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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 2023 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 include imposex (VDSI) and intersex (ISI), PAH-metabolites, ALA-D, and EROD.
In this report, 37 contaminants and in addition, BEM were chosen for in-depth presentation. EQSs (Environmental Quality Standards) were exceeded in blue mussel (21 %), cod (36 %) and common eider (25 %) expressed as datapoints (contaminants x stations). Contaminants above EQSs were mercury (Hg), sumPCB7 and sumBDE6. The sum of exceedances (sum of risk quotients) was highest in cod from the Inner Oslofjord. PROREFs (Norwegian provisional high reference contaminant concentrations) were exceeded in blue mussel (42 %) and cod (15 %) expressed as datapoints (contaminants x stations), and exceedances were higher in mussel (up to >20x PROREF) than for cod (5-10x PROREF). The sum of PROREFratio above background levels were highest in blue mussel from Gressholmen followed by Akershuskaia in the harbour of the Inner Oslofjord. Significant downward time trends for specific contaminants/effects dominated both recent (≤ 10 years) and whole period (>10 years) where trends could be statistically detected, still some significant upward trends were observed for contaminants exceeding EQS and/or PROREF. A recently published OSPAR method was used for trends, and the highest occurrence of upward whole and recent trends were found for blue mussel in the Inner Oslofjord, and for cod at Lista and Sandnessjøen. BEM (biomarker analysis) showed no effects of TBT in snail but confirm exposure of PAH and lead in cod. Cod health parameters varied among stations, with lowest rank (lowest health condition) in cod from 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

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Preface

The Norwegian environmental monitoring programme "Contaminants in coastal waters" (Miljøgifter i kystområdene - MILKYS) investigates contaminants in samples of blue mussel, cod, dogwhelk, common periwinkle, and common eider on a yearly basis. This report presents the findings from monitoring performed in 2023, the third year of the five-year period (2021-2025). The coastal monitoring program for contaminants has been performed since 1981. The 2023 campaign was carried out by the Norwegian Institute for Water Research (NIVA) contracted by the Norwegian Environment Agency (NEA, Miljødirektoratet). Coordinator at NEA is Gunn Lise Haugestøl (deputy coordinator Bård Nordbø) and the project manager at NIVA is Merete Schøyen (deputy project manager Merete Grung).

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Merete Schøyen

Project Manager, NIVA

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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 environment 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 2023 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 seven stations, common periwinkle (*Littorina littorea*) at two stations, 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 of diffuse loads of contaminants such as city harbour areas, and in more remote regions with presumed low exposure to pollution. In 2023 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) - principle metabolite of DDT as an indicator)
- hexachlorobenzene (HCB), pentachlorobenzene (QCB), octachlorostyrene (OCS)
- 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)

Biological effect methods (BEM) and parameters were used 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 planar PCBs, PAHs, and dioxins.

Significant downward time trends for contaminants dominated where trends could be detected, although some significant upward trends were observed for contaminants exceeding EQS (Environmental Quality Standards) and/or PROREF (Norwegian provisional high reference contaminant concentrations). The main findings in 2023 can be summarized as follows:

Levels

- The EQSs were exceeded in blue mussel (21 %) and cod (36 %) expressed as datapoints (contaminants x stations) and in common eider (25 %) (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 sum of exceedances (sum of risk quotients) was highest in cod from the Inner Oslofjord as well as the Inner Sørfjord followed by the Langesundfjord and urban areas (harbours).
- The PROREFs were exceeded in blue mussel (42 %) and cod (15 %) expressed as datapoints (contaminants x stations), and exceedances were higher in blue mussel (up to >20x PROREF) than cod (5-10x PROREF). The sum of PROREFratios above background levels were highest in blue mussel from Gressholmen followed by Akershuskaia in the Inner Oslofjord.

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 were 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 of PAH and lead in cod.

