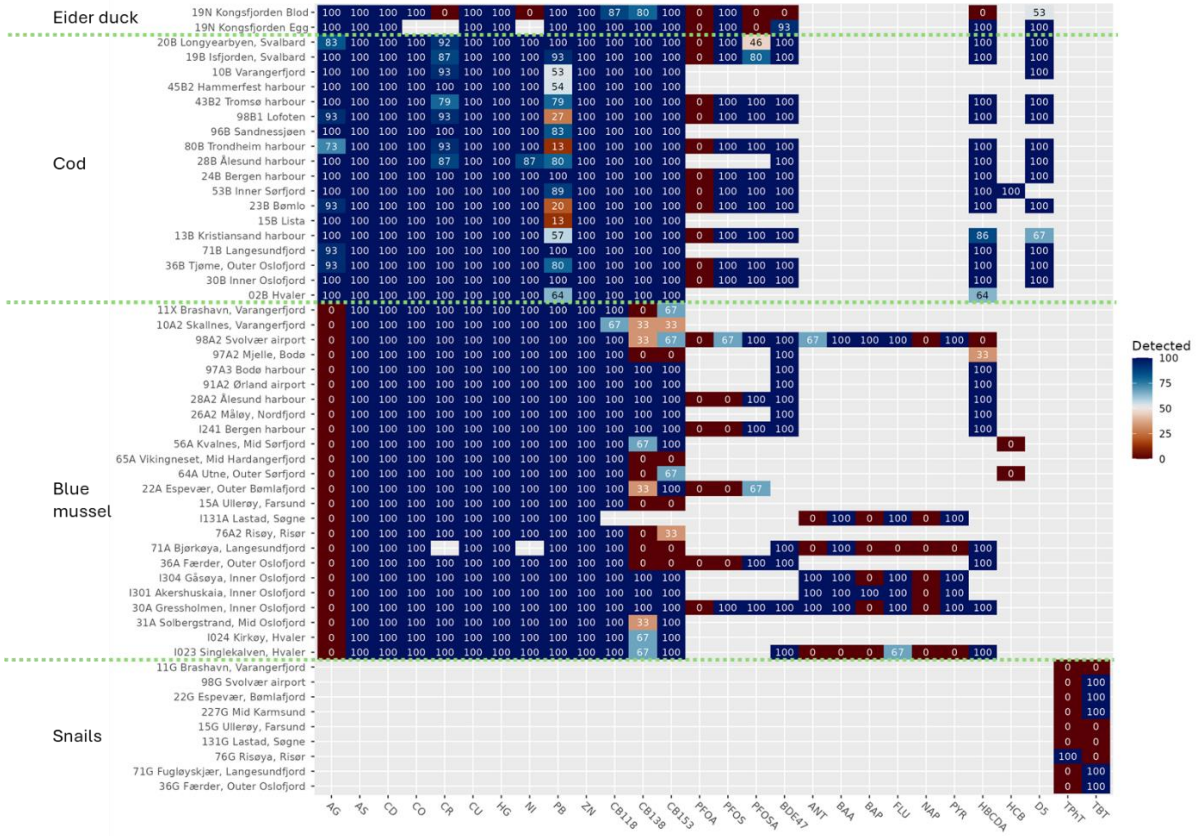
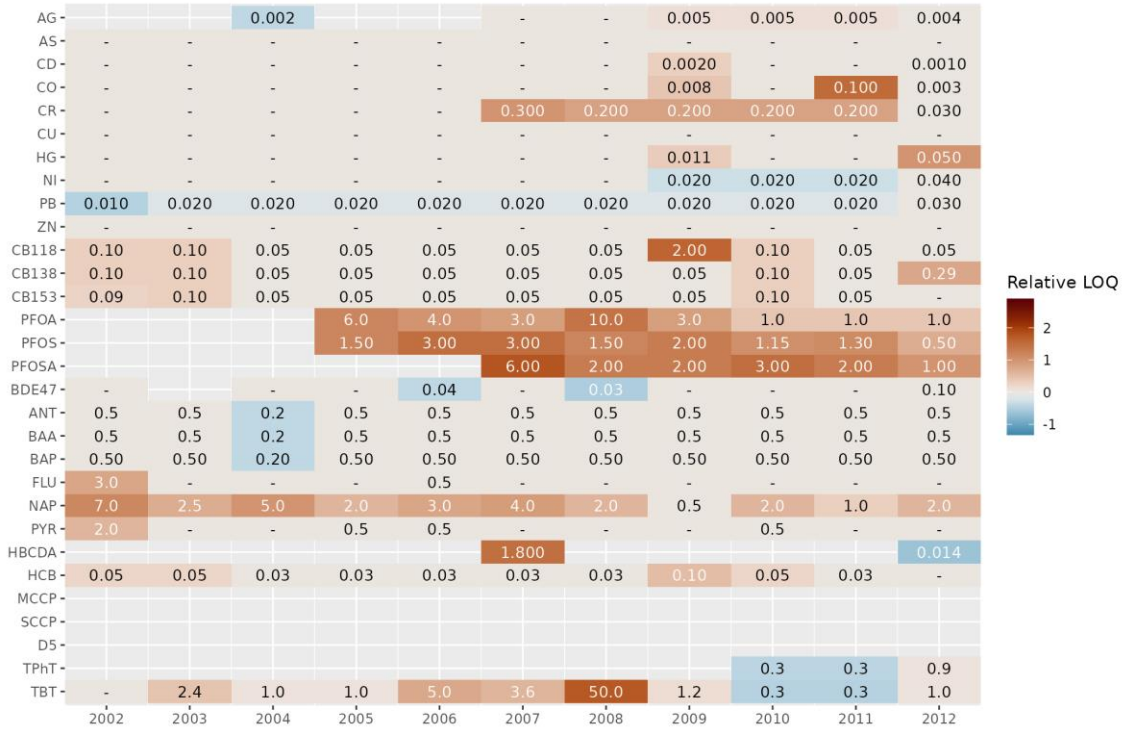


Figure 61. Proportion over LOQs (detection frequency, in %) of the compounds for each tissue in 2024. Within each species, the stations are ordered along the coastline starting north moving south.

[9] *Standard method prior to 2019 investigation was Standard method NS EN ISO 17294-2, and then Standard method NS EN ISO 15763 (2010) except for nickel, silver and zinc which then was Standard method NS EN ISO 17294-2-E29.*

(a) LOQ 2002 - 2012



(b) LOQ 2013 - 2024

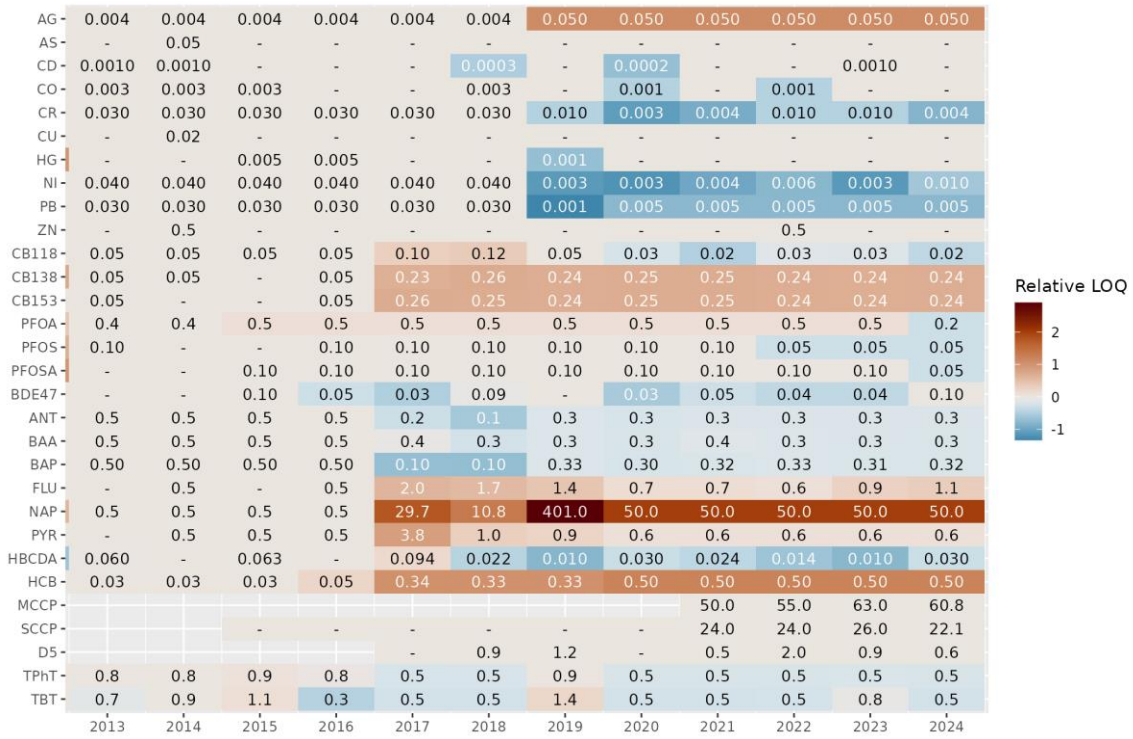


Figure 62. Changes in LOQ values over time. The numbers in the table show observed LOQ (median values, mg/kg ww for metals incl. Hg, and ug/kg ww for others). In blue mussel for various compounds in the periods 2002-2012 (a) and 2013-2024 (b). The colours indicate the "relative LOQ" compared to a reference period defined as 2013-2015 (median LOQ versus the median LOQ during the years 2013-2015). Blue colours show lower (better) LOQ and red colours shows higher LOQ compared to the reference period. For some groups, e.g. PFAS, there were no measurements in the reference period (shown in light grey).

7.5 Classification of environmental status and quality (EQS and PROREF)

There are several systems that can be used to classify the concentrations of contaminants observed. No system is complete in that it covers all the contaminants and target species-tissues investigated in this programme. Up to and including 2015 investigations, MILKYS relied largely on a national classification system prepared by the NEA as described in a report (Molvær, J. et al., 1997). This system was based on high background concentrations derived from an array of national and international monitoring programmes and investigative literature.

With the ratification of EU Water Framework Directive (WFD) (Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 Establishing a Framework for Community Action in the Field of Water Policy, 2000) by Norway in 2007 and the subsequent application of the daughter directive on EQS (Directive 2013/39/EU, 2013) the assessment of the environment using EQS became imperative. The daughter directive outlines 45 priority substances or groups of substances. Several of these substances are monitored by MILKYS. The EQS applies to concentrations in water, and for fifteen substances it also applies to concentrations in biota (see **Table 3** for contaminants in MILKYS). There is a provision in this daughter directive which allows a country to develop their own EQSs for water, sediment, and biota provided these offer the same level of protection as the EQS set for water. Norway used this approach and developed their own EQS for biota, water, and sediments for river basin specific pollutants and priority substances where EQSs are missing, not otherwise accounted for by the EU directives (Miljødirektoratet, 2025).

Assessing the risk to human consumption from elevated concentrations of contaminants in seafood has not been the task of this programme and hence, the EU foodstuff limits have not been applied. However, it should be noted that the NEA communicates the results to the Norwegian health authorities. Also, it should be noted that the background dossiers for the EQS (Directive 2013/39/EU, 2013) as well as the national environmental quality standards (Miljødirektoratet, 2016) applied foodstuff limits if these are lower than the limits found by assessing risk of secondary poisoning of marine organisms.

Both EU and national standards are referred to collectively in this report as EQSs. Both standards are risk-based, i.e., exceedances of EQSs are interpreted as potentially harmful to the environment and humans and remedial action should be considered.

The application of these standards has been discussed previously (N. W. Green et al., 2016), and three main challenges were noted. The first is that the standards for biota are generally not species or tissue specific but refer to whole organisms. The second is that the standards are often in large conflict with the system based on background concentrations (see **chapter 3.8.3** in the report (N. W. Green et al., 2016)). And lastly, the standards do not address all the contaminants in all the tissues that are monitored, for example, there are no EQSs for metals in biota except for mercury. To address this issue for this report, and in dialogue with the NEA, Norwegian provisional high reference contaminant concentrations (PROREF) were derived and used in parallel with the risk-based standards (see method description below).

This report investigations addresses the principal cases primarily where median concentrations exceeded EQS and secondarily where median concentrations exceeded PROREF (**Table 4**). Exceedances of PROREF (see derivation explained in **chapter 3.5.1** (N. W. Green et al., 2016)) were grouped in six factor-intervals: <PROREF, 1-2x (between PROREF and two times PROREF), 2-5x, 5-10x, 10-20x, and >20x.

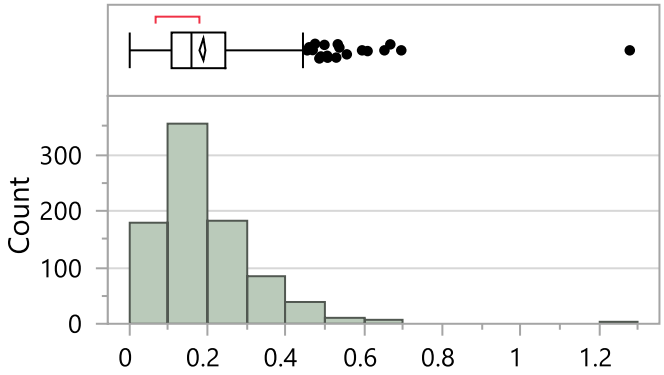
The EQS and PROREF as well as time trend analyses use concentrations on a wet weight (ww) basis. The choice of basis (i.e. concentrations on a wet weight, dry weight, or fat weight basis) follows the OSPAR approach aimed at meeting several considerations: scientific validity, uniformity for groups of contaminants for specific tissues, and a minimum loss of data. As to the latter, the choice of basis will affect the number of data that can be included in the assessment, depending on available information on dry weights, wet weights, and lipid weights.

In MILKYS, the compliance to EQSs has for a long time, and at least from 2005 been done by assessing the *median* concentration at the station, every year (N. Green et al., 2005). The median is a resistant measure of the central tendency of data (Helsel et al., 2020). The advantage of the median is that it is only minimally affected by the magnitude of any single observation. This resistance to the presence of outlying observations is often a desirable property. Also in ICES, the medians (after log transformation) has been used for temporal trend monitoring at least since 1998 (Nicholson et al., 1998). In that report another advantage with median values is mentioned; they are not affected by data below LOQ (provided that fewer than half of the values are below LOQ).

Which summary statistics to use for assessment of EQS is described in the guidance document (European Commission, 2014), chapter 2.1.1. The guidance documents state that priority substances in biota typically have a log-normal distribution (i.e. a positively skewed dataset), and that an estimate of the central tendency like mean or median is appropriate. It is further stated that: "The most reliable summary statistic (for comparison with an EQSbiota) is therefore the antilog of the mean of log-transformed concentrations after normalisation [...]". This mean is called the *geometric mean* and is often reported for positively skewed datasets (e.g. log-normal distributions). In the Norwegian guidance document (Direktoratsgruppen vanndirektivet, 2018), only use of the mean is mentioned, without specifying which mean to calculate. It should be mentioned here that it is not possible to calculate the geometric mean for LB data (that is, substituting data below LOQ with 0).

For positively skewed data, the geometric mean is usually quite close to the median (Helsel et al., 2020). This is illustrated in **Figure 63** where the mercury concentration (mg/kg ww) in cod at station 30B has a slightly positively skewed distribution (data is for the period 1984-2023). The geometric mean (0.16) is close to the median (0.16), while the mean (0.19) is affected by the outliers with higher concentrations. Both the median and the geometric mean is lower than lower 95% confidence interval of the mean. The median will be further removed from the mean when the skewness is more positive than in this case.

In summary, we believe that use of the median concentrations for assessment of EQS is quite close to the geometric mean recommended in the guidance document (European Commission, 2014). The time trend data requires use of the median, and therefore it is easier for us to use only one estimate for the central tendency of the data.



Mean	0.1878
Median	0.16
Geometric Mean	0.1560
Std Dev	0.1162
Std Err Mean	0.004034
Upper 95% Mean	0.1957
Lower 95% Mean	0.1798
Skewness	1.95
N	830

Figure 63. Histogram of mercury concentrations (mg/kg ww) in cod from station 30B (1984-2023). The boxplot above the histogram shows the median as a vertical line within the boxplot, while the mean is at the middle of the confidence diamond. The densest 50% of the data is marked with a red bracket. Statistical details of the distribution are listed in the table to the right.

7.6 PROREF

Since 1981, the MILKYS programme and its forerunners have generated over 400,000 analyses on concentrations of over 100 contaminants in biota alone, mostly for blue mussel and cod. This unique dataset was used to define and determine a reference value, Norwegian provisional high reference contaminant concentrations (PROREF). PROREF is a comprehensive set of species-tissue-basis-specific reference values for contaminant concentrations that are statistically low when considering all MILKYS-results for the period 1992-2016. The intention is to use objective criteria to determine a reference value, below which the concentrations for a given contaminant can be said to be low or close to background concentration for the given region/country (for naturally occurring chemicals, close to natural concentrations; for solely mad-made chemicals, resulting from only diffuse exposure). We consider PROREF to be a valuable method for assessing contaminants levels in addition to the risk-based EQS thresholds. The PROREF value can be interpreted as *the upper range of contaminant concentrations in reference (or background) stations* - i.e., stations far from point sources of contamination. Using the PROREF method, we have calculated PROREF values for 177 combinations of contaminant and species/tissue in 2017, with a revision in 2019 (which in only four cases changed the value by >20 %). We use the same values in this report.

The selection of background stations is objective and reproducible, based solely on concentration data (i.e., not based on expert judgment; see below). The derivation is done independently for each contaminant/species/tissue, taking into account that different contaminants may have various geographic patterns and therefore different stations should be considered to be "background". PROREF is a NIVA-developed concentration which can be described as “high background” as it represents the 95th percentile of concentrations found at reference stations in the MILKYS programme. The reference stations are identified among the current and previous MILKYS stations by a stepwise statistical method described more in detail below. We consider PROREF to provide a valuable method for assessing contaminant levels in addition to the risk based EQSs. We have calculated Norwegian PROREF values based MILKYS-results for the period 1992-2016.in the background stations are below PROREF. Thus, a station can be background for contaminant X in cod liver, but not for contaminant Y in the same matrix, or contaminant X in a different matrix.

The derivation of PROREF has two basic steps: first, determine the reference stations, and secondly, determine the upper range of concentrations at those stations (i.e., the PROREF value). In more detail, this is the procedure followed for a given contaminant in each species/tissue, measured on a given basis (wet-weight, dry-weight etc.):

1. Selection of reference stations:
    a. Only data from 1992 to 2016 were considered (at the time PROREF was calculated, the last 25 years) on the general assumption that prior to this time, important discharge reductions were not in place.
    b. For each station, calculate annual median concentrations (i.e. 25 numbers per station, if the time series is complete).
    c. For each station, discard the highest 10 % of the values from b (i.e., remove possible "outlier years").
    d. Discard stations with less than five years of data, counting only years with at least two analysed samples for blue mussel stations and 10 analysed samples for cod stations.
    e. For each remaining station, calculate the logarithm of the median of the values from c.
    f. Set values below the limit of quantification (LOQ) to a random value between 0.5*LOQ and 1*LOQ.
    g. Order stations by concentration, from the lowest to the highest.
    h. Test the difference between station 1 and station 2 using a t-test.
    i. If station 1 is not statistically different from station 2 (at level P = 0.05), combine the values of both stations, and test the difference between station 1+2 and station 3 (again, using a t-test).
    j. If station 1+2 is not statistically different from station 3, combine 1,2 and 3 and test the difference between station 1+2+3 and station 4.
    k. Continue this procedure until a statistically significant difference is encountered. The reference stations are defined as all stations that were <u>not</u> statistically different.
2. Determine the upper range of concentrations at the reference stations.
    a. Combine the concentrations (raw data, i.e. concentrations at sample level) from the reference stations.
    b. Calculate the upper 95 percentile of these concentrations.
3. Determine the PROREF value.
    a. If all concentrations are above LOQ, the outcome of 2b equals the PROREF value.
    b. If some concentrations are below LOQ, repeat step 1 and 2 *n* times (in order to minimize the effect of the random value selection in step 1f). This results in *n* values (outcomes of step 2b). PROREF is defined as the median value of these values. We used *n* = 21.

The PROREF values applied in this report are shown in **Table 4** of the MILKYS report for 2020 data (Schøyen, Lund, et al., 2024).

7.7 Statistical time trend analysis

We have used the HARSAT tool version 1.0.3.1008 (Arctic Monitoring and Assessment Programme et al. 2025) for statistical trend analysis. HARSAT (Harmonised Regional Seas Assessment Tool) is a tool that is applied by The Arctic Monitoring and Assessment Programme (AMAP), the Helsinki Commission (HELCOM) and the OSPAR Commission (OSPAR). The time trend analysis takes into account both data under LOQ, chemical analytical uncertainty, and possibly non-linear time trends (OSPAR, 2025a). Concentrations are log transformed and changes in the log concentrations over time are modelled using a linear or a non-linear (spline) model:

A. No change over time: mean concentration = a
B. Linear change over time: mean concentration = a + b*Year
C. Non-linear change over time: mean concentration = s(Year),
   where *s* is a smoother with either 2, 3, or 4 degrees of freedom (denoted C2, C3, and C4).

For every time series, several models may be fitted, and the model that fits the data best (the most parsimonious model) is used. The type of models that are considered depend on the number of years of data, counting only years with at least one concentration over LOQ:

- 1-4 years: no model is fitted
- 5-6 years: models A and B
- 7-9 years: models A, B, and C2
- 10-14 years: models A, B, C2, and C3
- 15 years or more: models A, B, C2, C3, and C4

In order to prevent over-fitting if there are many less-thans or if the less-thans are unevenly distributed across the time series, there is a special algorithm for the selection of "accepted" years, for instance avoiding that time series start with years with values under LOQ.

The model is fitted by maximum likelihood, assuming each of the random effects are independent and normally distributed. The analysis takes into account that the analytical error (the uncertainty in the chemical determination of concentrations), adjusting the likelihood correspondingly. This error varies from 5 – 50% depending on substance and laboratory. The analytical error was assumed to be known, based on information from the laboratories. The likelihood was also depending both on over-LOQ and under-LOQ values, where the latter likelihood was taken as the likelihood of values being between zero and LOQ (OSPAR, 2025b).

For sum parameters, such as sumPCB7, HARSAT performs the trend analysis as if it was a single substance. If one or more of the seven substances is under LOQ, that sum value is classified as an under-LOQ value (Rob Fryer pers.comm.). In contrast, in the previous report, sum parameters with were handled by fitting a trend line based on the lower limit and the upper limit of the sum (lower limit = sum of all over-LOQ concentrations, upper limit = sum of all over-LOQ and under-LOQ concentrations). This may change in future updates of HARSAT.

Analyses were performed using R version 4.4.3.

When there is a significant non-linear time trend, the trend results are classified for a given period (i.e., either the whole series or the last 10 years (recent)) by comparing the height of the time series curve at the start and end of the period (taking into account the uncertainty of these two times). These two points may not differ even if the time trend in itself is significantly different (**Figure 64**). We have

denoted these cases as “no change” as short for “non-linear trend but no net change over the time period”. Again, this follows the practice of (OSPAR, 2025a).

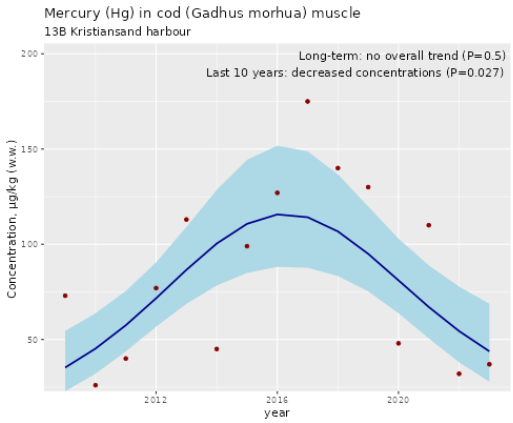


Figure 64. Example of time series (station 13B, Kristiansand harbour) classified for whole trend as “no change”. The time series has a non-linear trend for the whole period, but there is no significant difference between the start point and last point of the curve. The recent trend was, however, significant downwards.

The statistical analysis of time trends was carried out on all the results, including those for biological effect parameters.

7.8 Sum parameters

In MILKYS, we have changed the practice for reporting sum parameters including the reporting of data for the survey in 2021 (Schøyen et al., 2022). The method is described in a NIVA note (Grung, M. et al., personal communication, 2023).

There are two estimates for reporting sum parameters below LOQ; EFSA (European Food Safety Authority) describes these as lower bound [10] (LB) and upper bound [11] (UB). When summing several isomers, the partial sum of *not* quantified partial sums can either be set to 0 (LB) or to LOQ (UB). LB will be the lowest estimate for the sum parameter while UB will be the highest estimate. According to the Water Frame Directive, LB must be used for total parameters (Commission Directive 2009/90/EC, 2009). For sum parameters (e.g. sumPCB7, sumPAH16, sumBDE6, and MCCP/SCCP) the concentrations in MILKYS (including reporting of the survey in 2020; (Schøyen, Lund, et al., 2024)) have mainly been reported as UB – i.e. data below LOQ were set to LOQ for the subtotal. The exception was MCCP and SCCP which were analysed by NILU (eider from Svalbard), where the sum parameters were reported as LB (the pragmatic reason for this is that NILU and EF reports data in different ways).

7.9 Data treatment and figures

JMP [12] statistical software (version 19.0.1) was used for data treatment after initial treatment in R. Most figures in this report were produced using JMP.

[10] *lower bound estimate | EFSA (europa.eu)*

[11] *upper bound estimate | EFSA (europa.eu)*

[12] *https://www.jmp.com/*

8 References

Alling, V., Lund, E., Lusher, A., Rødland, E. S., Knight, J., Schmidt., N., Herzke, D., Pakhomova, S., Hjelset, S., Consolaro, C., Collard, F., Gjeitnes, M., Galtung, K., & Snekkevik, V. K. (2025). *Monitoring of microplastics and tyre wear particles in the Norwegian environment (Mikronor): 2024* (No. M–3032; p. 108). https://www.miljodirektoratet.no/publikasjoner/2025/oktober-2025/mikronor-2024-monitoring-of-microplastics-and-tyre-wear-particles-in-the-norwegian-environment/

Arctic Monitoring and Assessment Programme (AMAP), Helsinki Commission (HELCOM), OSPAR Commission (OSPAR), International Council for the Exploration of the Sea (ICES), & AmbieSense Ltd. (2025). *harsat: Harmonized Regional Seas Assessment Tool* (Version 1.0.3.1008) [R]. OSPAR Commission. https://github.com/osparcomm/HARSAT (Original work published 2022)

Arnold, W. A., Blum, A., Branyan, J., Bruton, T. A., Carignan, C. C., Cortopassi, G., Datta, S., DeWitt, J., Doherty, A.-C., Halden, R. U., Harari, H., Hartmann, E. M., Hrubec, T. C., Iyer, S., Kwiatkowski, C. F., LaPier, J., Li, D., Li, L., Muñiz Ortiz, J. G., … Zheng, G. (2023). Quaternary Ammonium Compounds: A Chemical Class of Emerging Concern. *Environmental Science & Technology*, *57*(20), 7645–7665. https://doi.org/10.1021/acs.est.2c08244

Bauer, B., Fioroni, P., Ide, I., Liebe, S., Oehlmann, J., Stroben, E., & Watermann, B. (1995). TBT effects on the female genital system of Littorina littorea: A possible indicator of tributyltin pollution. *Hydrobiologia*, *309*(1), 15–27. https://doi.org/10.1007/BF00014468

Beyer, J., Green, N. W., Brooks, S., Allan, I. J., Ruus, A., Gomes, T., Bråte, I. L. N., & Schøyen, M. (2017). Blue mussels (Mytilus edulis spp.) as sentinel organisms in coastal pollution monitoring: A review. *Marine Environmental Research*, *130*, 338–365. https://doi.org/10.1016/j.marenvres.2017.07.024

Blaber, S. J. M. (1970). The occurrence of a penis-like outgrowth behind the right tentacle in spent females of Nucella lapillus (L.). In *Proceedings of the Malacological Society of London* (pp. 231–233). Dulau & Co.

Bland, J. M., & Altman, D. G. (1986). Statistical methods for assessing agreement between two methods of clinical measurement. *The Lancet*, *327*(8476), 307–310. https://doi.org/10.1016/S0140-6736(86)90837-8

Brooks, S. J., & Farmen, E. (2013). The Distribution of the Mussel Mytilus Species Along the Norwegian Coast. *Journal of Shellfish Research*, *32*(2), 265–270. https://doi.org/10.2983/035.032.0203

Commission Directive 2009/90/EC, 2009/90/EC, 2009/90/EC 3 (2009). https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:201:0036:0038:EN:PDF

Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 Establishing a Framework for Community Action in the Field of Water Policy, 2000/60 82 (2000). http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CONSLEG:2000L0060:20090625:EN:PDF

Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 Establishing a Framework for Community Action in the Field of Marine Environmental Policy (Marine Strategy Framework Directive) (Text with EEA Relevance), EP, CONSIL, 164 OJ L (2008). http://data.europa.eu/eli/dir/2008/56/oj/eng

Directive 2013/39/EU, 2013/39/EU, EP, CONSIL, 226 OJ L (2013). http://data.europa.eu/eli/dir/2013/39/oj/eng

Direktoratsgruppen vanndirektivet. (2018). *Veileder 02:2018 Klassifisering* (p. 220). https://www.vannportalen.no/veiledere/klassifiseringsveileder/

Eriksen, T. E., Thrane, J.-E., Myrvold, K. M., Grung, M., Vogt, R. D., Velle, G., Persson, J., & Kemp, J. L. (2024). Overvåking i referanseelver Oppsummering av data for perioden 2017-2023. In *60*. Norsk institutt for vannforskning. https://hdl.handle.net/11250/3159827

European Commission. (2014). *Common Implementation Strategy for the Water Framework Directive (2000/60/EC). Guidance Document No. 32 on biota monitoring (the implementation of EQSbiota) under the Water Framework Directive.* Publications Office. https://mcc.jrc.ec.europa.eu/documents/201603212046.pdf

European Commission. (2022). *European Commission—Have your say*. European Commission - Have Your Say. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52022PC0540

Fliedner, A., Rüdel, H., Lohmann, N., Buchmeier, G., & Koschorreck, J. (2018). Biota monitoring under the Water Framework Directive: On tissue choice and fish species selection. *Environmental Pollution*, *235*, 129–140. https://doi.org/10.1016/j.envpol.2017.12.052

Følsvik, N., Berge, J. A., Brevik, E. M., & Walday, M. (1999). Quantification of organotin compounds and determination of imposex in populations of dogwhelks (Nucella lapillus) from Norway. *Chemosphere*, *38*(3), 681–691. https://doi.org/10.1016/S0045-6535(98)00202-1

Gibbs, P. E. (1999). *Biological effects of contaminants: Use of imposex in the dogwhelk (Nucella lapillus) as a bioindicator of tributyltin pollution.* [Report]. International Council for the Exploration of the Sea (ICES). https://doi.org/10.25607/OBP-272

Gibbs, P. E., Bryan, G. W., Pascoe, P. L., & Burt, G. R. (1987). The use of the dog-whelk, Nucella lapillus, as an indicator of tributyltin (TBT) contamination. *Journal of the Marine Biological Association of the United Kingdom*, *67*(3), 507–523. https://doi.org/10.1017/S0025315400027260

Green, N., Ruus, A., Schøyen, M., Tveiten, L., & Walday, M. (2005). Joint Assessment and Monitoring Programme (JAMP) National Comments regarding the Norwegian Data for 2004. In *235*. Norsk institutt for vannforskning. https://niva.brage.unit.no/niva-xmlui/handle/11250/212994

Green, N. W., Dahl, I., Kringstad, A., & Schlabach, M. (NILU). (2008). *Joint Assessment and Monitoring Programme (JAMP) Overview of Norwegian analytical methods 1981-2007*. Norsk institutt for vannforskning. https://niva.brage.unit.no/niva-xmlui/handle/11250/274683

Green, N. W., Schøyen, M., Hjermann, D. Ø., Øxnevad, S., Ruus, A., Grung, M., Beylich, B., Lund, E., Tveiten, L., Jenssen, M. T. S., Håvardstun, J., Ribeiro, A. L., Doyer, I., & Bæk, K. (2020). *Contaminants in coastal waters of Norway 2019*. https://hdl.handle.net/11250/2724662. https://hdl.handle.net/11250/2997095

Green, N. W., Schøyen, M., Øxnevad, S., Ruus, A., Allan, I., Hjermann, D. Ø., Høgåsen, T., Beylich, B., Håvardstun, J., Lund, E., Tveiten, L. A., & Bæk, K. (2015). *Contaminants in coastal waters of Norway 2014*. Norsk institutt for vannforskning. https://niva.brage.unit.no/niva-xmlui/handle/11250/2379444

Green, N. W., Schøyen, M., Øxnevad, S., Ruus, A., Allan, I., Hjermann, D., Severinsen, G., Høgåsen, T., Beylich, B., Håvardstun, J., Lund, E., Tveiten, L., & Bæk, K. (2016). *Contaminants in coastal waters of Norway 2015. Miljøgifter i norske kystområder 2015.* Norsk institutt for vannforskning. https://brage.bibsys.no/xmlui/handle/11250/2435393

Grung, M., Schøyen, M., Hjermann, D., Ruus, A., & Lund, E. (2023). *Endring av metode for rapportering av summeparametere for MILKYS. journal no. 0003/2023.* [Personal communication].

Helland, A., Åberg, G., & Skei, J. (2002). Source dependent behaviour of lead and organic matter in the Glomma estuary, SE Norway: Evidence from isotope ratios. *Marine Chemistry*, *78*(2), 149–169. https://doi.org/10.1016/S0304-4203(02)00016-6

Helsel, D. R., Hirsch, R. M., Ryberg, K. R., Arcfield, S. A., & Gilroy, E. J. (2020). *Statistical Methods in Water Resources*. https://pubs.usgs.gov/tm/04/a03/tm4a3.pdf

ICES. (1996). *ICES Environmental Data Reporting Formats. Version 2.2*. https:// www.ices.dk/data/Documents/ENV/ERF3.2.doc

Jensen, K. B., Banica, A., & Bellec. (2024). *Miljøkjemiske data og dateringsresultater fra områdene SK04, SK05, SK06, SK07, SK08, SK09, Kvitøyrenna, Rijpfjorden midtre, Rijpfjorden ytre, Utsira nord og NS04 (Skagerrak)—Mareano* (No. 2023.020). ISSN: 2387-3515. https://static.ngu.no/upload/Publikasjoner/Rapporter/2023/2023_020.pdf

Kwaśniak, J., & Falkowska, L. (2012). Mercury distribution in muscles and internal organs of the juvenile and adult Baltic cod (Gadus morrhua callarias Linnaeus, 1758). *Oceanological and Hydrobiological Studies*, *41*(2), 65–71. https://doi.org/10.2478/s13545-012-0018-y

Lara-Martín, P. A., Gómez-Parra, A., Sanz, J. L., & González-Mazo, E. (2010). Anaerobic Degradation Pathway of Linear Alkylbenzene Sulfonates (LAS) in Sulfate-Reducing Marine Sediments. *Environmental Science & Technology*, *44*(5), 1670–1676. https://doi.org/10.1021/es9032887

Layman, C. A., Araujo, M. S., Boucek, R., Hammerschlag-Peyer, C. M., Harrison, E., Jud, Z. R., Matich, P., Rosenblatt, A. E., Vaudo, J. J., Yeager, L. A., Post, D. M., & Bearhop, S. (2012). Applying stable isotopes to examine food-web structure: An overview of analytical tools. *Biological Reviews*, *87*(3), 545–562. https://doi.org/10.1111/j.1469-185X.2011.00208.x

Li, X., & Brownawell, B. J. (2010). Quaternary Ammonium Compounds in Urban Estuarine Sediment Environments—A Class of Contaminants in Need of Increased Attention? *Environmental Science & Technology*, *44*(19), 7561–7568. https://doi.org/10.1021/es1011669

Martínez-Carballo, E., Sitka, A., González-Barreiro, C., Kreuzinger, N., Fürhacker, M., Scharf, S., & Gans, O. (2007). Determination of selected quaternary ammonium compounds by liquid chromatography with mass spectrometry. Part I. Application to surface, waste and indirect discharge water samples in Austria. *Environmental Pollution*, *145*(2), 489–496. https://doi.org/10.1016/j.envpol.2006.04.033

Miljødirektoratet. (2015). *Vaske- og rengjøringsmidler – krav til merking og databladVaske- og rengjøringsmidler – krav til merking og datablad. M71*. https://www.environmentagency.no/globalassets/publikasjoner/M71/M71.pdf

Miljødirektoratet. (2016). *Grenseverdier for klassifisering av vann, sediment og biota – revidert 30.10.2020* (No. M608). https://www.miljodirektoratet.no/globalassets/publikasjoner/M608/M608.pdf

Miljødirektoratet. (2025, January 31). *Klassifisering av prioriterte- og vannregionspesifikke stoffer*. Vannportalen. https://www.vannportalen.no/veiledere/klassifiseringsveileder/klassifisering-av-kjemisk-tilstand-av-vann/klassifisering-av-kjemisk-tilstand/grenseverdier-for-klassifisering-av-prioriterte--og-vannregionspesifikke-stoffer/

Molvær, J., Knutzen, J., Magnusson, J., Rygg, B., Skei, J., & Sørensen, J. (1997). *Klassifisering av miljøkvalitet i fjorder og kystfarvann. Veiledning. TA-1467/1997* (No. TA-1467/1997; p. 36). http://www.miljodirektoratet.no/no/Publikasjoner/Publikasjoner/2004/Februar/Klassifisering_av_miljokvalitet_i_fjorder_og_kystfarvann/

Nicholson, M. D., Fryer, R.J., & Larsen, J.R. (1998). *Temporal trend monitoring: Robust method for analysing contaminant trend monitoring data* (p. 22) [ICES Techniques in marine environmental sciences].

Norwegian Standard. (2017). *Vannundersøkelse – Overvåking av miljøgifter i blåskjell (Mytilus spp.) – Innsamling av utplasserte eller stedegne skjell og prøvebehandling. Water Quality – Monitoring of environmental contaminants in blue mussel (Mytilus spp.) – Collection of caged or native mussels and sample treatment*. Norsk Standard.

OSPAR. (2008). *2007/2008 CEMP Assessment: Trends and concentrations of selected hazardous substances in sediments and trends in TBT-specific biological effects*. https://www.ospar.org/documents?v=7111

OSPAR. (2013a). *Background document and technical annexes for biological effects monitoring, Update 2013* (No. 589/2013; p. 238).

OSPAR. (2013b). *Background Document on CEMP Assessment Criteria for QSR 2010*. https://www.ospar.org/documents?v=7167

OSPAR. (2021). *CEMP guidelines for coordinated monitoring for hazardous substances* (p. 9). https://ospar-archive.s3-eu-west-1.amazonaws.com/DECRECS/AGREEMENTS/16-04e_agreement_cemp_guideline_cemp_mime.pdf?response-content-disposition=attachment%3B%20filename%3D%2216-04e_agreement_cemp_guideline_cemp_mime.pdf%22&AWSAccessKeyId=AKIAIJK7KOBLO3FPJYIA&Expires=1646210081&Signature=kR2UQroBoTJoH3PPKoa8nsaBuOE%3D

OSPAR. (2022). *OSPAR Joint Assessment and Monitoring Programme (JAMP) 2014 – 2023*. https://www.ospar.org/documents?v=44125

OSPAR. (2025a). *Assessment methodology for contaminants in biota*. https://dome.ices.dk/OHAT/trDocuments/2025/help_methods_biota_contaminants.html

OSPAR. (2025b). *Treatment of 'less-than' measurements*. https://dome.ices.dk/OHAT/trDocuments/2025/help_methods_less_thans.html

Post, D. M. (2002). Using Stable Isotopes to Estimate Trophic Position: Models, Methods, and Assumptions. *Ecology*, *83*(3), 703–718. https://doi.org/10.1890/0012-9658(2002)083

Ruus, A., Hjermann, D. Ø., Beylich, B., Schøyen, M., Øxnevad, S., & Green, N. W. (2017). Mercury concentration trend as a possible result of changes in cod population demography. *Marine Environmental Research*, *130*, 85–92. https://doi.org/10.1016/j.marenvres.2017.07.018

Schøyen, M., Allan, I. J., Ruus, A., Håvardstun, J., Hjermann, D. Ø., & Beyer, J. (2017). Comparison of caged and native blue mussels (Mytilus edulis spp.) for environmental monitoring of PAH, PCB and trace metals. *Marine Environmental Research*, *130*, 221–232. https://doi.org/10.1016/j.marenvres.2017.07.025

Schøyen, M., Green, N. W., Hjermann, D. Ø., Tveiten, L., Beylich, B., Øxnevad, S., & Beyer, J. (2019). Levels and trends of tributyltin (TBT) and imposex in dogwhelk (Nucella lapillus) along the Norwegian coastline from 1991 to 2017. *Marine Environmental Research*, *144*, 1–8. https://doi.org/10.1016/j.marenvres.2018.11.011

Schøyen, M., Grung, M., Lund, E., Hjermann, D. Ø., Ruus, A., Øxnevad, S., Beylich, B., Jenssen, M. T. S., Tveiten, L. A., Håvardstun, J., Ribeiro, A. L., Doyer, I., & Bæk, K. (2022). *Contaminants in coastal waters 2021 / Miljøgifter i kystområdene 2021*. Norsk institutt for vannforskning. https://hdl.handle.net/11250/3045116

Schøyen, M., Grung, M., Lund, E., Hjermann, D. Ø., Ruus, A., Øxnevad, S., Christensen, G., Beylich, B., Jenssen, M. T. S., Tveiten, L. A., Håvardstun, J., Eftevåg, V. S., & Bæk, K. (2024). Contaminants in coastal waters 2022. In *83*. Norsk institutt for vannforskning. https://hdl.handle.net/11250/3127406

Schøyen, M., Grung, M., Lund, E., Hjermann, D. Ø., Ruus, A., Øxnevad, S., Christensen, G., Beylich, B., Jenssen, M. T. S., Tveiten, L. A., Håvardstun, J., Sagerup, K., Eftevåg, V. S., & Bæk, K. (2024). *Contaminants in coastal waters 2023*. Norsk institutt for vannforskning og Miljødirektoratet. https://hdl.handle.net/11250/3176335

Schøyen, M., Lund, E., Hjermann, D. Ø., Ruus, A., Beylich, B., Jenssen, M. T. S., Tveiten, L. A., Håvardstun, J., Ribeiro, A. L., Doyer, I., Bæk, K., & Øxnevad, S. (2024). *Contaminants in coastal waters of Norway 2020*. Norsk institutt for vannforskning. https://hdl.handle.net/11250/3158408

Stransky, C., Baumann, H., Fevolden, S.-E., Harbitz, A., Høie, H., Nedreaas, K. H., Salberg, A.-B., & Skarstein, T. H. (2008). Separation of Norwegian coastal cod and Northeast Arctic cod by outer otolith shape analysis. *Fisheries Research*, *90*(1), 26–35. https://doi.org/10.1016/j.fishres.2007.09.009

Sweeting, C. J., Polunin, N. V. C., & Jennings, S. (2006). Effects of chemical lipid extraction and arithmetic lipid correction on stable isotope ratios of fish tissues. *Rapid Communications in Mass Spectrometry*, *20*(4), 595–601. https://doi.org/10.1002/rcm.2347

Tim. (2016, September 12). *Bland-Altman Plot / Tukey Mean Difference Plot*. Statistics How To. https://www.statisticshowto.com/bland-altman-plot/

Vitale, F., Clausen, L. W., & G. Ní Chonchúir. (2019). *Handbook of fish age estimation protocols and validation methods* (Report No. 346; p. 180). ICES Cooperative Research Reports (CRR). https://doi.org/10.17895/ices.pub.5221

Supplementary data

Regular monitoring program

PROREF

Assessments of exceedances of PROREF for contaminants not selected for presentation in 2024 are given here. The contaminants are listed in **Table S1**.