EQS

A total of 329 assessments of EQSs for 20 contaminants have been evaluated. EQSs were exceeded in blue mussel (21 %), cod (36 %), and common eider (25 %) expressed as datapoints (contaminants x stations). No exceedances of EQSs were observed in snails. In 2022, the exceedances were 15 % in blue mussel and 36 % in cod.

Contaminants often exceeding EQSs were mercury (there are no EQS values for other metals in biota), sumBDE6, and sumPCB7 for blue mussel and cod.

Blue mussel in the Inner and Outer Oslofjord, in other harbour areas, and in the industrialized Sørfjord had highest number of exceedances of EQS. 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 reference levels. PROREF (provisional high reference contaminant concentrations) 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 42 % of the datapoints (contaminants x stations), and 10 % of the datapoints could not be classified vs. PROREF since the limit of quantification (LOQ) was higher than PROREF. In cod, 15 % of the samples exceeded PROREF, and the exceedances were lower for cod (2-5x PROREF) compared to mussel (up to >20x PROREF).

For comparison with 2022, blue mussel exceeded PROREF for 38 % of the datapoints, and the highest exceedances were up to 10-20x PROREF.

For blue mussel, the highest exceedances of PROREFs were found for PCB118 at Gressholmen in the Inner Oslofjord. Blue mussel stations in the Inner Oslofjord had many exceedances of PROREFs, and among these, Gressholmen and Akershuskaia had the most and highest exceedances. PCBs had the highest exceedances, which were observed in several urban stations; harbours of Ålesund, Bergen, and Oslo. For metals, the highest exceedances of PROREFs were found for lead at Kvalnes in the Sørfjord.

For cod, there were most exceedances of PROREF in the Inner Oslofjord and Inner Sørfjord, and in the harbours of Bergen and Ålesund.

Time trends

A recently published OSPAR method was used for the first time. A total of 774 time trends (whole and recent) were estimated for the contaminants presented in the extended summary. In general, there were fewer whole trends estimated (due to insufficient data), while no trends and downward trends dominated. 2022 was also dominated by no trends followed by downward trends.

Recent time trends
There were more datapoints (contaminants x stations) that could be determined for recent time trends (≤ 10 years) than whole trends for both blue mussel and cod. "No change" dominated for blue mussel (57 %), followed by downward trend (20 %). The same data in cod were 56 % (no change) and 27 % (downward trend). Upward recent trends were found both in mussels and cod (10 % and 5 %, respectively). In blue mussel, there were instances of upward recent trends for most metals and for some stations PCBs. For cod, there were upward recent trends for metals at some stations, and for PCB and PBDE at some stations. Notably, a recent upward trend of PFOS in cod from Isfjorden, Svalbard was observed. The highest occurrences of upward whole and recent trends were found at blue mussel stations in the Inner Oslofjord, and at cod stations at Lista and Sandnessjøen. "No change" dominated for common eider (60 %), followed by downward trends (19 %). No upward trends were observed.

Whole time trends
Whole time trends (> 10 years) in blue mussel were dominated by "no change" (46 %) followed by downward trends (27 %). Upward trends were observed for 6 % of data. In the rest of the data trends could not be determined due to lacks in the dataset. The picture was similar for whole trends in cod compared to blue mussel, but the percentage of downward trends was somewhat higher (29 %). "No change" were observed for 39 % of data for cod and upward trends for 6 %.

Upward time trends with exceedances of EQS and/or PROREF
Special attention needs to be paid on the upward time trends for contaminants which at the same time exceed EQS and/or PROREF (≥5 for mussel and ≥2 for cod). This was the case for seven combinations of contaminants, stations, and species. In cod fillet from the Inner Oslofjord, Kristiansand harbour and Lista, there were upward time trends in addition to exceedance of EQS (RQ) and PROREF for mercury. In blue mussel from Gressholmen in the Inner Oslofjord, there were upward time trends in addition to exceedance of PROREF for some PCB parameters (CB118, CB138 and CB153), and this was also the case for mercury at Akershuskaia.

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).

Results of OH-pyrene metabolites in bile could only be obtained from station Lista (15B), and the median concentration was below the ICES/OSPAR assessment criterion (background assessment criteria), however, with large variation.