Table S1. List of contaminants not selected in 2024 for which a PROREF exists. The PROREFs are given in µg/kg (ng/g ww), except for Tin (Sn) given in mg/kg ww, and VDSI (index). PROREF is given with two significant digits.

		PROREF for contaminants				
	Contaminant	**Unit**	**Blue mussel**	**Cod**	**Dogwhelk**	**Common periwinkle**
Metals	Tin (Sn)	mg/kg ww	0.3	0.3		
PFAS	Perfluorobutane sulfonate (PFBS)	µg/kg ww		8		
	Perfluorononanoic acid (PFNA)			5		
PBDEs	PBDE congener -28 (BDE28)			1.4		
	PBDE congener -49 (BDE49)			4.0		
	PBDE congener -66 (BDE66)			0.6		
	PBDE congener -71 (BDE71)			0.4		
	PBDE congener -77 (BDE77)			1.7		
	PBDE congener -85 (BDE85)			1.7		
	PBDE congener -99 (BDE99)		0.06	0.75		
	PBDE congener -126 (BDE126)		0.05	0.1		
	PBDE congener -138 (BDE138)			0.3		
	PBDE congener -153 (BDE153)		0.05	0.15		
	PBDE congener -183 (BDE183)		0.3	0.6		
	PBDE congener -196 (BDE196)		0.3	1		
	PBDE congener -209 (BDE209)		1.3	2		
PAHs	Naphthalene (NAP)		17			
	Acenaphthene (ACNE)		0.8			
	Acenaphthylene ACNLE		1			
	Fluorene (FLE)		1.6			
	Anthracene (ANT)		0.8			
	Phenanthrene (PA)		2.3			
	Benzo[k]fluoranthene (BKF)		1.5			
	Benzo[b+j]fluoranthene (BBJF)		6.2			
	Benzo[ghi]perylene (BGHIP)		2.1			
	Dibenz[a,c/a,h]anthracene (DBA3A)		0.5			
	Indeno[1,2,3-cd]pyrene (ICDP)		1.7			
PCBs	PCB congener 28 (CB28)		0.12	8		
	PCB congener 52 (CB52)		0.2	16		
	PCB congener 101 (CB101)		0.2	32		
	PCB congener 180 (CB180)		0.1	46		
HBCDs	ß-hexabromocyclododecane (HBCDB)		0.02	0.4		
	γ-hexabromocyclododecane (HBCDG)		0.03	0.89		
DDTs	p,p'-DDE (a DDT metabolite)		0.22	160		
	p,p'-DDD (TDEPP)		0.1	32		
Pesticides	α HCH = alpha HCH (HCHA)			8		
	Lindane, γ HCH = gamma			11		
TBT-related compounds	Dibutyltin (DBT)					2.0
	Dioctyltin (DOT)				1.2	
	Monobutyltin (MBT)					1.3
	Monooctyltin (MOT)				1.2	
	Tributyltin (TBT)				24	
	Tricyclohexyl-stannylium (TCHT)				2.3	
	Triphenyltin (TPhT)				1.7	
	Tetrabutyltin (TTBT)				1	
Biomarkers	Vas Deferens Sequence Index (VDSI)	index			3.7	

The figures with exceedances of PROREF are shown in **Figure S1** to **Figure S6**.

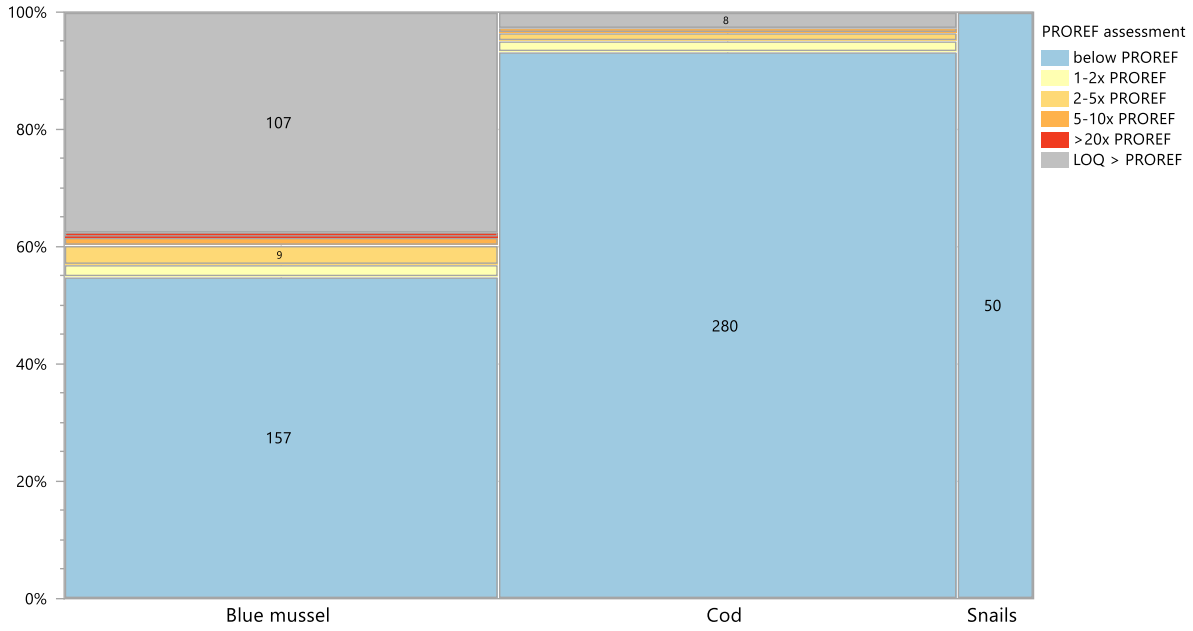


Figure S1. Assessment vs PROREF for contaminants not selected for presentation in 2024 in a mosaic plot. The cells are labelled by the number of stations and parameters. The exceedances are considered by the median for each station and species. The colours represent below or above exceedance of PROFEF (darker yellow to red), or that the PROREF was below LOQ, and therefore could not be classified (grey).

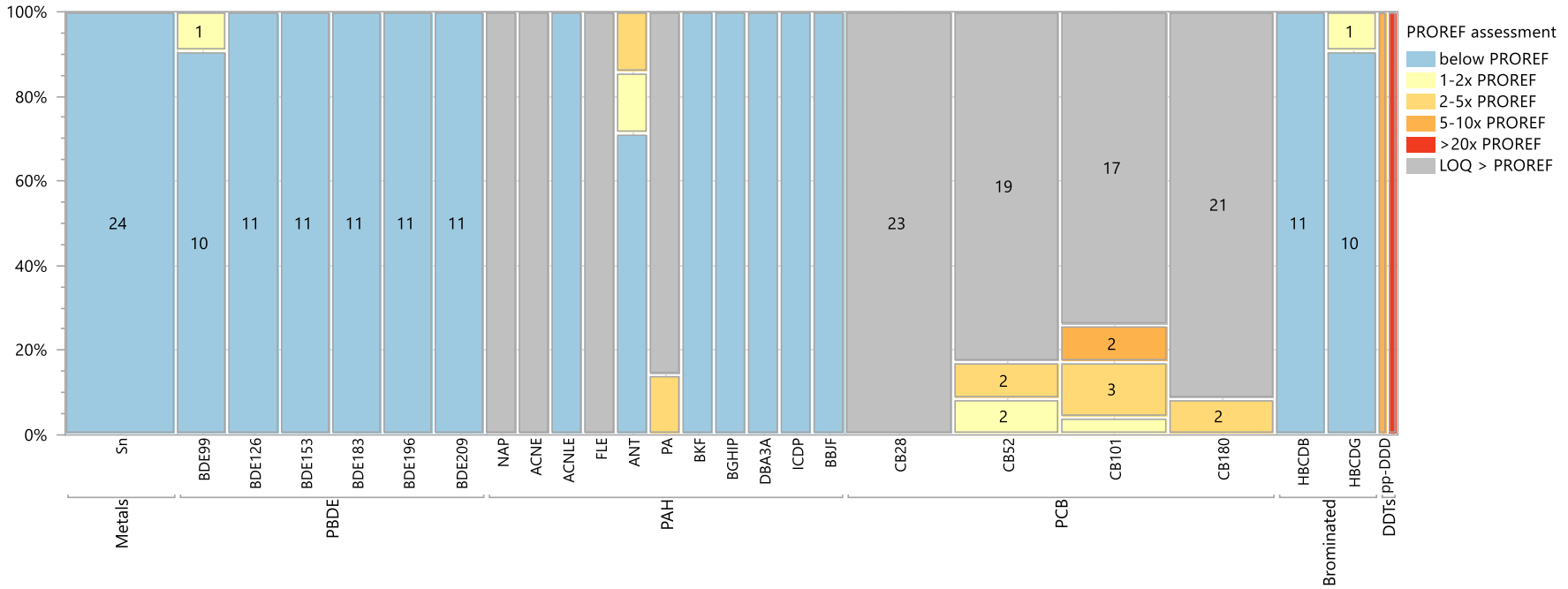


Figure S2. Assessment vs PROREF for contaminants not selected for presentation in 2024 in blue mussel by contaminant and group of contaminants. The cells are labelled by the number of stations sampled. The exceedances are considered by the median for each station. The colours represent below or above exceedance of PROFEF (darker yellow to red), or that the PROREF was below LOQ, and therefore could not be classified (grey).

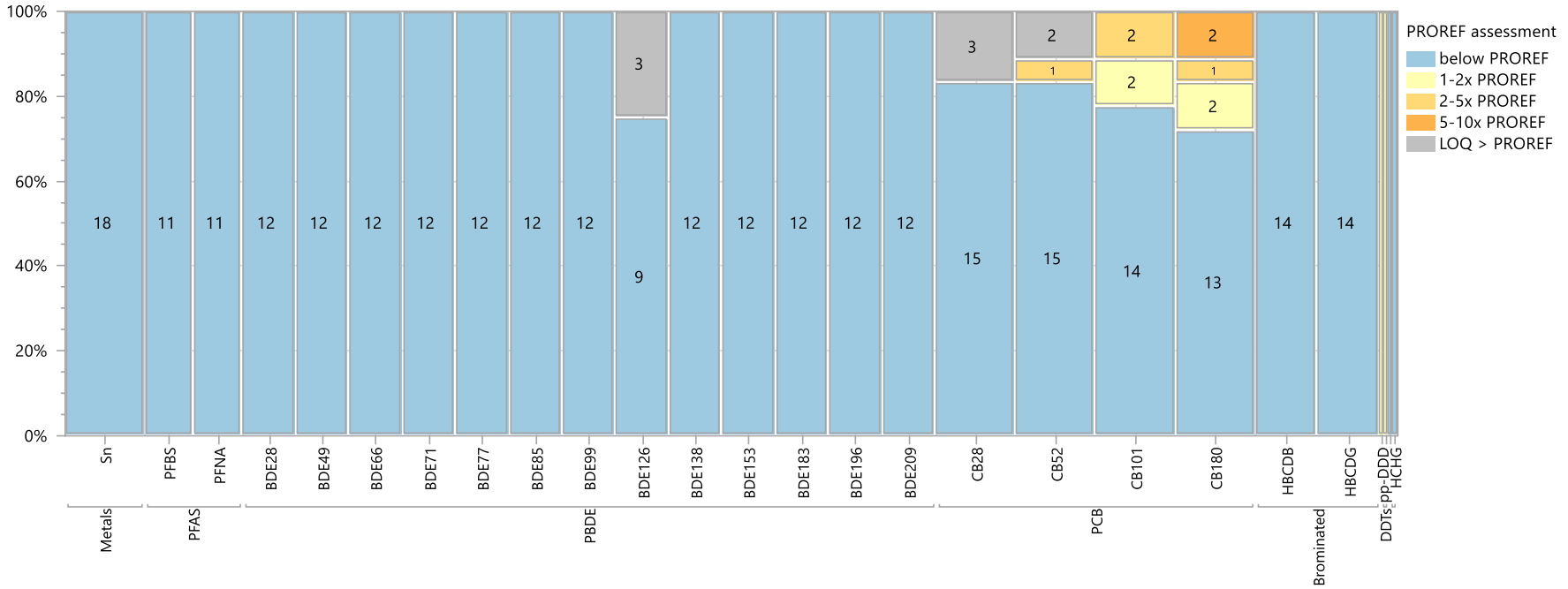


Figure S3. Assessment vs PROREF for contaminants in cod not selected for presentation in 2024 by parameter and group of contaminants. The cells are labelled by the number of stations sampled. The exceedances are considered by the median for each station. The colours represent below or above exceedance of PROFEF (darker yellow to red), or that the PROREF was below LOQ, and therefore could not be classified (grey).

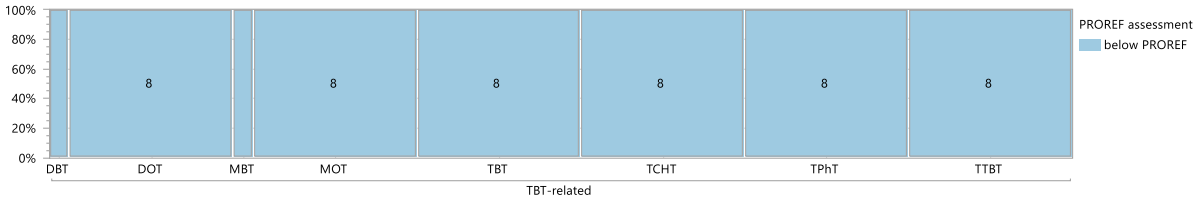


Figure S4. Assessment vs PROREF for contaminants in snails not selected for presentation in 2024 by parameter and group of parameters. The cells are labelled by the number of stations sampled. The exceedances are considered by the median for each station. The colours represent below or above exceedance of PROFEF (darker yellow to red), or that the PROREF was below LOQ, and therefore could not be classified (grey).

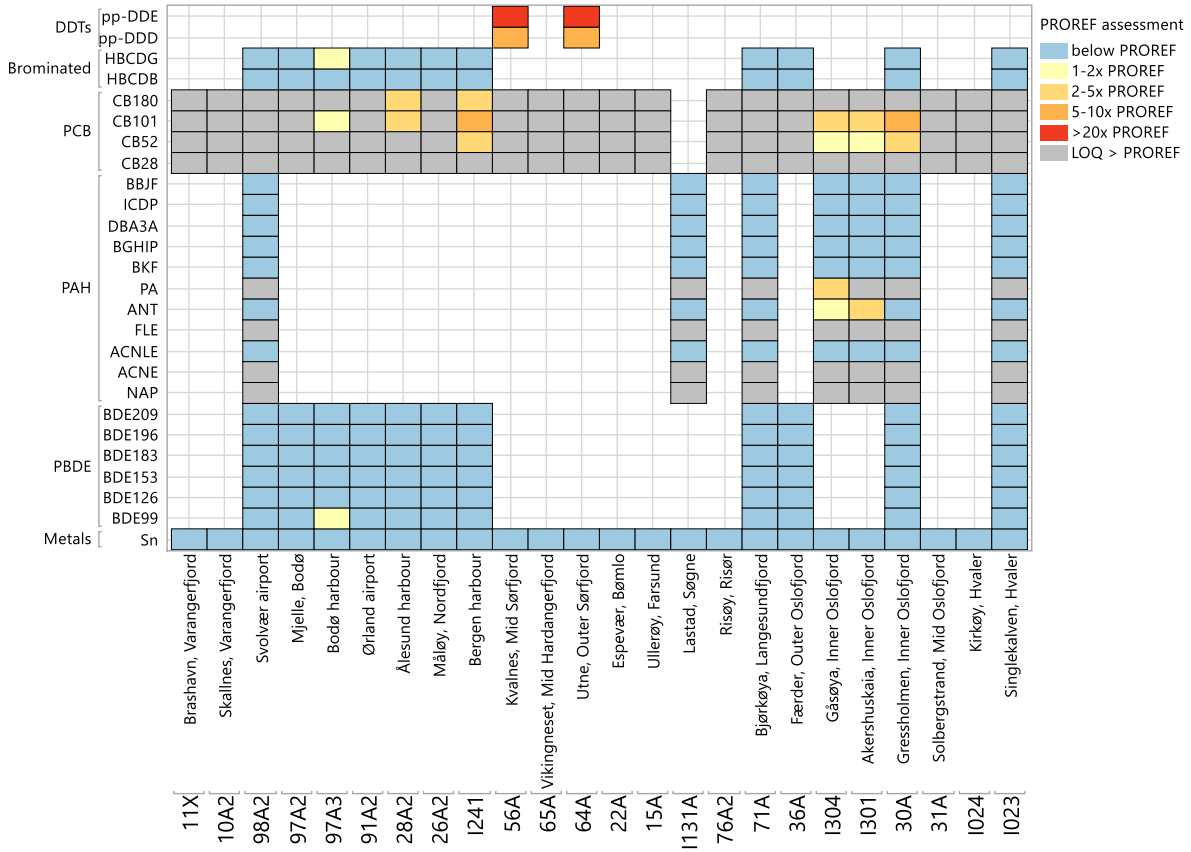


Figure S5. Heatmap of assessment vs PROREF in mussel for contaminants not selected for presentation in 2024. The colours represent below or above exceedance of PROREF. Empty “cells” mean that the contaminant was not analysed for at the indicated station. Grey lines show the midpoint of each station and contaminant.

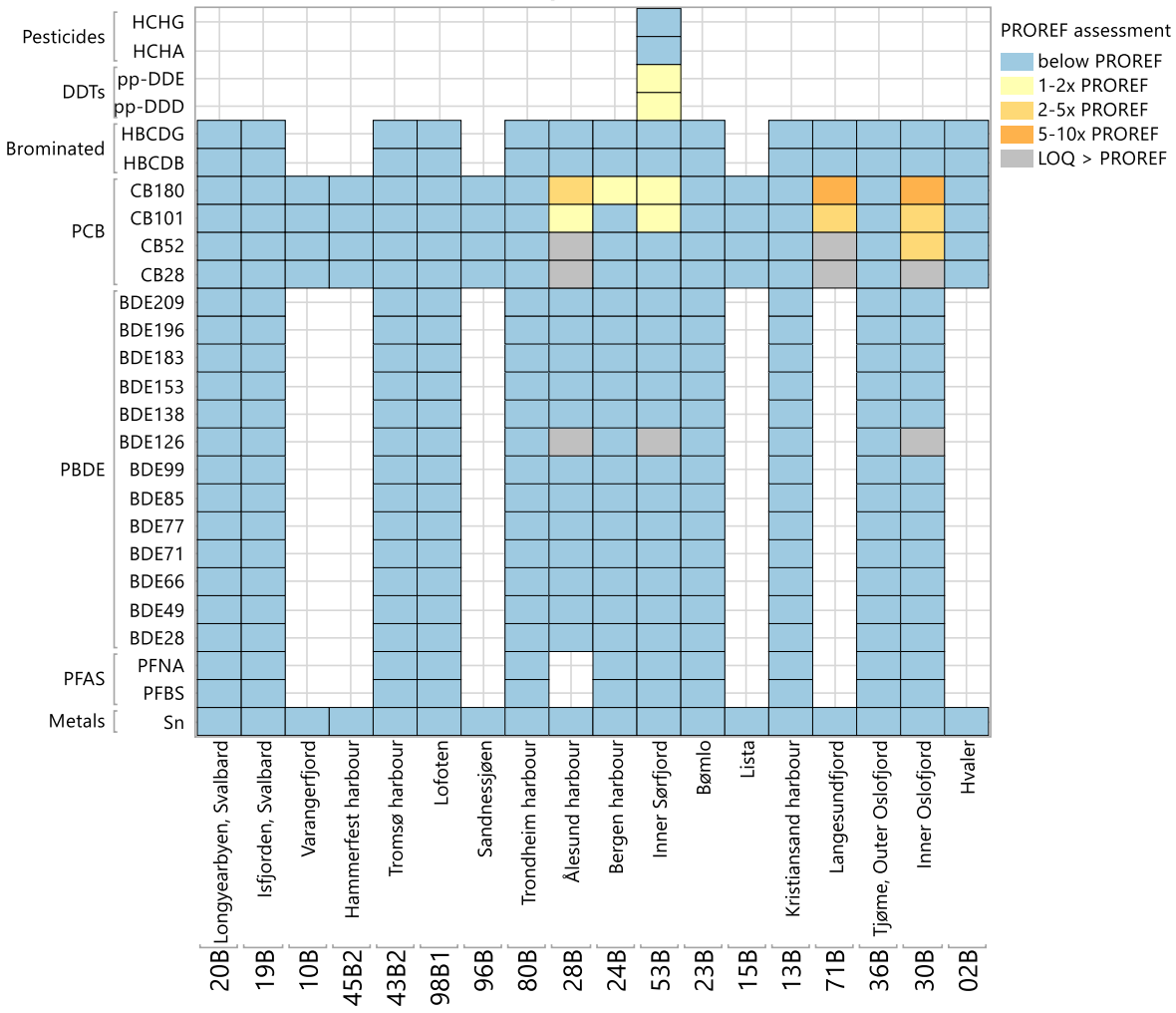


Figure S6. Heatmap of assessment vs PROREF in cod for contaminants not selected for presentation in 2024. The colours represent below or above exceedance of PROREF. Empty "cells" mean that the contaminant was not analysed for at the indicated station. Grey lines show the midpoint of each station and contaminant.

Time trends (combinations of contaminant × station) have also been estimated for contaminants not selected for presentation in 2024. The contaminants are listed in **Table S2**. The figures with time trends are shown in **Figure S7** to **Figure S13**. The time trends presented for selected contaminants (**chapter 3.3**) have been manually quality assured, but the time trends presented in this chapter have not undergone a manual quality assurance. Care must therefore be taken, especially for upward time trends in cases where the LOQ has increased in the later years. Examples of such contaminants are silver and PCB.

Time trends

Table S2. List of parameters for which a time trend is shown in supplementary data .The numbers are count of station time trends.

Contaminant group	Contaminant	Blue mussel	Cod	Common eider	Snails
Metals	Sn	24	18	2	0
PFAS	PFBS	6	11	2	0
	PFDA	6	11	2	0
	PFDS	6	11	2	0
	PFHxS	6	11	2	0
	PFNA	6	11	2	0
	PFTrDA	6	11	2	0
	PFUnDA	6	11	2	0
PBDE	BDE28	11	12	2	0
	BDE66	11	12	2	0
	BDE85	11	12	2	0
	BDE99	11	12	2	0
	BDE126	11	12	2	0
	BDE153	11	12	2	0
	BDE183	11	12	2	0
	BDE209	11	12	2	0
	sumBDE	11	12	2	0
PAH	NAP	7	0	0	0
	ACNE	7	0	0	0
	ACNLE	7	0	0	0
	FLE	7	0	0	0
	ANT	7	0	0	0
	PA	7	0	0	0
	BGHIP	7	0	0	0
	ICDP	7	0	0	0
	CHR	7	0	0	0
PCB	CB28	23	18	2	0
	CB52	23	18	2	0
	CB101	23	18	2	0
	CB180	23	18	2	0
	CB105	0	0	2	0
	CB156	0	0	2	0
	sumPCB7	23	18	2	0
Siloxanes	D4	0	13	2	0
	D6	0	13	2	0
Brominated	HBCDB	11	14	2	0
	HBCDG	11	14	2	0
	sumHBCD	10	14	2	0
DDTs	op-DDT	2	1	0	0
	pp-DDD	2	1	0	0
	pp-DDE	2	1	0	0
Pesticides	HCHA	2	1	0	0
	HCHB	2	1	0	0
	HCHG	2	1	0	0
	Heptachlor epoxide	2	1	0	0
	Oxychlordan	2	1	0	0
	sumHCH	2	1	0	0
TBT-related	DBT	0	0	0	9
	MBT	0	0	0	9
	TBT	0	0	0	9
	TPhT	0	0	0	9
BEM	VDSI	0	0	0	8
	ISI	0	0	0	1*
	EROD	0	3	0	0
	VDSI	0	3	0	0

* Shown with VDSI in figures

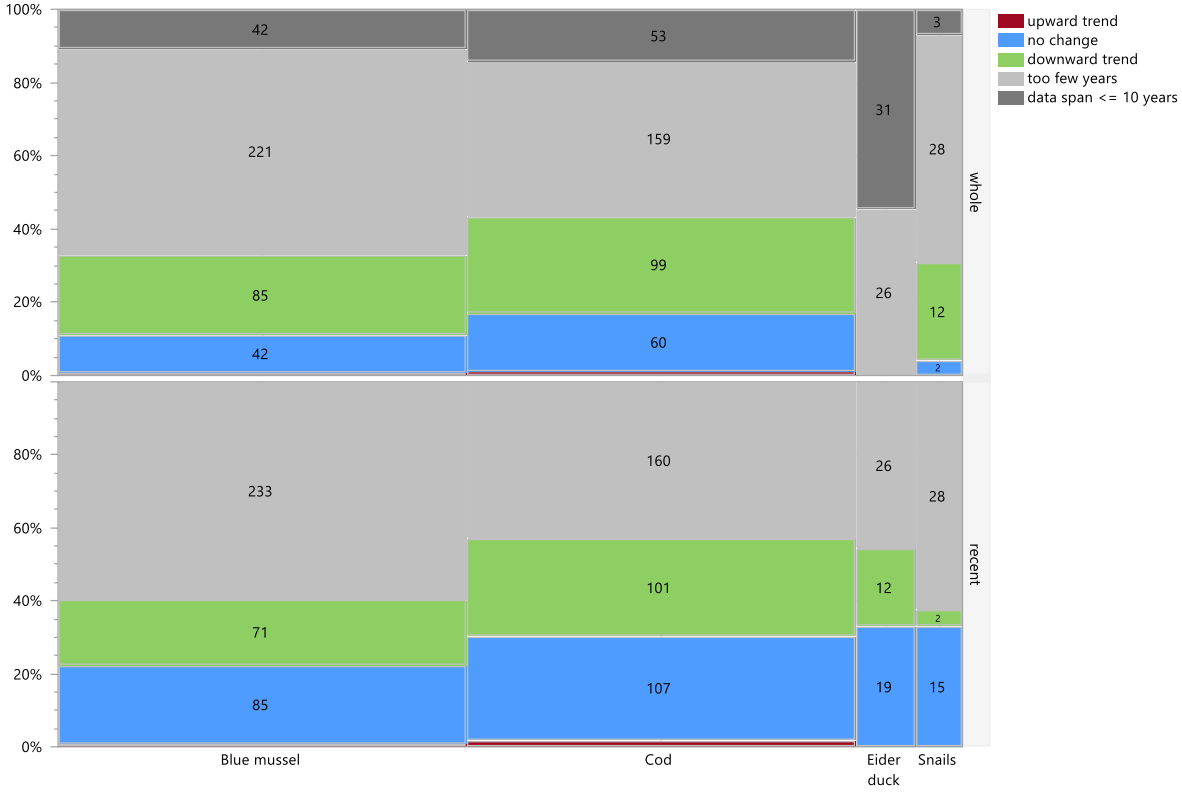


Figure S7. Mosaic plot of time trends for contaminants in blue mussel, cod, eider, and snails not selected for presentation in 2024. Upper panel shows recent period trends, while lower panel shows whole trends. The number of stations/species/tissues are indicated in the respective cells.

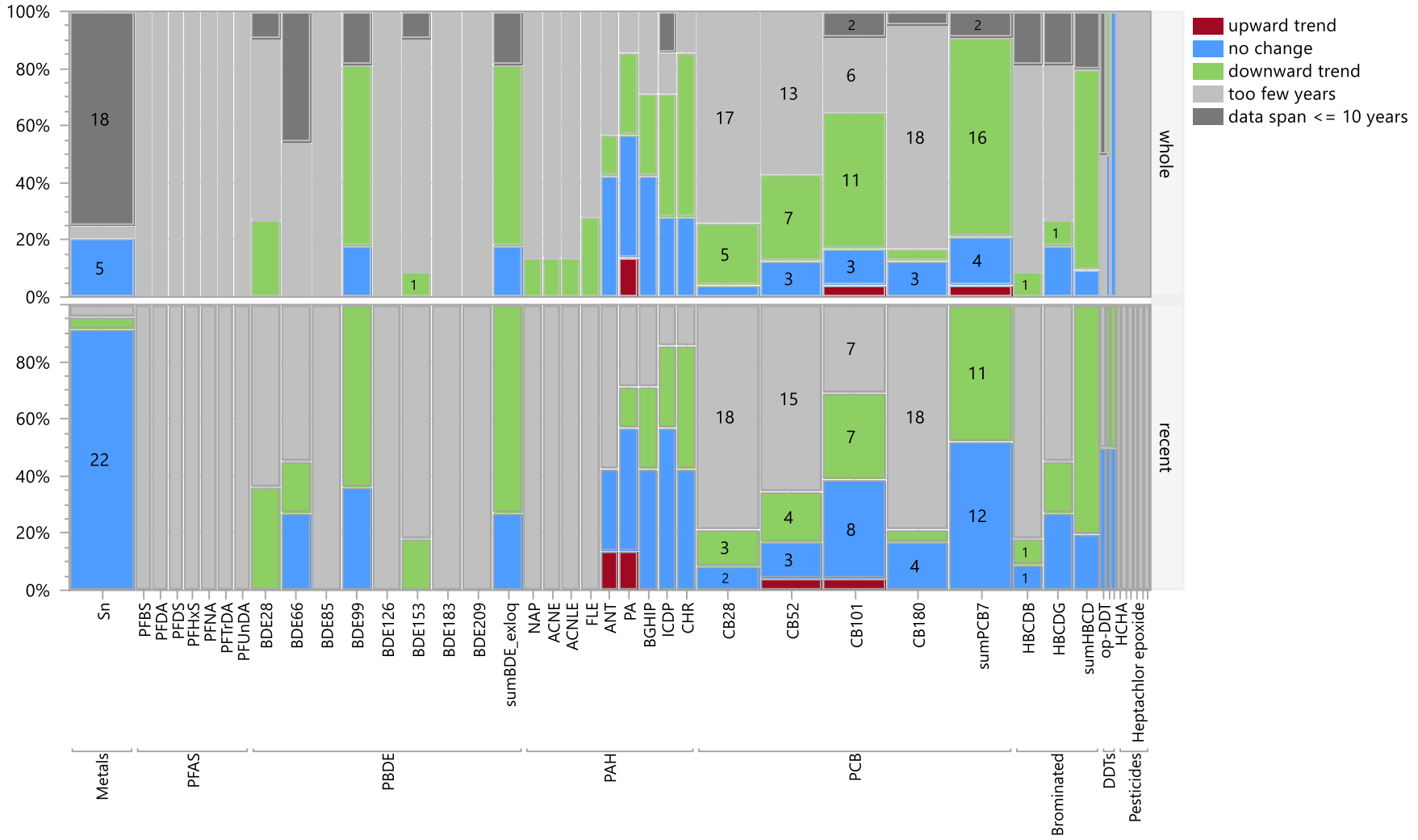


Figure S8. Time trends in blue mussel for contaminants not selected for presentation in 2024. Upper panel shows recent trends, while lower panel shows whole trends. The number of stations is indicated in the respective cells. For contaminant names not visible in this figure, please see **Figure S12**.

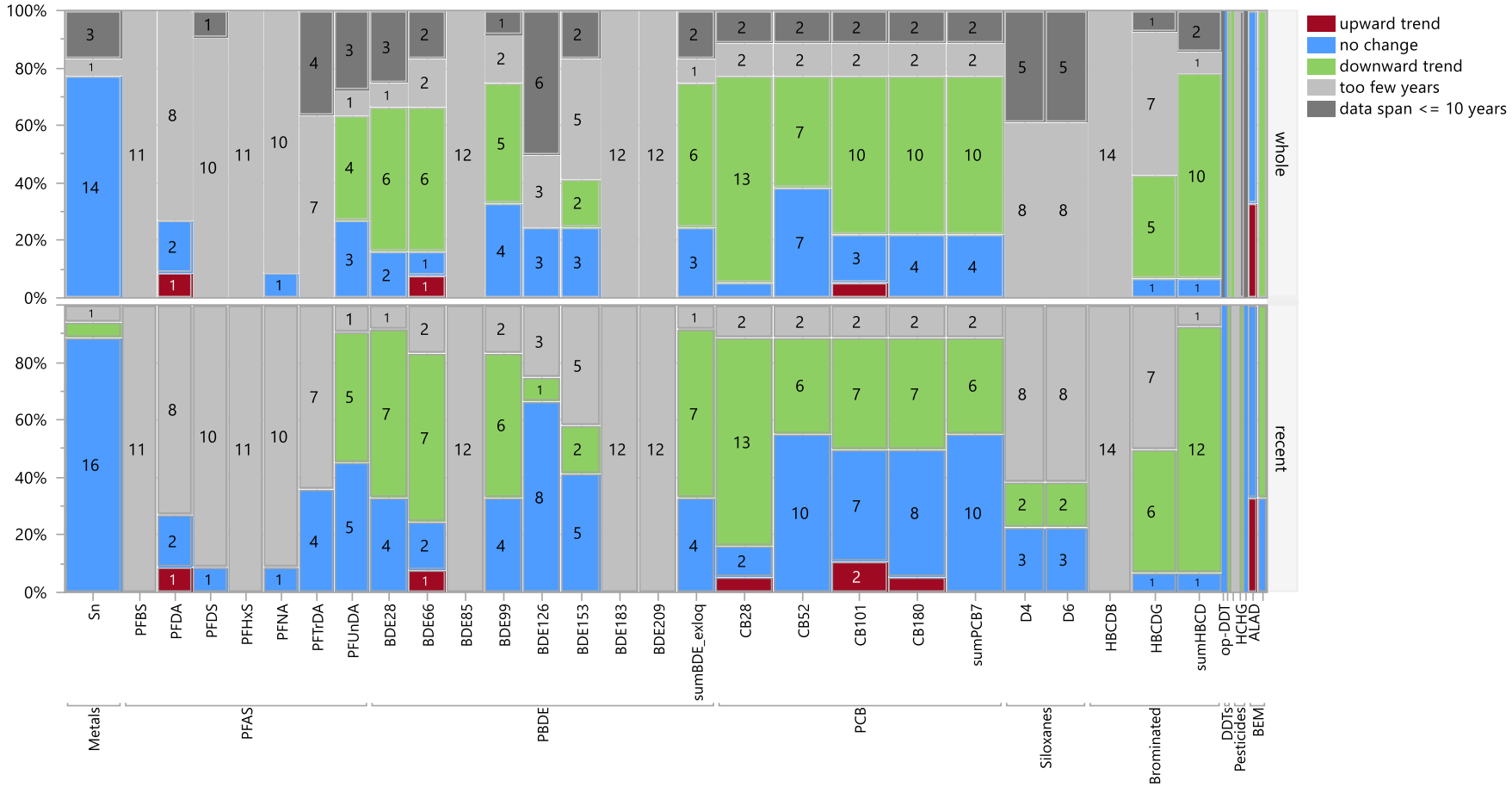


Figure S9. Time trends in cod for contaminants not selected for presentation in 2024. Upper panel shows recent trends, while lower panel shows whole trends. The number of stations is indicated in the respective cells. For contaminant names not visible in this figure, please see **Figure S13** and **Figure S14**.

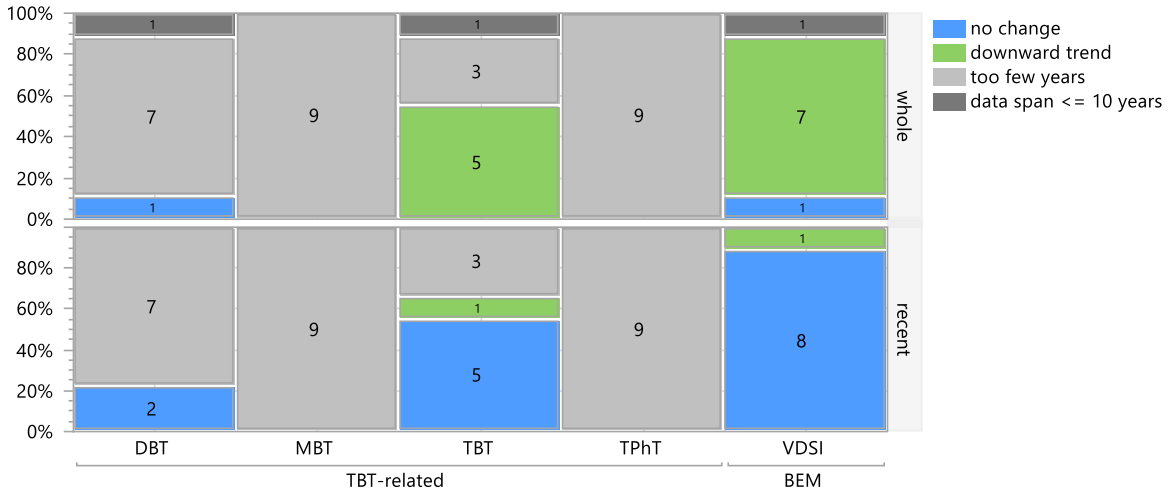


Figure S10. Time trends in snails for contaminants not selected for presentation in 2024. Upper panel shows whole trends, while lower panel shows recent trends. The number of stations is indicated in the respective cells.

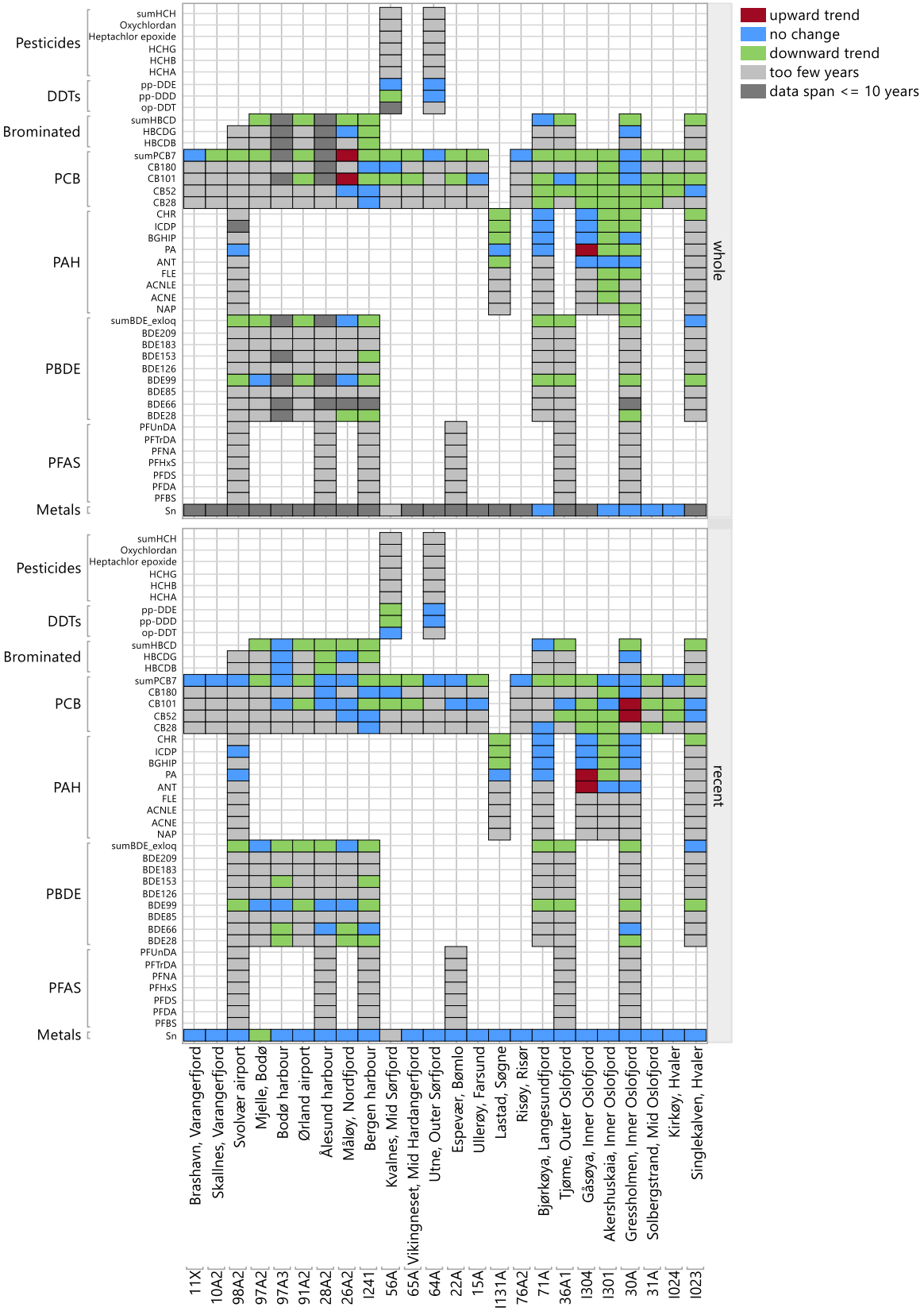


Figure S11. Heatmap for time trends in blue mussel for contaminants not selected for presentation in 2024. The colours represent time trends observed at stations. Empty "cells" mean that the contaminant was not analysed for at the indicated station. Grey lines show the midpoint of each station and contaminant.