ALA-D activity in cod blood in the Inner Sørfjord was significantly lower than at the reference station (Bømlo). Reduced activities of ALA-D reflect higher exposure to lead. The highest (among all stations) hepatic concentrations of lead were found in cod from the Inner Sørfjord (53B).

The median EROD activity appeared lower at Bømlo (23B, reference station), than in the Inner Oslofjord (30B) and Inner Sørfjord (53B), however the difference was only statistically significant from the Inner Oslofjord. Median EROD activities were below the ICES/OSPAR assessment criterion (background assessment criteria), at all stations. No particularly elevated EROD activity could be observed in the cod specimens accumulating very high PCB concentrations in the Sørfjord.

Cod health parameters

For the first time, health parameters of cod is included in this report. A ranking of fish health parameters (Fulton CI (Fulton condition index), HSI (hepatosomatic index) and “weight at age” (weight/age)) showed that the highest indices were found in cod from Bømlo (23B), Ålesund harbour (28B), Lofoten (98B1) and Tromsø harbour (43B2), while lowest indices was found in cod from the Inner Oslofjord (30B). This means that cod from the Inner Oslofjord had lowest health condition for parameters investigated.

Sammendrag

Tittel: Miljøgifter i kystområdene 2023.
År: 2024.
Forfatter(e): 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 (Akvaplan-niva) Veronica Eftevåg, og Kine Bæk.
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Overvåkingsprogrammet «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 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 2023 omfattet overvåkingen miljøgifter i blåskjell (*Mytilus edulis*) fra 24 stasjoner, torsk (*Gadus morhua*) fra 18 stasjoner, purpursnegl (*Nucella lapillus*) fra syv stasjoner, strandsnegl (*Littorina littorea*) fra to stasjoner 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. Overvåkingen i 2023 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 (PCBer)
- diklordifenyltrikloretan (DDT, bruker diklordifenyldikloretylen (DDE) metabolitt av DDT som indikator)
- heksaklorbenzen (HCB), pentaklorbenzen (QCB), oktaklorbenzen (OCB)
- 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)

Biologiske effekt metoder (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 plane PCBer, PAHer og dioksiner.

Signifikante nedadgående tidstrender for miljøgifter dominerte der hvor trender kan påvises, likevel ble det observert signifikante økende trender for miljøgifter som overskred EQS (Environmental Quality

Standards) og/eller PROREF (norsk provisorisk høy referansekonsentrasjon for miljøgifter). Hovedfunnene i 2023 kan oppsummeres slik:

Nivåer

- Det var overskridelser av EQS i blåskjell (21 %) og torsk (36 %) målt ved datapunkter (miljøgifter x stasjoner) og i ærfugl (25 %) (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). Summen av overskridelser (sum risikokvotienter) var høyest i torsk fra indre Oslofjord samt indre Sørfjorden etterfulgt av Langesundsfjorden og urbane områder (havner).
- Det var overskridelser av PROREF i blåskjell (42 %) og torsk (15 %) målt ved datapunkter (miljøgifter x stasjoner), og overskridelsene var høyere i blåskjell (opptil >20x PROREF) enn torsk (5-10x PROREF). Summen av PROREFratio over bakgrunnsnivåer var høyest i blåskjell fra Gressholmen etterfulgt av Akershuskaia i indre Oslofjord.

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 329 vurderinger av EQS for 20 miljøgifter. EQS ble overskredet i blåskjell (21 %), torsk (36 %) og ærfugl (25 %) målt ved datapunkter (miljøgifter x stasjoner). Det var ingen overskridelser av EQS i snegl. For sammenlikning med 2022, var overskridelsene 15 % i blåskjell og 36 % i torsk.

Miljøgifter som ofte overskrider EQS var kvikksølv (det fines ikke EQS-verdier for andre metaller i biota), sumBDE6 og sumPCB7 for blåskjell og torsk.