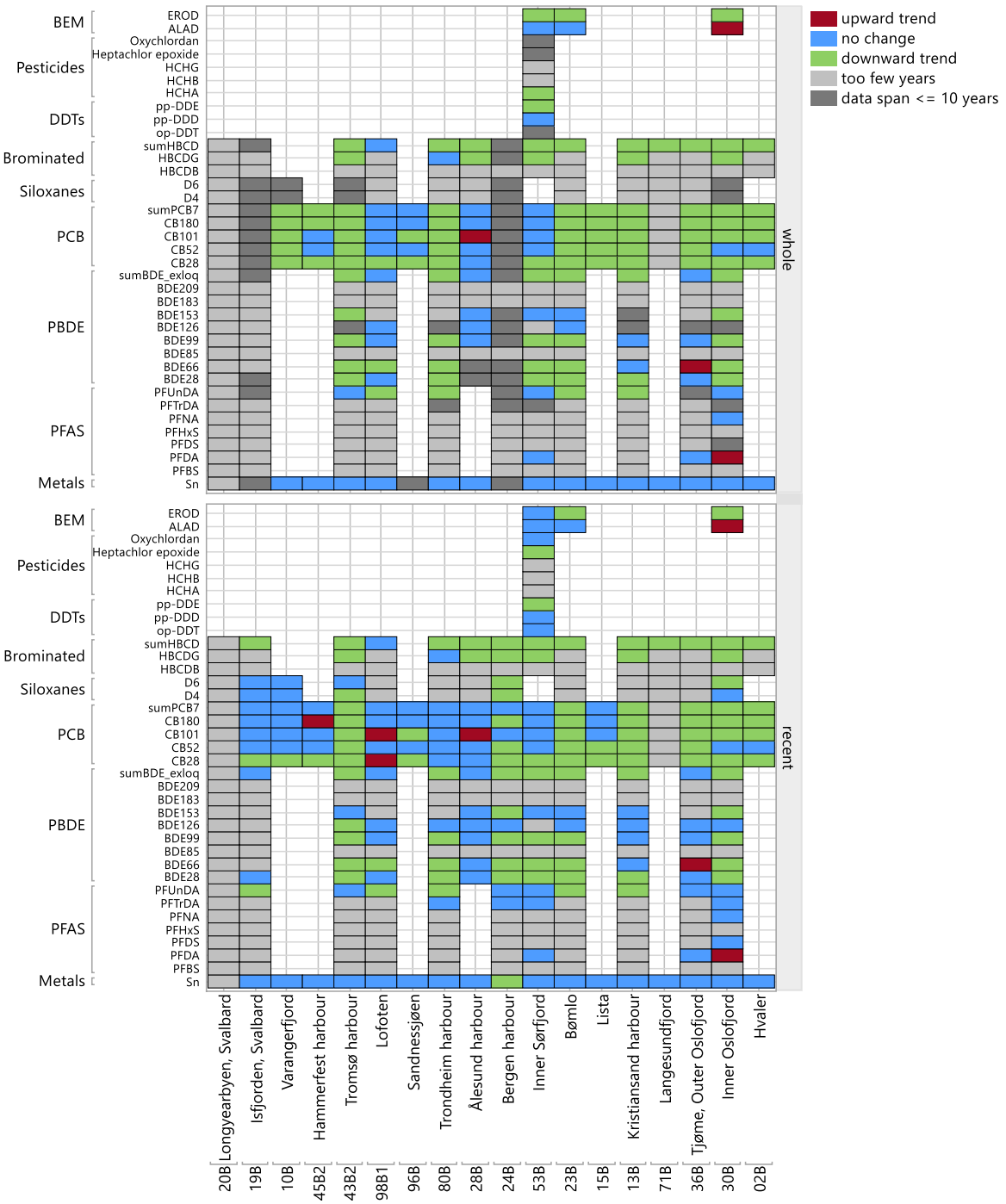


Figure S12. Heatmap for time trends in cod for contaminants not selected for presentation in 2024. The colours represent time trends observed at stations. Empty "cells" mean that the contaminant was not analysed for at the indicated station. Grey lines show the midpoint of each station and contaminant.

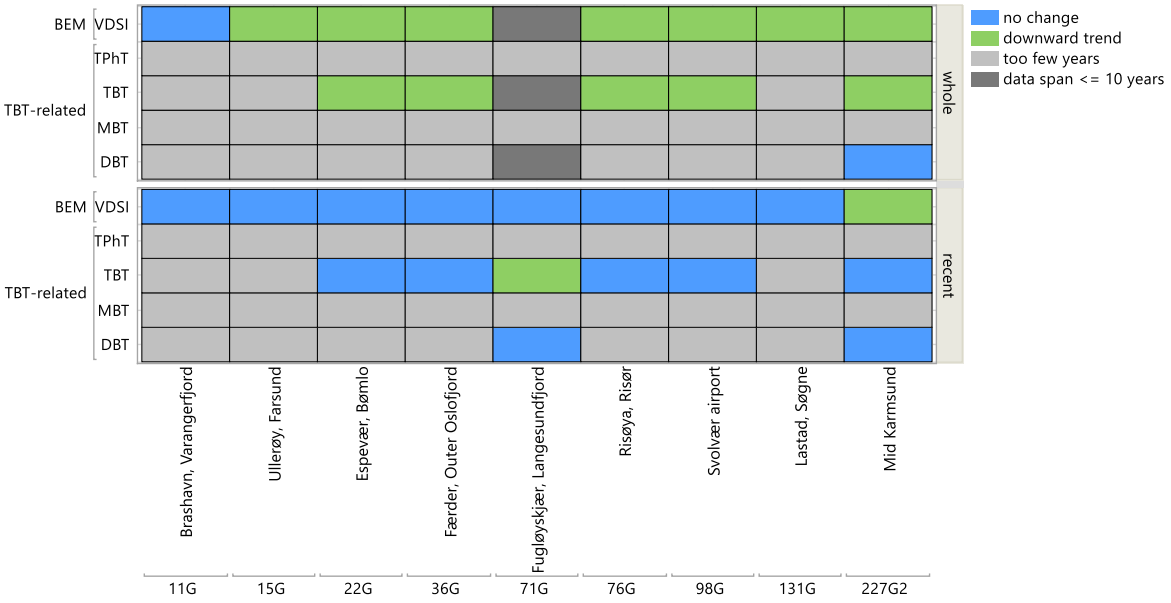


Figure S13. Heatmap for time trends in snails for contaminants not selected for presentation in 2024. The colours represent time trends observed at stations.

Station names

Table S 3. Stations names used in this report and stations names used in Vannmiljø.

Species	Station code	Station name	Latitude	Longitude	Station name in Vannmiljø
Blue mussel (*Mytilus edulis*)	11X	Brashavn, Varangerfjord	69.8993	29.741	Brashamna, Varangerfjorden
	10A2	Skallnes, Varangerfjord	70.1373	30.3417	Skallneset, Varangerfjorden
	98A2	Svolvær airport	68.2492	14.6627	Husvågen, Svolvær
	97A2	Mjelle, Bodø	67.4127	14.6219	Bodø, Mjelle
	97A3	Bodø harbour	67.2963	14.3956	Bodø havn
	91A2	Ørland airport	63.6514	9.5639	Ørland, ytre Trondheimsfjorden
	28A2	Ålesund harbour	62.4659	6.2396	Ålesund havn
	26A2	Måløy, Nordfjord	61.9362	5.0488	Måløy
	I241	Bergen harbour	60.4008	5.304	Nordnes, Bergen
	56A	Kvalnes, Mid Sørfjord	60.2205	6.602	Kvalnes, Sørfjorden
	65A	Vikingneset, Mid Hardangerfjord	60.2423	6.1527	Vikingnes, Hardangerfjorden
	64A	Utne, Outer Sørfjord	60.4239	6.6223	Utne, ytre Sørfjorden
	22A	Espevær, Bømlo	59.5871	5.152	Espevær, Bømlo
	15A	Ullerøy, Farsund	58.0461	6.9159	Gåsøy, Lista
	I131A	Lastad, Søgne	58.0556	7.7083	Lastad (Selskjær), Trysfjorden
	76A2	Risøy, Risør	58.7327	9.281	Store Vardøya, Risør
	71A	Bjørkøya, Langesundfjord	59.0233	9.7537	Risøyodden (Bjørkøya),
	36A	Færder, Outer Oslofjord	59.0274	10.525	Tjøme (36A1)
	I304	Gåsøya, Inner Oslofjord	59.8513	10.589	Gåsøya, Indre Oslofjord
	I301	Akershuskaia, Inner Oslofjord	59.9053	10.7363	Akershuskaia, Indre Oslofjord
	30A	Gressholmen, Inner Oslofjord	59.8836	10.711	Gressholmen, Indre Oslofjord
	31A	Solbergstrand, Mid Oslofjord	59.6155	10.6515	Solbergstrand, Indre Oslofjord
	I024	Kirkøy, Hvaler	59.0791	10.9873	Hvaler-Singlefjorden, Kirkøy
	I023	Singlekalven, Hvaler	59.0951	11.1368	Hvaler-Singlefjorden,
Cod (*Gadus morhua*)	20B	Longyearbyen, Svalbard	78.2623	15.4795	Longyearbyen
	19B	Isfjorden, Svalbard	78.17	13.46	Svalbard
	10B	Varangerfjord	69.8162	29.7602	Bugøynes, Varangerfjorden
	45B2	Hammerfest harbour	70.65	23.6333	Hammerfest havn
	43B2	Tromsø harbour	69.653	18.974	Tromsø havn
	98B1	Lofoten	68.1858	14.7081	Bjørnerøya øst, Lofoten
	96B	Sandnessjøen	66.0444	12.5036	Helgeland
	80B	Trondheim harbour	63.4456	10.3717	Munkholmen, indre
	28B	Ålesund harbour	62.4678	6.0686	Ålesund, område ved Hundsvær
	24B	Bergen harbour	60.3966	5.2707	Bergen havn
	53B	Inner Sørfjord	60.0973	6.5397	Indre Sørfjorden
	23B	Bømlo	59.8956	5.1086	Karihavet, Bømlo
	15B	Lista	58.0514	6.7469	Ullerø-området, Lista
	13B	Kristiansand harbour	58.1328	7.9885	Kristiansand havn
	71B	Langesundfjord	59.0465	9.7028	Grenlandsfjordene,
	36B	Tjøme, Outer Oslofjord	59.0405	10.4358	Færder-området, Ytre Oslofjord
	30B	Inner Oslofjord	59.8127	10.5518	Oslo-området, Indre Oslofjord
	02B	Hvaler	59.0648	10.9735	Hvalerbassenget, Kirkøy nord
Dogwhelk (*Nucella lapillus*)	11G	Brashavn, Varangerfjord	69.8995	29.7419	Brashamna Varangerfjorden
	98G	Svolvær airport	68.247	14.6664	Husvågen, Svolvær
	22G	Espevær, Bømlo	59.5837	5.1445	Espevær, Bømlo
	227G	Mid Karmsund	59.3396	5.3122	Flatskjer, Karmsundet (227G1)
	15G	Ullerøy, Farsund	58.0493	6.9012	Gåsøy, Lista
	131G	Lastad, Søgne	58.0284	7.699	Lastad (Selskjær), Trysfjorden
	76G	Risøya, Risør	58.728	9.2755	Risøya, Risør
	36G	Færder, Outer Oslofjord	59.0278	10.5256	Færder, Ytre Oslofjord
Common periwinkle	71G	Fugløyskjær, Langesundfjord	58.985	9.8046	Fugløya, Langesundbukta
Common eider (*Somateria mollissima*)	19N	Kongsfjorden, Svalbard	79.004	12.11	Breøyane
Sediments (Option 3)	42S2	Tromsø-Nordbotn	69.675650	18.801383	Tromsø-Nordbotn
	24S2	Bergen-Raunefjord	60.273867	5.144783	Bergen-Raunefjord
	30S2	Steilene2	59.819051	10.567270	Steilene2
Alternative species to cod (Option 11) Pollack (*Pollachius pollachius)*	30B	Inner Oslofjord	59.8127	10.5518	Oslo-området, Indre Oslofjord

Species	Station code	Station name	Latitude	Longitude	Station name in Vannmiljø
Haddock (*Melanogrammus aeglefinus*) **Whiting (*Merlangius merlangus*)**					

Dating of sediment cores from the University of Copenhagen

The table numbers and figure numbers of this chapter has been retained as originally received.

Gamma Dating Center Copenhagen

Copenhagen, November 22nd, 2024

Thorbjørn J. Andersen
Department of Geosciences and Natural Resource Management (IGN)
University of Copenhagen
Oester Voldgade 10
1350 Copenhagen K
e-mail tja@ign.ku.dk
phone +45 35 32 25 03
fax +45 35 32 25 01

Dating of core Oslo

Dating of core Oslo

Methods

The samples have been analysed for the activity of ^{210}Pb, ^{226}Ra and ^{137}Cs via gammaspectrometry at the Gamma Dating Center, Institute of Geography, University of Copenhagen. The measurements were carried out on a Canberra ultralow-background Ge-detector. ^{210}Pb was measured via its gamma-peak at 46,5 keV, ^{226}Ra via the granddaughter ^{214}Pb (peaks at 295 and 352 keV) and ^{137}Cs via its peak at 661 keV.

Results

The core showed surface contents of unsupported ^{210}Pb of around 130 Bq kg^{-1} with a tendency for exponential with depth below 10 cm depth and fairly uniform levels above that level (fig 1).
The calculated flux of unsupported ^{210}Pb is 292 m^{-2} y^{-1} which is about twice the expected flux (based on data shown in Appleby, 2001). This indicates that the site is subject to sediment focusing.

The content of the isotope ^{137}Cs was low, showing a broad peak centered around 12 cm depth and the isotope was generally absent below 28 cm depth.

CRS-modelling has been applied on the profile using a modified method (Appleby, 2001; Andersen 2017) where the activity below 42 cm is calculated on the basis of the regression shown in fig 2. The result is given in table 2 and fig 3 and 4.

The chronology given in table 2 is only valid if bioturbation and other sediment mixing is negligible. If this is not the case, ages given in table 2 are underestimated and accumulation rates are overestimated.

The fairly uniform content of unsupported ^{210}Pb in the upper 10 cm indicates that bioturbation is in fact significant. However, the elevated content of ^{137}Cs in layers dated to after the early 1980´s is consistent with the likely Chernobyl origin of this material (1986 accident). The calculated chronology should be considered as indicative.

Thorbjørn J. Andersen
Professor,
IGN, University of Copenhagen
Oester Voldgade 10, 1350 Copenhagen K, Denmark

References:

Andersen, T.J., 2017. Some Practical Considerations Regarding the Application of ^{210}Pb and ^{137}Cs Dating to Estuarine Sediments. Applications of Paleoenvironmental Techniques in Estuarine Studies . Developments in Paleoenvironmental Research (DPER), Vol. 20, p 121-140.

Appleby, P.G., 2001. Chronostratigraphic techniques in recent sediments. In: Last, W.M & Smol, J.P. (eds) Tracking environmental change using lake sediments. Volume 1: Basin analysis, coring and chronological techniques. Kluwer Academic Publishers, the Netherlands.

Table 1. Radiometric data, core Oslo.

Depth	Pb-210tot	error Pb-210 tot	Pb-210 sup	error pb-210 sup	Pb-210 unsup	error pb-210 unsup	Cs-137	error Cs-137
cm	Bq kg-1	Bq kg-1	Bq kg-1	Bq kg-1	Bq kg-1	Bq kg-1	Bq kg-1	Bq kg-1
1.0	156	15	28	1	129	16	7	3
3.0	142	13	29	2	113	15	13	3
7.0	132	13	19	16	113	29	14	4
9.0	160	14	25	0	135	15	18	3
11.0	106	8	28	3	78	11	15	2
13.0	98	5	31	1	67	6	19	1
17.0	68	4	26	0	42	4	13	1
21.0	80	4	30	1	51	6	5	1
27.0	73	6	29	0	43	6	4	1
29.0	39	5	33	2	6	6	0	0
33.0	42	4	33	2	8	6	1	1
39.0	46	4	35	1	11	5	2	1
41.0	43	4	37	0	5	4	0	0

Table 2. Chronology, core Oslo.

Depth	Age	error age	Date	acc rate	error rate
cm	y	y	y	kg m-2 y-1	kg m-2 y-1
			2024		
1.0	1	2	2023	2.24	0.30
3.0	3	2	2021	2.26	0.32
7.0	10	2	2014	2.12	0.54
9.0	15	2	2009	1.62	0.19
11.0	20	3	2004	1.61	0.24
13.0	24	3	2000	2.05	0.22
17.0	32	3	1992	2.27	0.31
21.0	41	4	1983	2.04	0.30
27.0	69	8	1955	1.16	0.34
29.0	77	8	1947	1.23	1.26
33.0	83	10	1941	3.43	2.18
39.0	102	14	1922	1.71	0.96
41.0	110	8	1914	1.29	0.32

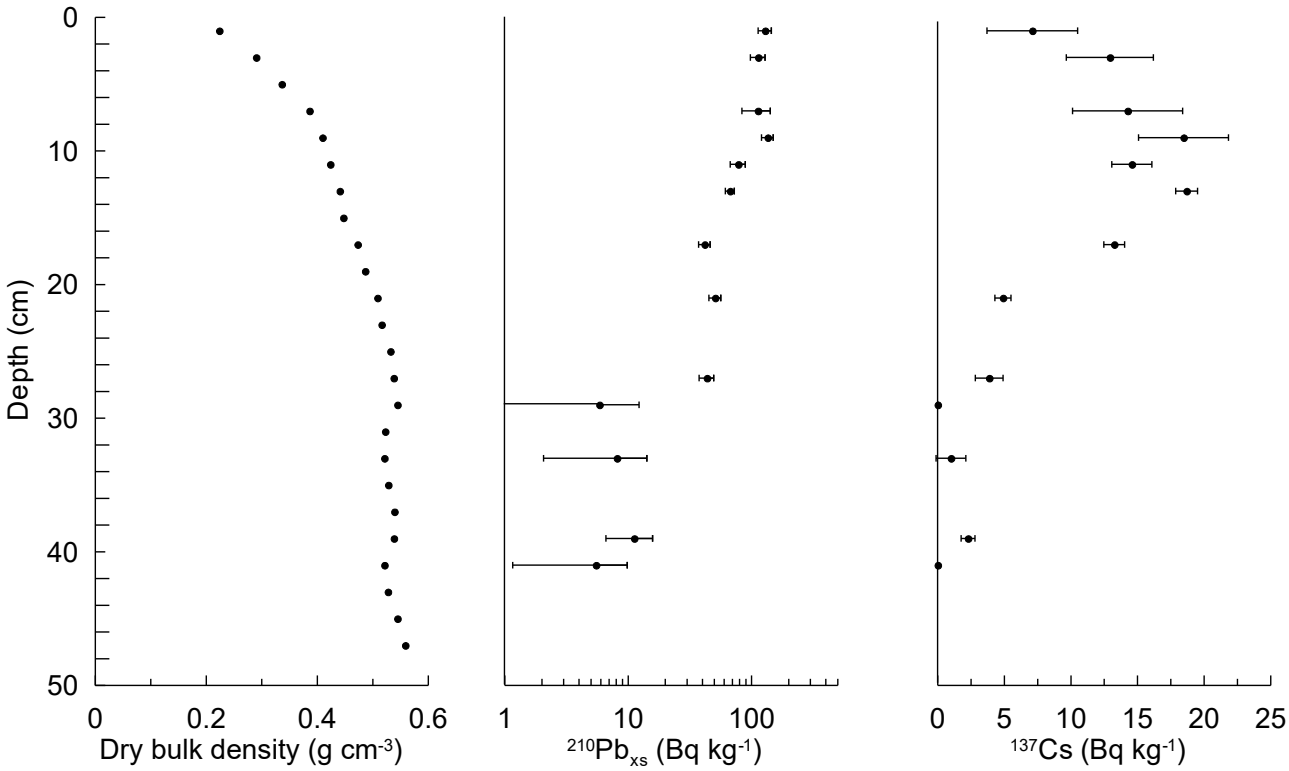


Fig 1. Radiometric data.

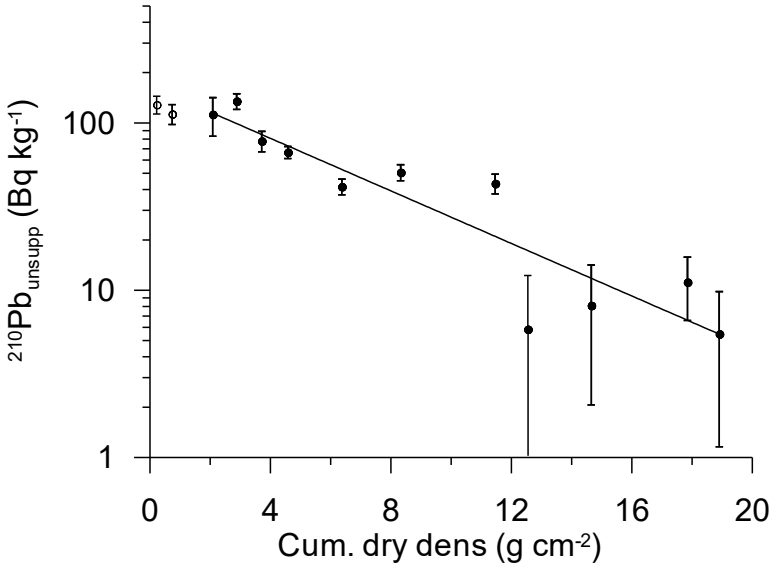


Fig 2. Regression of unsupported ^{210}Pb vs accumulated dry density.