Blåskjell fra indre og ytre Oslofjord, i andre 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. PROREF (provisional high reference contaminant concentrations) 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 42 % av datapunktene (miljøgifter x stasjoner), og 10 % av datapunktene kunne ikke klassifiseres vs. PROREF, fordi kvantifiseringsgrensen (limit of quantification, LOQ) var høyere enn

PROREF. For torsk var 15 % av prøvene over PROREF, og de høyeste overskridelsene var lavere for torsk (2-5x PROREF) sammenliknet med blåskjell (opptil >20x PROREF).

For sammenligning med 2022, ble PROREF i blåskjell overskredet for 38 % av datapunktene, og de høyeste overskridelsene var opptil 10-20x PROREF.

For blåskjell var de høyeste overskridelsene av PROREF for PCB118 på Gressholmen i indre Oslofjord. Blåskjellstasjoner i indre Oslofjord hadde mange overskridelser av PROREF, og blant disse hadde Gressholmen og Akershuskaia de fleste og høyeste overskridelsene. PCB hadde mange overskridelser som ble påvist i flere urbane stasjoner; havner i Ålesund, Bergen og Oslo. For metaller var høyest overskridelse for bly på Kvalnes i Sørfjorden.

For torsk var det flest overskridelser av PROREF i indre Oslofjord, indre Sørfjord og i havnene i Bergen og Ålesund.

Tidstrender

En nylig publisert OSPAR metode ble brukt for første gang. Totalt 774 tidstrender (både langtidstrender og korttidstrender) ble utregnet for miljøgifter presentert i det utvidede sammendraget. Generelt var det færre langtidstrender (på grunn av utilstrekkelig med data), mens ingen trender eller nedadgående trender dominerte. 2022 var også dominert av ingen trender etterfulgt av nedadgående trender.

Korttidstrender
For både blåskjell og torsk var det flere datapunkter (miljøgifter x stasjoner) hvor det kunne utregnes korttidstrender (≤ 10 år) enn langtidstrender. Det var «ingen endring» (57 %) som dominerte for blåskjell etterfulgt av nedadgående trend (20 %). Samme data for torsk var 53 % (ingen endring) og 27 % (nedadgående trend). Det ble påvist oppadgående korttidstrender i både blåskjell og torsk (henholdsvis 10 % og 5 %). For blåskjell ble det funnet tilfeller av oppadgående korttidstrender for de fleste metaller, og for PCB ved noen stasjoner. For torsk var det oppadgående korttidstrender for metaller ved noen stasjoner, og for PCB og PBDE ved noen få stasjoner. Spesielt ble det observert en oppadgående korttidstrend for PFOS i torsk fra Isfjorden på Svalbard. Høyest antall forekomst av oppadgående lang- og korttidstidstrender ble funnet på blåskjellstasjoner i indre Oslofjord, og på torskestasjonene ved Lista og Sandnessjøen. Det var «ingen endring» som dominerte for ærfugl (60 %), etterfulgt av nedadgående trender (19 %). Ingen oppadgående trender ble observert.

Langtidstrender
Ved analyse av langtidstrender (> 10 år) i blåskjell var det flest tilfeller av «ingen endring» (46 %), men for 27 % av dataene var det nedadgående langtidstrender. Oppadgående trender ble observert for 6 % av dataene. Resten av dataene hadde mangler i datasett for at trender kunne bestemmes. Bildet var likt for langtidstrender i torsk sammenliknet med blåskjell, men prosentandelen av nedadgående trender var høyere (29 %). For torsk ble «ingen endring» observert for 39 % av dataene, mens for 6 % var det oppadgående trender.

Oppadgående tidstrender med overskridelser av EQS og/eller PROREF
Spesiell oppmerksomhet må gis ved økende tidstrender for miljøgifter som samtidig overskrider EQS og/eller PROREF (≥5 for blåskjell og ≥2 for torsk). Dette var tilfellet for syv kombinasjoner av miljøgifter, stasjoner og arter. I torskefilet fra indre Oslofjord, Kristiansand havn og Lista var det oppadgående tidstrender i tillegg til overskridelse av EQS (RQ) og PROREF for kvikksølv. I blåskjell fra Gressholmen i

indre Oslofjord var det oppadgående tidstrender i tillegg til overskridelse av PROREF for noen PCB-forbindelser (CB118, CB138 and CB153), og det samme var det for kvikksølv ved Akershuskaia..

Biologiske effekter

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

Resultater for OH-pyrenmetabolitter i galle kunne kun oppnås fra stasjon Lista (15B), og median-konsentrasjonen var under ICES/OSPARs vurderingskriterium for bakgrunnsnivå («background assessment criteria», BAC), men variasjonen var stor.

ALA-D-aktivitet i torskeblod fra Indre Sørfjorden var signifikant lavere enn ved referansestasjonen (Bømlo). Redusert aktivitet av ALA-D tyder på høyere eksponering for bly. De høyeste hepatiske konsentrasjonene av bly (blant alle stasjoner) ble funnet i torsk fra Indre Sørfjorden (53B).

Median EROD-aktivitet fremsto lavere ved Bømlo (23B, referansestasjon) enn i Indre Oslofjord (30B) og Indre Sørfjord (53B), men forskjellen var bare statistisk signifikant fra Indre Oslofjord. EROD-aktiviteter (medianer) var lavere enn ICES/OSPARs vurderingskriterium for bakgrunnsnivå (BAC) på alle stasjoner. Ingen spesielt forhøyet EROD-aktivitet kunne observeres i torskeindivider, som akkumulerte svært høye PCB-konsentrasjoner, i Indre Sørfjorden.

Torskehelseparametere

Helsetilstand for torsk er for første gang tatt med i denne rapporteringen. Det var stor variasjon i helsetilstand mellom de undersøkte stasjonene. En rangering av fiskehelseparametere (Fulton CI (Fulton kondisjonsindeks), HSI (leversomatisk indeks) og «vekt ved alder» (vekt/alder)) viste at de høyeste indeksene ble funnet for torsk fra Bømlo (23B), Ålesund havn (28B), Lofoten (98B1) og Tromsø havn (43B2), mens de lavest indeksene ble funnet i torsk fra indre Oslofjord (30B). Dette indikerer at torsk fra indre Oslofjord hadde dårligst helsetilstand for parametere som ble undersøkt.

1 Introduction

1.1 Background

The national environmental monitoring programme "Contaminants in coastal waters" (Miljøgifter i kystområdene - MILKYS) is administered by the Norwegian Environment Agency (NEA), that 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). All the results in this report are considered part of the Norwegian contribution to the CEMP programme as well as 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 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 of the European Parliament and of the Council of

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

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

12 August 2013 Amending Directives 2000/60/EC and 2008/105/EC as Regards Priority Substances in the Field of Water Policy, 2013) to achieve good chemical status by assessing the results using EU EQSD in Norway. In this regard, Norway has supplemented the EQS with their own EQS for river basin specific pollutants assessed for ecological status. The results from MILKYS can also be useful in addressing aspects 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 manmade synthetic substances. OSPAR has also adopted this goal[3].

The MILKYS programme investigates contaminants in blue mussel, cod, dogwhelk, common periwinkle, and common eider on a yearly basis. This report presents the findings from monitoring performed in 2023, the third year of the five-year period (2021-2025). The program started in 1981 and has since been advanced. The reporting format has been changed from the 2020 investigation (Schøyen, Grung, Lund, Hjermann, Ruus, Øxnevad, Beylich, et al., 2024) to a shorter for the 2022 investigation (Schøyen, Grung, Lund, Hjermann, Ruus, Øxnevad, Christensen, 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 (Schøyen, Grung, Lund, Hjermann, Ruus, Øxnevad, Beylich, et al., 2024).