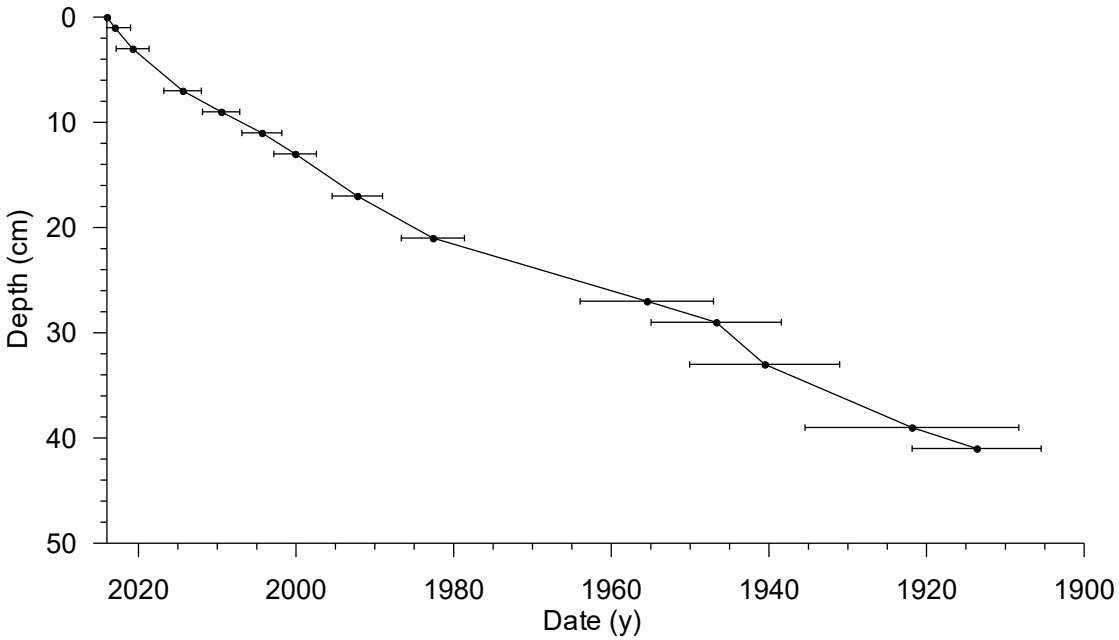


Fig 3. Age-depth figure.

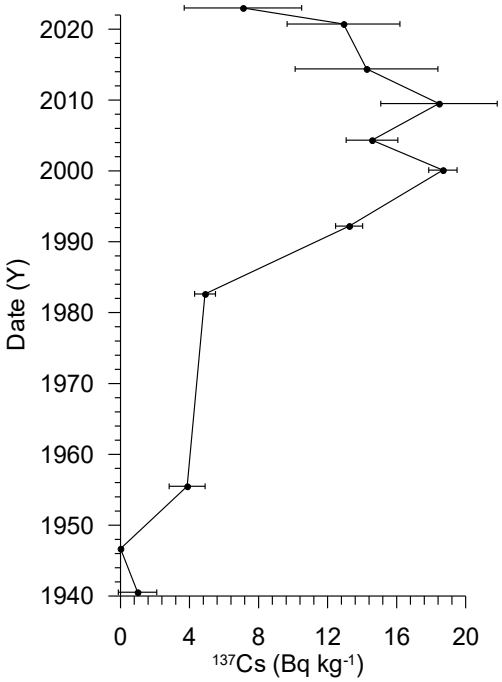


Fig 4. ^{137}Cs profile as dated by ^{210}Pb-dating.

Gamma Dating Center Copenhagen

Copenhagen, November 22nd, 2024

Thorbjørn J. Andersen
Department of Geosciences and Natural Resource Management (IGN)
University of Copenhagen
Oester Voldgade 10
1350 Copenhagen K
e-mail tja@ign.ku.dk
phone +45 35 32 25 03
fax +45 35 32 25 01

Dating of core Bergen

Dating of core Bergen

Methods

The samples have been analysed for the activity of ^{210}Pb, ^{226}Ra and ^{137}Cs via gammaspectrometry at the Gamma Dating Center, Institute of Geography, University of Copenhagen. The measurements were carried out on a Canberra ultralow-background Ge-detector. ^{210}Pb was measured via its gamma-peak at 46,5 keV, ^{226}Ra via the granddaughter ^{214}Pb (peaks at 295 and 352 keV) and ^{137}Cs via its peak at 661 keV.

Results

The core showed surface contents of unsupported ^{210}Pb of around 380 Bq kg^{-1} with a tendency for exponential with depth (fig 1). The calculated flux of unsupported ^{210}Pb is 570 m^{-2} y^{-1} which is about four times higher than the expected flux (based on data shown in Appleby, 2001). This indicates that the site is subject to sediment focusing.

The content of the isotope ^{137}Cs was low, showing a broad peak centered around 12 cm depth but traces were found down to about 25 cm depth.

CRS-modelling has been applied on the profile using a modified method (Appleby, 2001; Andersen 2017) where the activity below 34 cm is calculated on the basis of the regression shown in fig 2. The result is given in table 2 and fig 3 and 4.

The chronology given in table 2 is only valid if bioturbation and other sediment mixing is negligible. If this is not the case, ages given in table 2 are underestimated and accumulation rates are overestimated.

The exponential decline in the content of unsupported ^{210}Pb is indicative of fairly constant sedimentation during the last ~100 years and the chronology is believed to be reliable. However, traces of ^{137}Cs were found in layers dated to well before the initial release of the isotope into nature (mid 1950´s) and slight sediment mixing is therefore indicated.

Thorbjørn J. Andersen
Professor,
IGN, University of Copenhagen
Oester Voldgade 10, 1350 Copenhagen K, Denmark

References:

Andersen, T.J., 2017. Some Practical Considerations Regarding the Application of ^{210}Pb and ^{137}Cs Dating to Estuarine Sediments. Applications of Paleoenvironmental Techniques in Estuarine Studies . Developments in Paleoenvironmental Research (DPER), Vol. 20, p 121-140.

Appleby, P.G., 2001. Chronostratigraphic techniques in recent sediments. In: Last, W.M & Smol, J.P. (eds) Tracking environmental change using lake sediments. Volume 1: Basin analysis, coring and chronological techniques. Kluwer Academic Publishers, the Netherlands.

Table 1. Radiometric data, core Bergen

Depth	Pb-210tot	error Pb-210 tot	Pb-210 sup	error pb-210 sup	Pb-210 unsup	error pb-210 unsup	Cs-137	error Cs-137
cm	Bq kg-1	Bq kg-1	Bq kg-1	Bq kg-1	Bq kg-1	Bq kg-1	Bq kg-1	Bq kg-1
1.0	393	30	14	6	380	36	7	4
3.0	340	24	20	7	320	31	6	2
5.0	294	20	16	7	278	27	8	2
7.0	255	18	16	3	239	21	7	2
9.0	265	22	19	3	246	24	10	3
11.0	216	11	18	2	198	13	8	1
15.0	135	6	18	1	117	7	9	1
19.0	60	5	12	2	49	6	4	1
23.0	48	5	18	2	30	7	5	1
25.0	55	6	18	2	36	8	4	2
29.0	30	3	20	1	10	4	1	1
31.0	26	2	19	2	7	4	1	1
33.0	31	4	19	1	11	5	0	0

Table 2. Chronology, core Bergen.

Depth	Age	error age	Date	acc rate	error rate
cm	y	y	y	kg m-2 y-1	kg m-2 y-1
			2024		
1.0	2	1	2022	1.46	0.14
3.0	6	1	2018	1.44	0.14
5.0	11	1	2013	1.46	0.15
7.0	17	1	2007	1.44	0.13
9.0	23	2	2001	1.27	0.13
11.0	31	2	1993	1.10	0.08
15.0	49	3	1975	1.04	0.10
19.0	67	4	1957	1.13	0.18
23.0	82	5	1942	1.41	0.36
25.0	92	5	1932	1.13	0.26
29.0	116	9	1908	1.00	0.48
31.0	123	8	1901	1.72	0.99

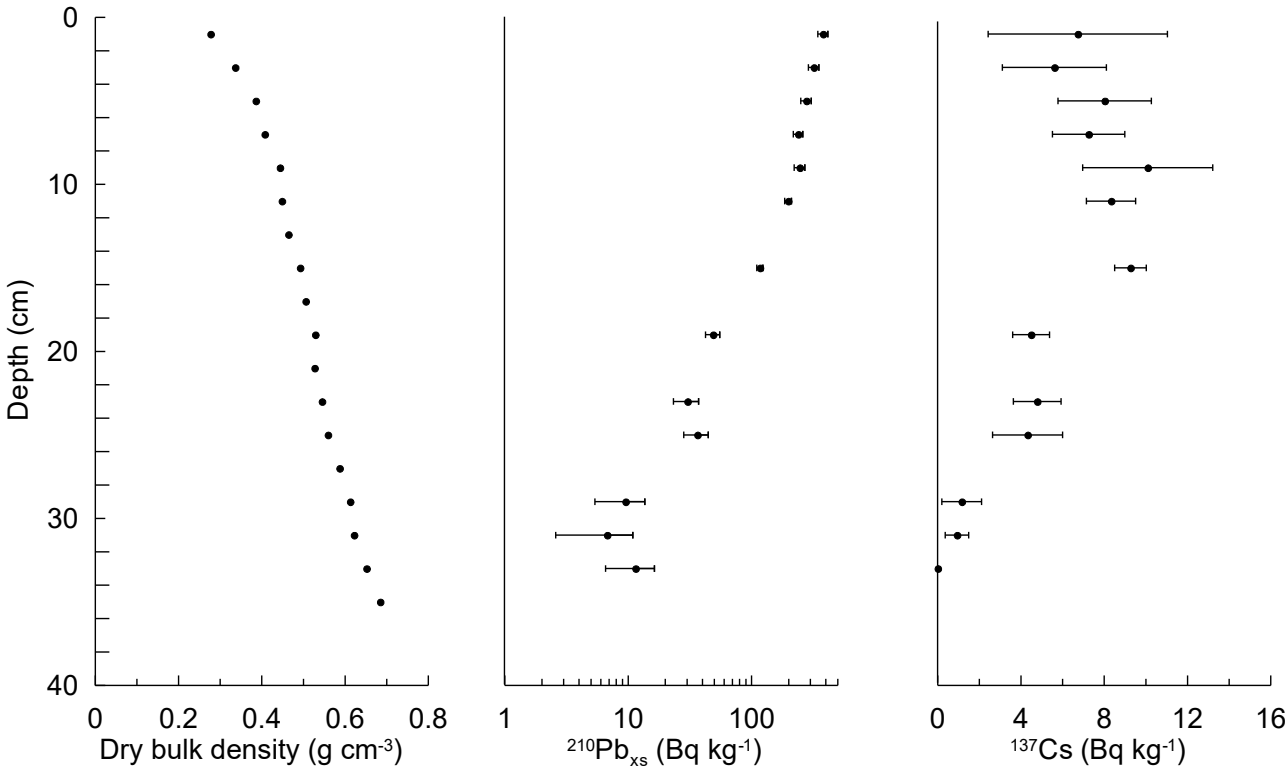


Fig 2. Radiometric data.

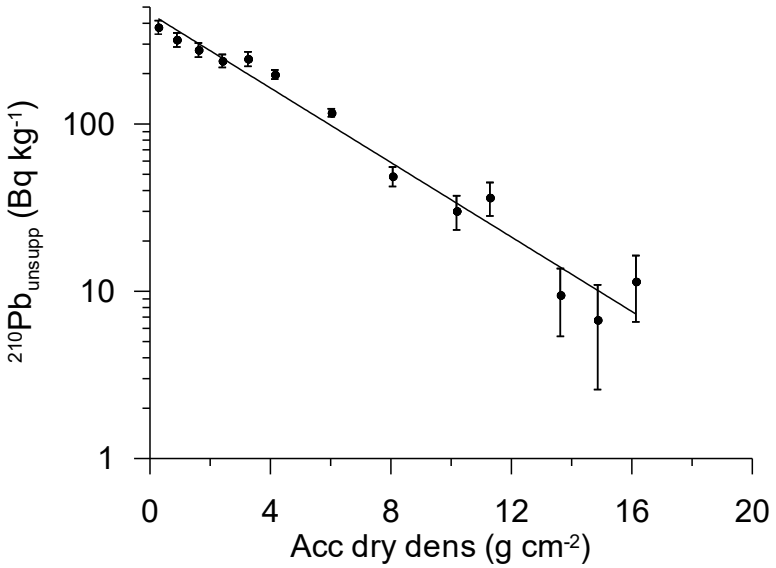


Fig 2. Regression of unsupported ^{210}Pb vs accumulated dry density.

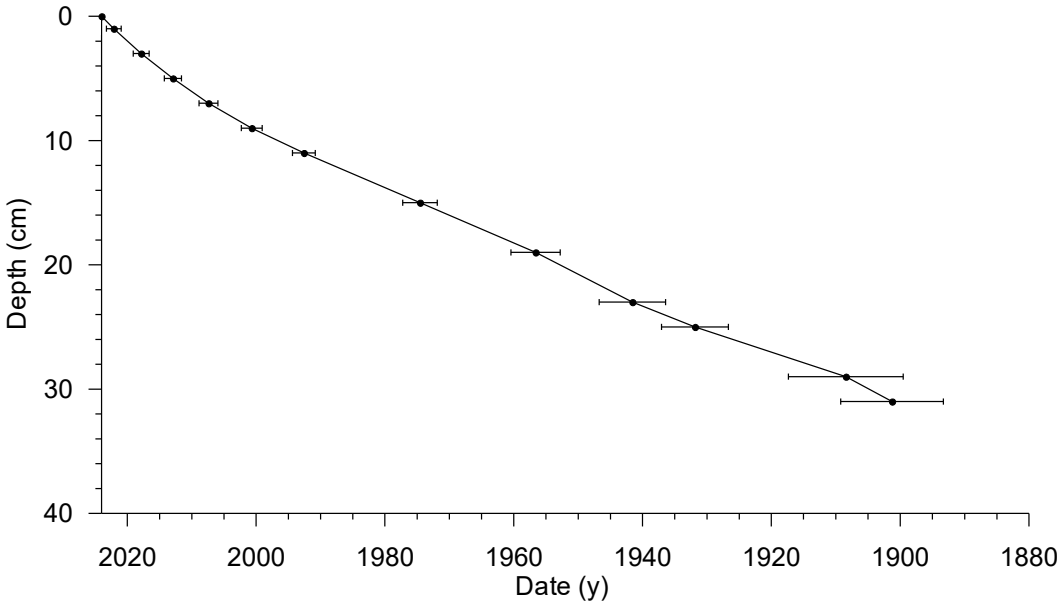


Fig 3. Age-depth figure.

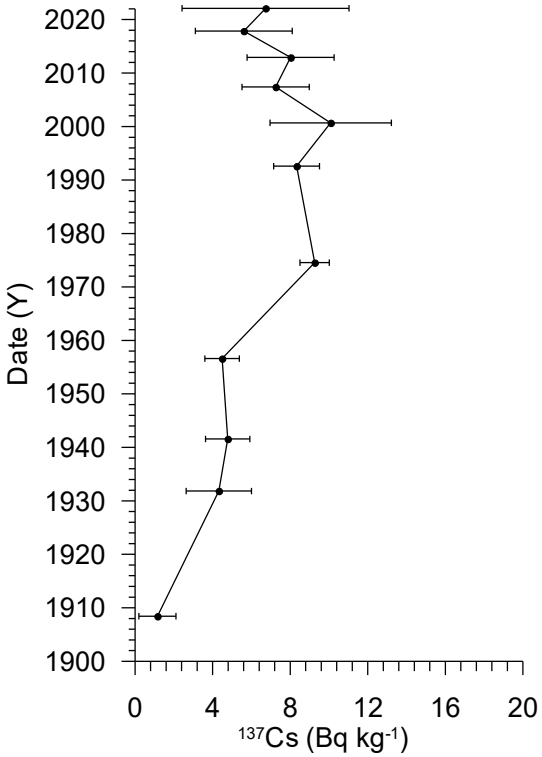


Fig 4. ^{137}Cs profile as dated by ^{210}Pb-dating.

Gamma Dating Center Copenhagen

Copenhagen, October 29th, 2024

Thorbjørn J. Andersen
Department of Geosciences and Natural Resource Management (IGN)
University of Copenhagen
Oester Voldgade 10
1350 Copenhagen K
e-mail tja@ign.ku.dk
phone +45 35 32 25 03
fax +45 35 32 25 01

Dating of core Tromsø

Dating of core Tromsø

Methods

The samples have been analysed for the activity of ^{210}Pb, ^{226}Ra and ^{137}Cs via gammaspectrometry at the Gamma Dating Center, Institute of Geography, University of Copenhagen. The measurements were carried out on a Canberra ultralow-background Ge-detector. ^{210}Pb was measured via its gamma-peak at 46,5 keV, ^{226}Ra via the granddaughter ^{214}Pb (peaks at 295 and 352 keV) and ^{137}Cs via its peak at 661 keV.

Results

The core showed surface contents of unsupported ^{210}Pb of around 160 Bq kg^{-1} with a clear tendency for exponential with depth below 10 cm depth and fairly uniform levels above that level (fig 1).
The calculated flux of unsupported ^{210}Pb is 238 m^{-2} y^{-1} which is about twice the expected flux (based on data shown in Appleby, 2001). This indicates that the site is subject to sediment focusing.

The content of the isotope ^{137}Cs was low and generally absent below 12 cm depth.

CRS-modelling has been applied on the profile using a modified method (Appleby, 2001; Andersen 2017) where the activity below 26 cm is calculated on the basis of the regression shown in fig 2. The result is given in table 2 and fig 3 and 4.

The chronology given in table 2 is only valid if bioturbation and other sediment mixing is negligible. If this is not the case, ages given in table 2 are underestimated and accumulation rates are overestimated.

The fairly uniform content of unsupported ^{210}Pb in the upper 10 cm indicates that bioturbation is in fact significant. However, the dated profile of ^{137}Cs is consistent with the known history of the release of the isotope into nature as measurable levels are only detected in layers dated to after 1960.

The calculated chronology should be considered as indicative.

Thorbjørn J. Andersen
Professor,
IGN, University of Copenhagen
Oester Voldgade 10, 1350 Copenhagen K, Denmark

References:

Andersen, T.J., 2017. Some Practical Considerations Regarding the Application of ^{210}Pb and ^{137}Cs Dating to Estuarine Sediments. Applications of Paleoenvironmental Techniques in Estuarine Studies . Developments in Paleoenvironmental Research (DPER), Vol. 20, p 121-140.

Appleby, P.G., 2001. Chronostratigraphic techniques in recent sediments. In: Last, W.M & Smol, J.P. (eds) Tracking environmental change using lake sediments. Volume 1: Basin analysis, coring and chronological techniques. Kluwer Academic Publishers, the Netherlands.

Table 1. Radiometric data, core Tromsø.

Depth	Pb-210tot	error Pb-210 tot	Pb-210 sup	error pb-210 sup	Pb-210 unsup	error pb-210 unsup	Cs-137	error Cs-137
cm	Bq kg-1	Bq kg-1	Bq kg-1	Bq kg-1	Bq kg-1	Bq kg-1	Bq kg-1	Bq kg-1
1.0	179	14	15	3	164	17	7	2
3.0	167	13	16	4	151	17	9	2
5.0	157	13	14	0	143	13	5	2
7.0	160	13	15	1	145	13	8	2
9.0	136	9	15	1	120	10	11	1
11.0	95	7	18	0	77	7	9	1
13.0	67	7	19	2	49	9	0	0
15.0	37	4	22	2	15	6	0	0
17.0	36	4	18	4	18	7	3	1
19.0	25	3	18	1	7	4	0	0
21.0	27	3	20	1	8	4	0	0
23.0	21	3	18	2	3	4	0	0
25.0	15	2	19	1	0	3	0	0

Table 2. Chronology, core Tromsø.

Depth	Age	error age	Date	acc rate	error rate
cm	y	y	y	kg m-2 y-1	kg m-2 y-1
			2024		
1.0	2	2	2022	1.4	0.1
3.0	8	2	2016	1.3	0.1
5.0	14	2	2010	1.1	0.1
7.0	23	2	2001	0.9	0.1
9.0	35	3	1989	0.7	0.1
11.0	51	4	1973	0.6	0.1
13.0	68	6	1956	0.6	0.1
15.0	84	8	1940	0.7	0.3
17.0	97	12	1927	0.9	0.4
19.0	114	15	1910	0.7	0.4
21.0	131	23	1893	0.7	0.6

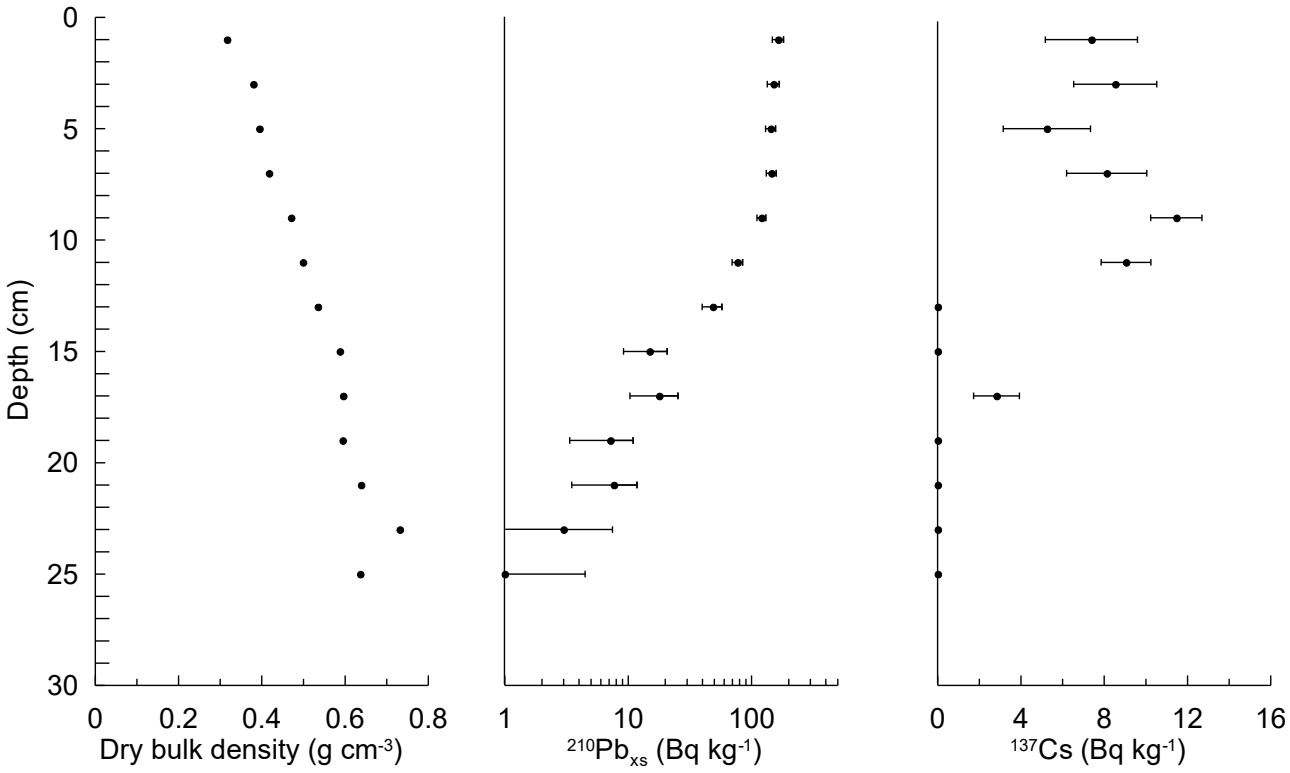


Fig 3. Radiometric data.

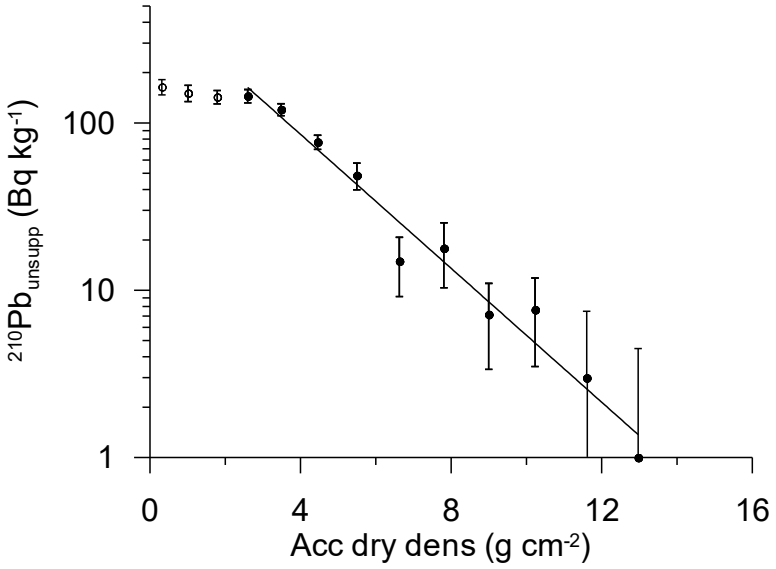


Fig 2. Regression of unsupported ^{210}Pb vs accumulated dry density.

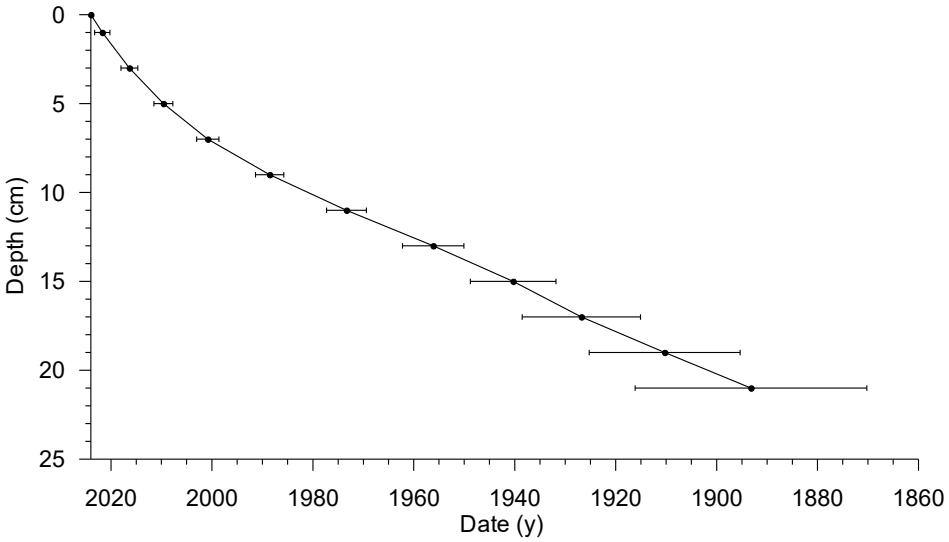


Fig 3. Age-depth figure.

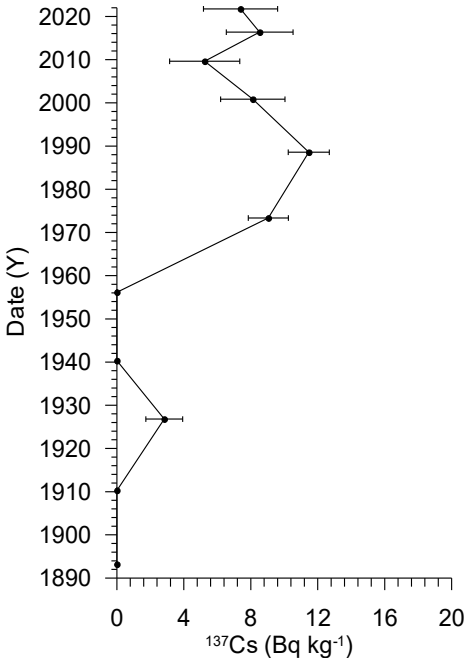


Fig 4. ^{137}Cs profile as dated by ^{210}Pb-dating.

X-ray radiographic imaging (XRI) from NGU

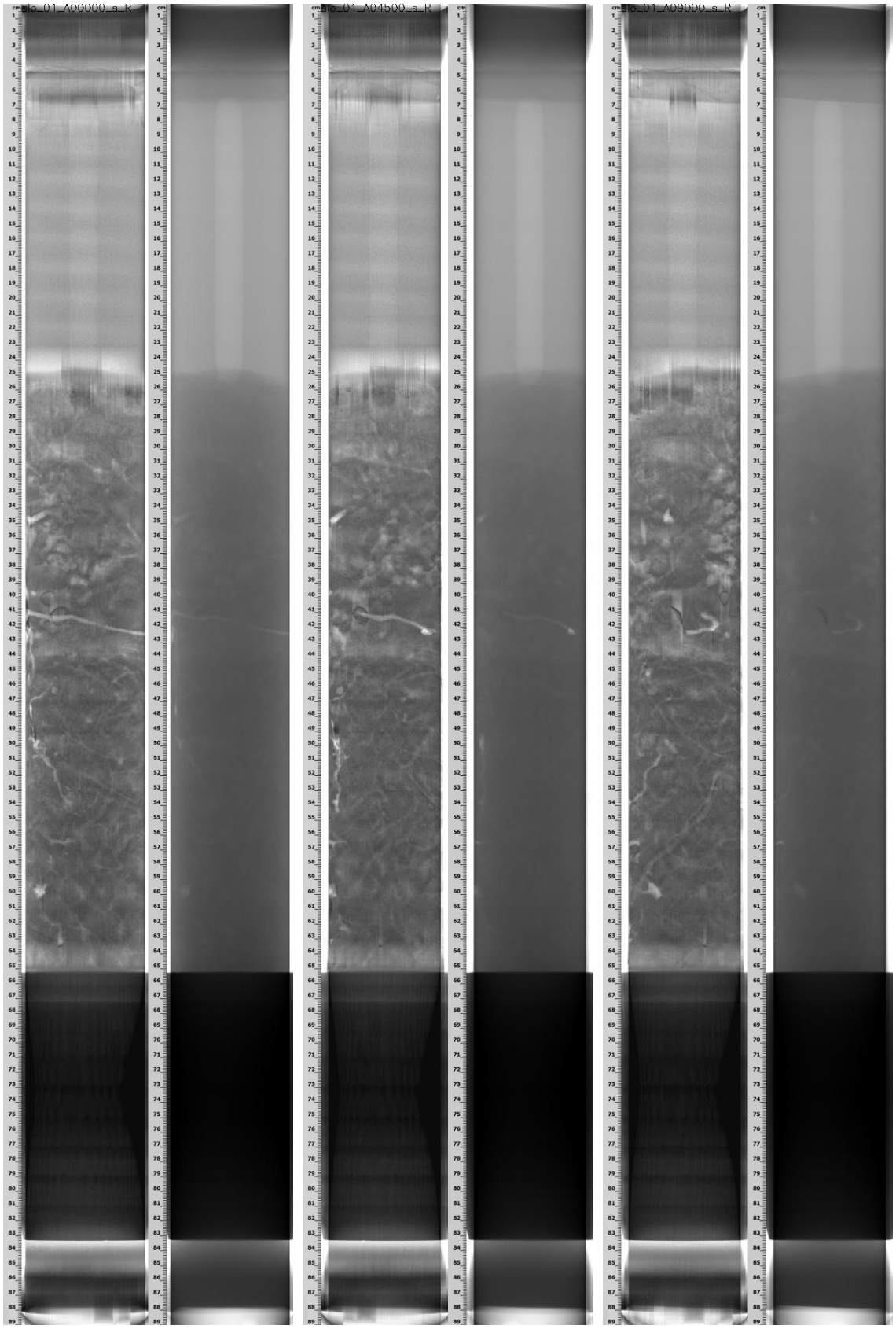


Figure S 14. XRI for sediment core from the Inner Oslo-Steilene (30S2). Regular RXI (right) and enhanced RXI (left) from angles 0°, 45° and 90°, and around their own axis along the core's longitudinal direction. The water column extends from 0 to 25 cm, and the sediment layer from 25 to 65 cm.

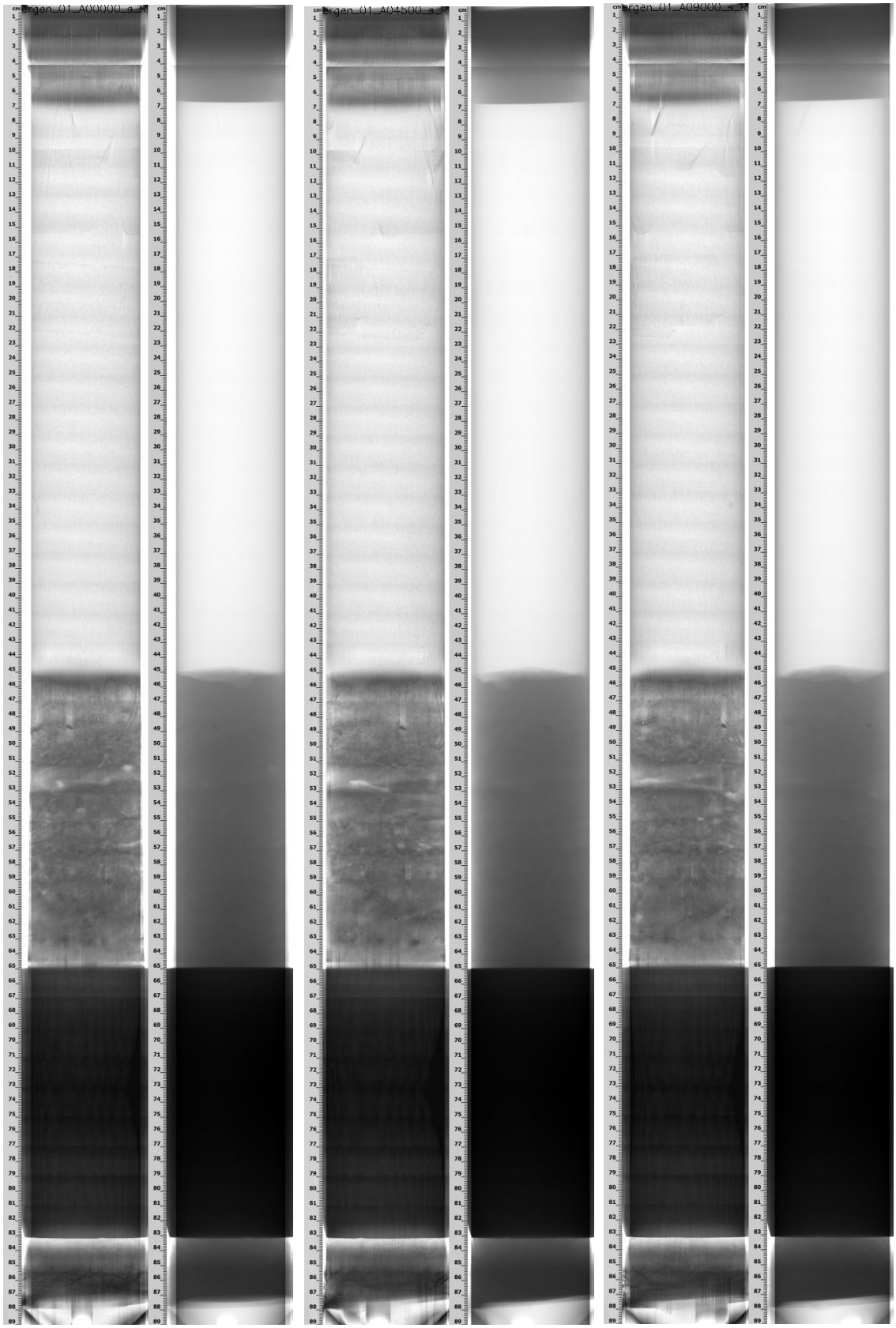


Figure S 15. XRI for sediment core from Bergen-Raunefjord (24S). Regular RXI (right) and enhanced RXI (left) from angles 0°, 45° and 90°, and around their own axis along the core's longitudinal direction. The water column extends from 0 to 45 cm, and the sediment layer from 45 to 65 cm.

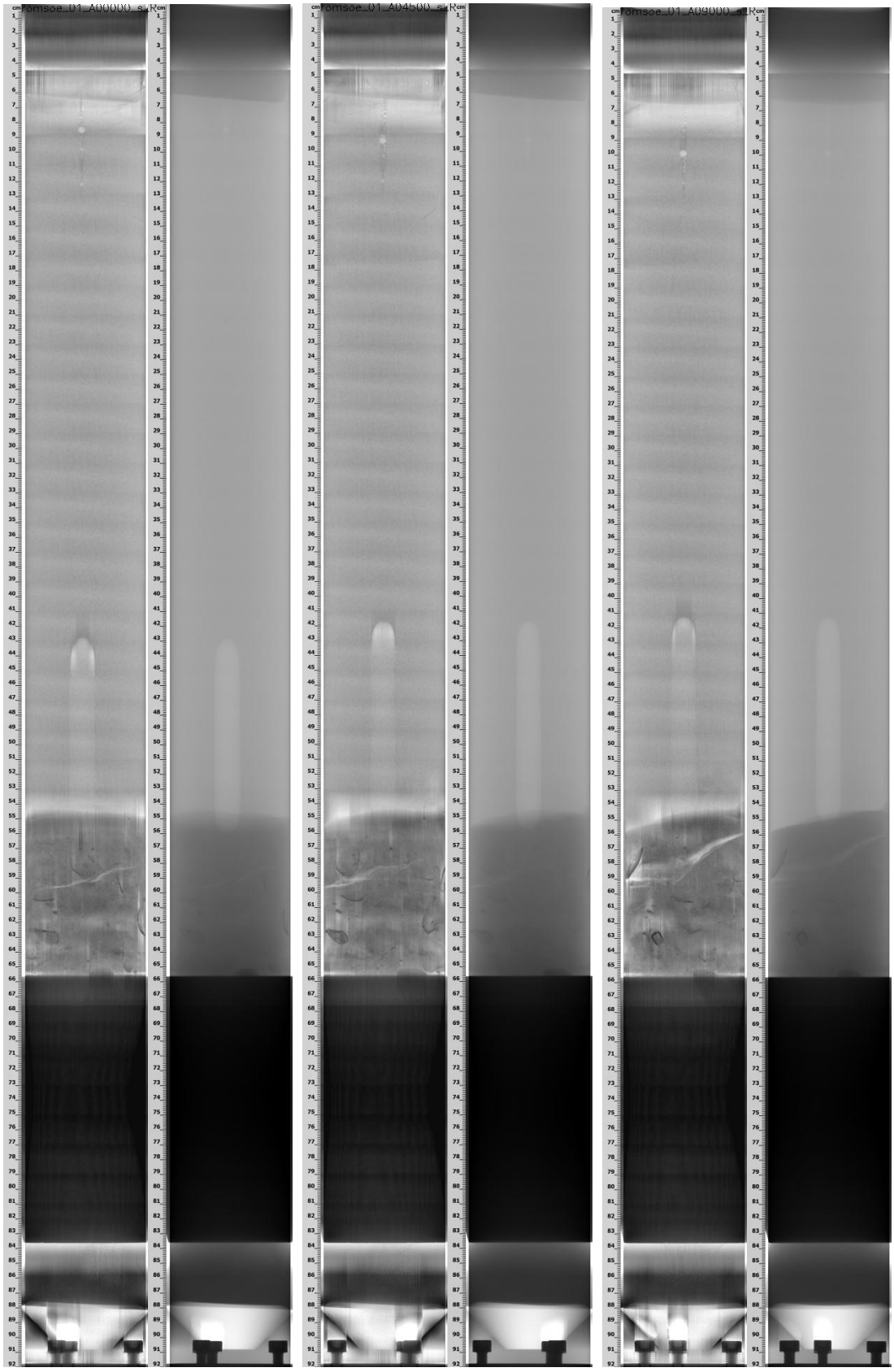


Figure S 16. XRI for sediment core from Tromsø-Nordbotn (42S). Regular RXI (right) and enhanced RXI (left) from angles 0°, 45° and 90°, and around their own axis along the core's longitudinal direction. The water column extends from 0 to 54,5 cm, and the sediment layer from 54,5 to 66 cm.

Matched pairs statistics, by species and normalisation

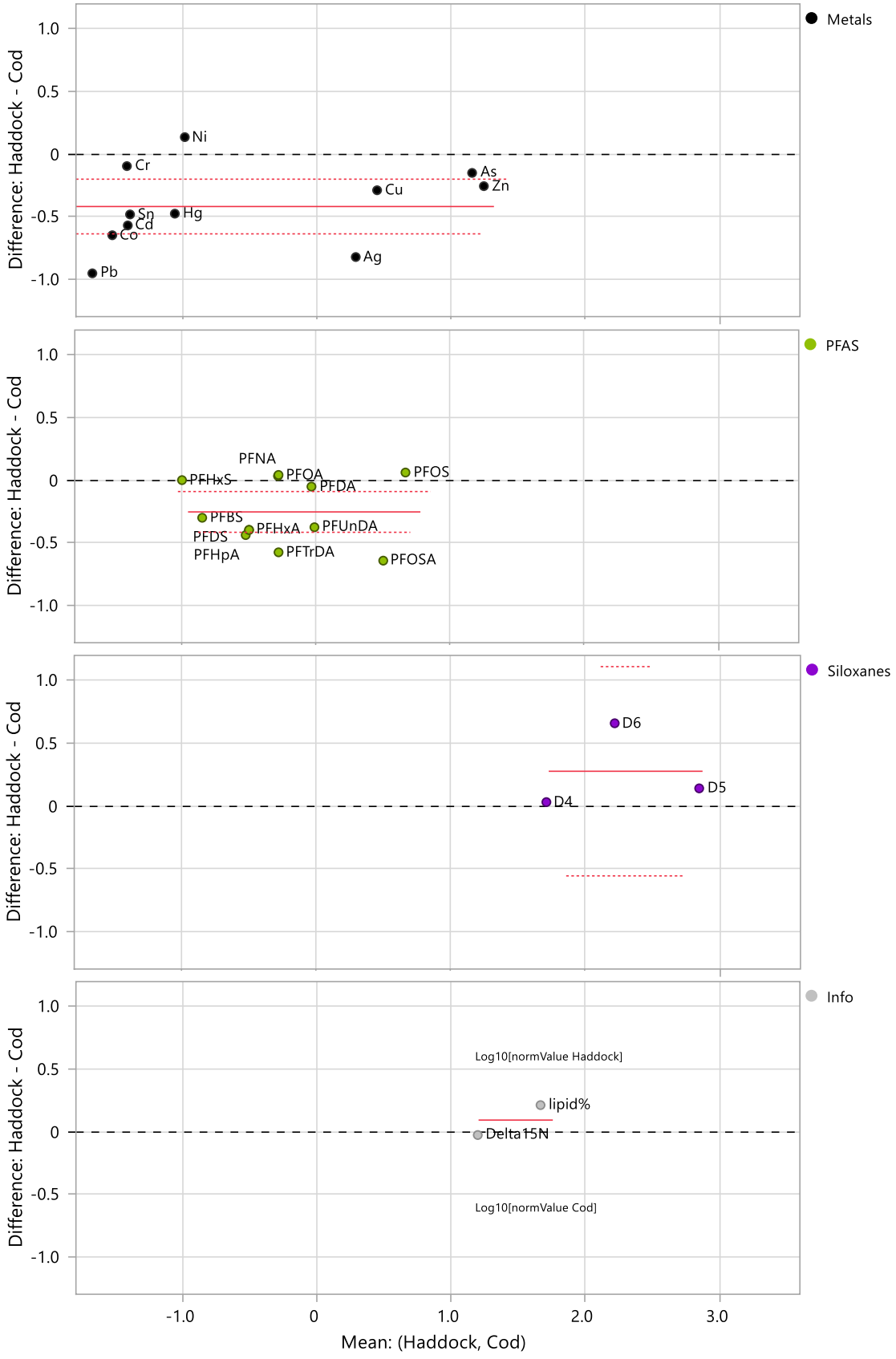


Figure S 17. Mixed pairs statistics for groups normalised to ww in haddock and cod.

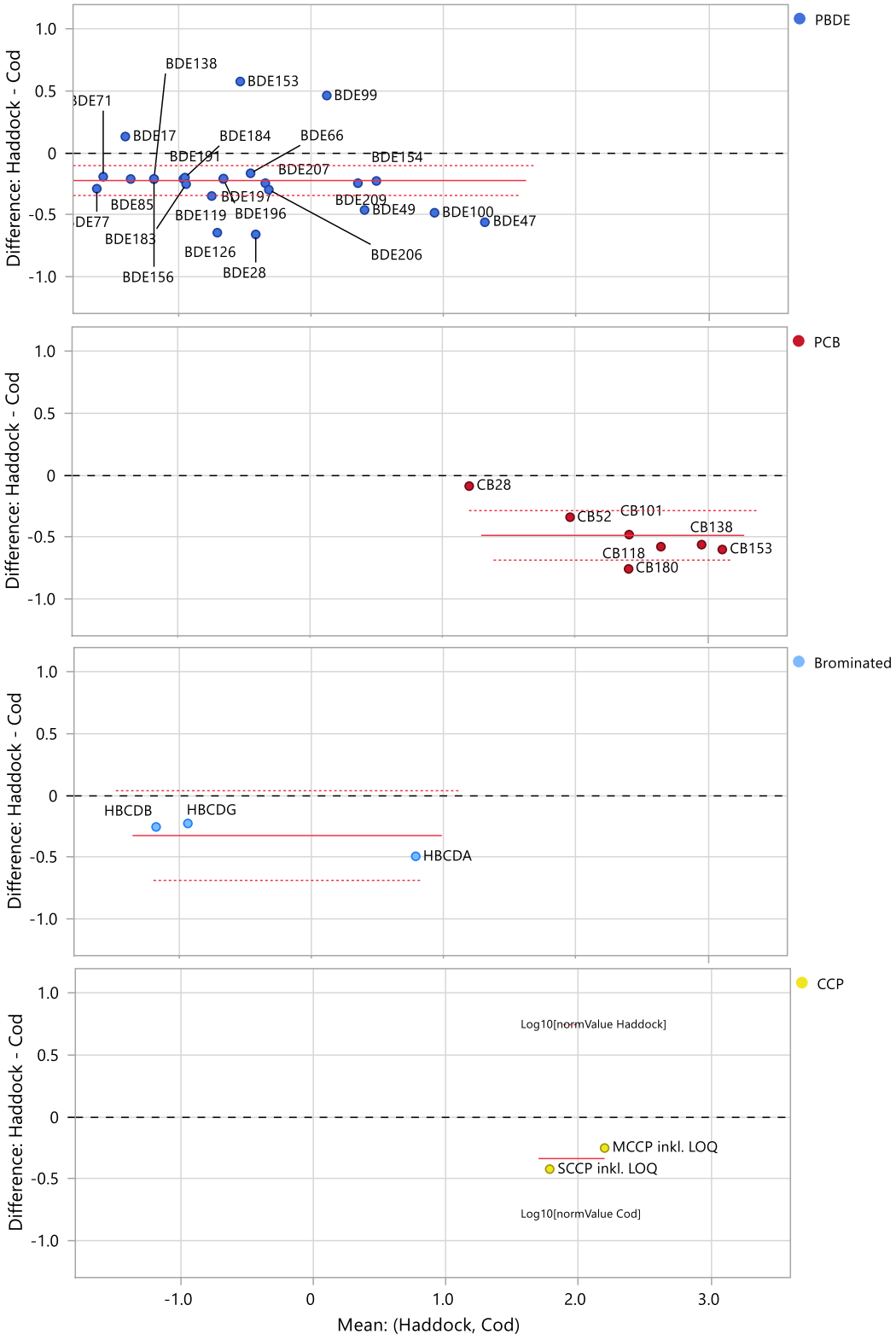


Figure S 18. Mixed pairs statistics for groups normalised to lw (lipid weight) in haddock and cod.

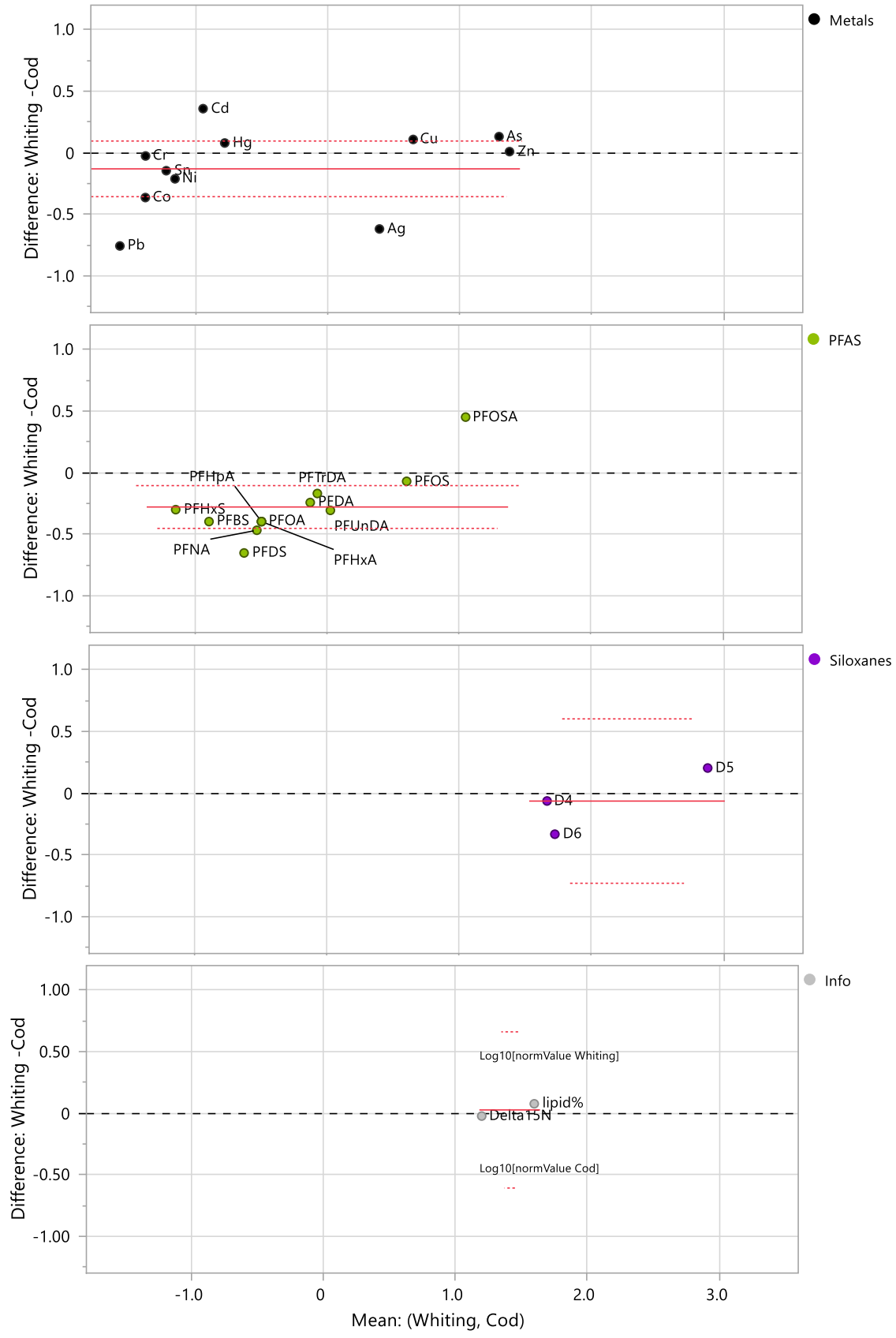


Figure S 19. Mixed pairs statistics for groups normalised to ww in whiting and cod.

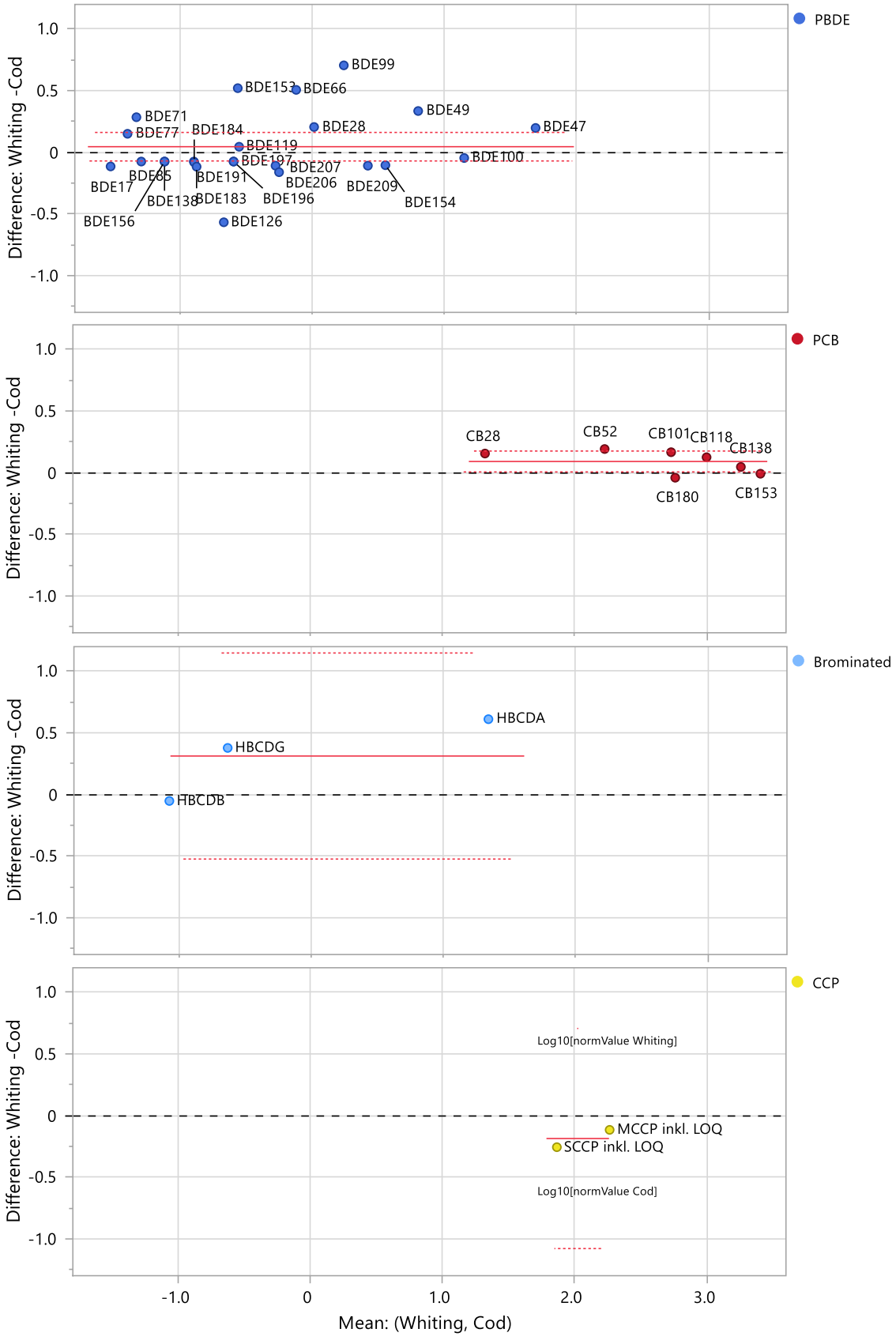


Figure S 20. Mixed pairs statistics for groups normalised to lw in whiting and cod.

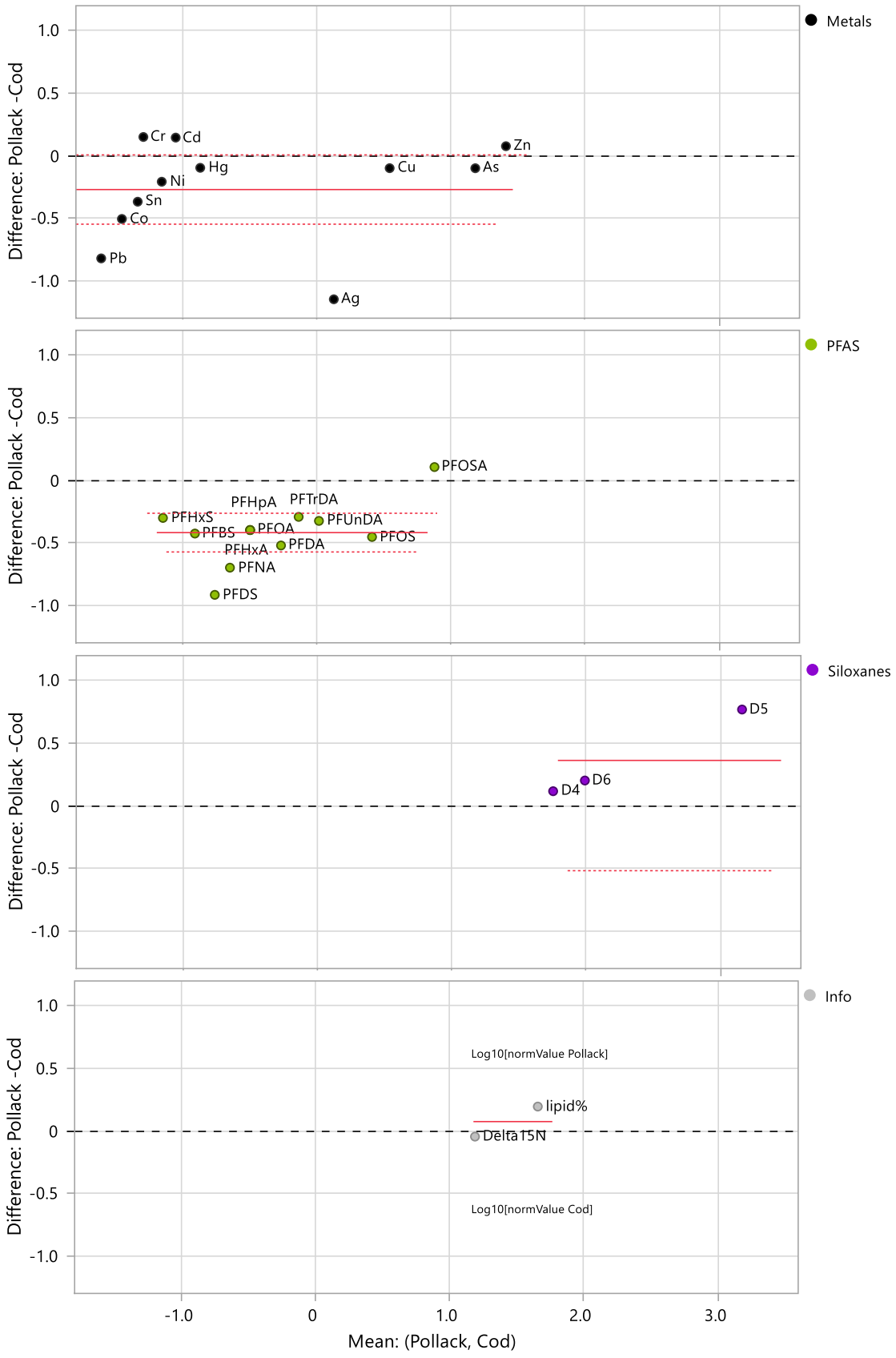


Figure S 21. Mixed pairs statistics for groups normalised to ww in pollack and cod.

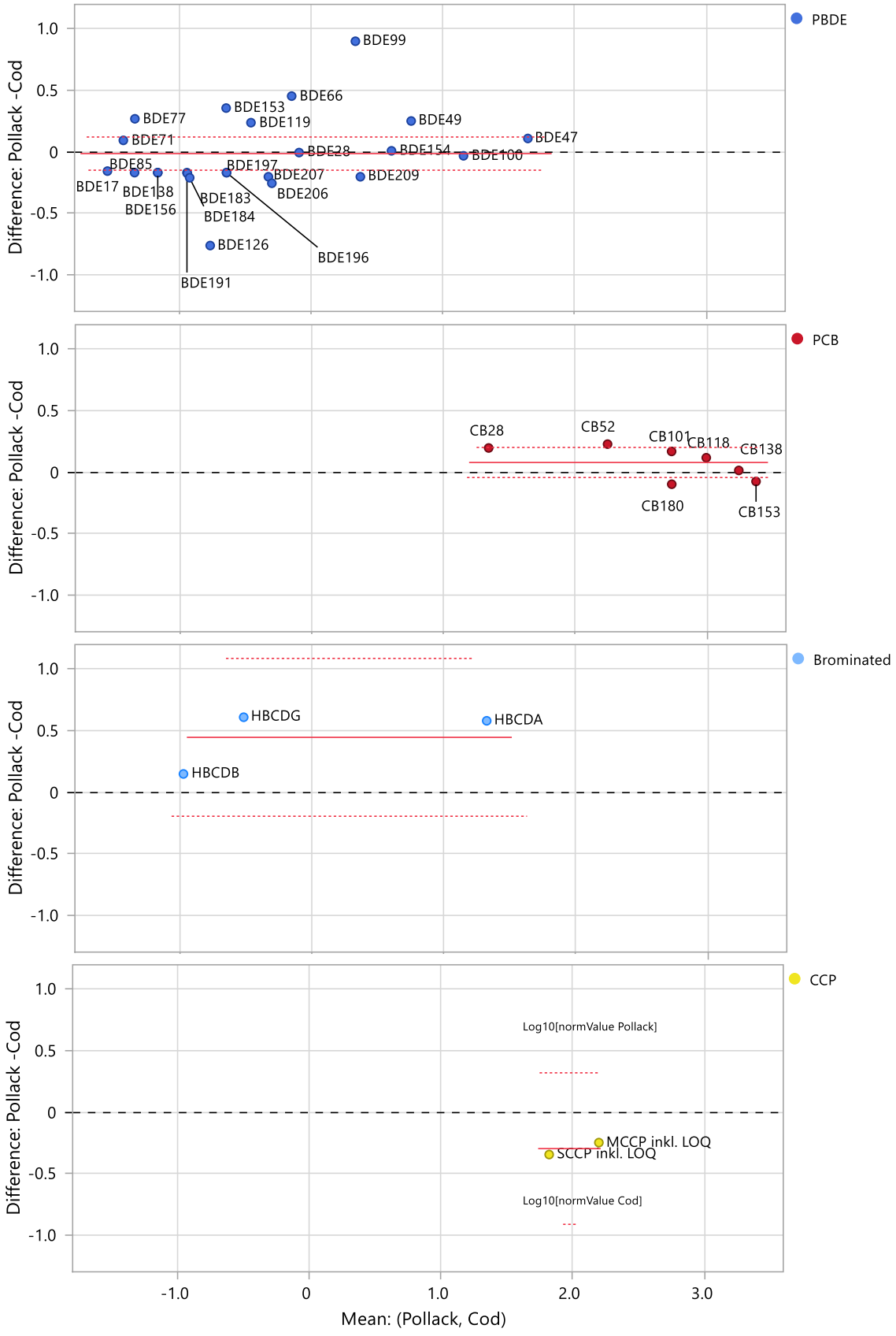


Figure S 22. Mixed pairs statistics for groups normalised to lw in pollack and cod.

Norsk institutt for vannforskning STI (Norwegian Institute for Water Research)

We are Norway's premier research institute in the fields of water and the environment. We are experts on ecosystems in both freshwater and marine environments, from mountains, lakes and rivers, to fjords, coasts and oceans. We develop science-based knowledge and solutions to challenges related to the interaction between water and climate, the environment, nature, people, resources and society.