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

2 Extended summary of MILKYS 2023

2.1 Samples, localities and chemical analyses

Location of stations sampled in MILKYS 2023 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 selected because they represent the contaminant group, and also, they reveal important exceedances of EQS and PROREF. This extended summary presents the main results. Many contaminants in addition to those discussed in the extended summary were analysed, 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 2023 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**).

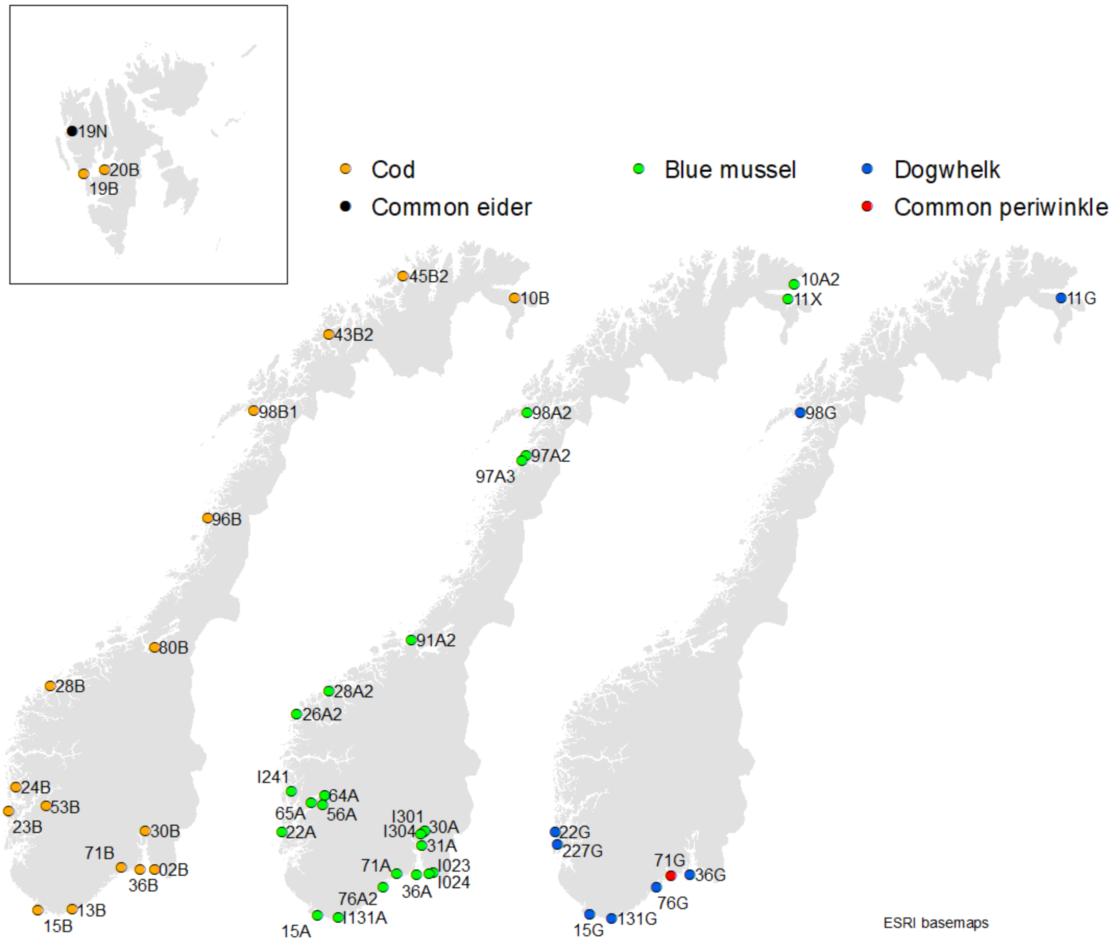

Figure 1. Stations where cod (*Gadus morhua*) and common eider (*Somateria mollissima*) (left), blue mussel (*Mytilus edulis*) (middle), dogwhelk (*Nucella lapillus*) and common periwinkle (*Littorina littorea*) (right) were sampled in Norway and Svalbard (inset). Dogwhelk at Farsund (15G) was not found in 2023. Common periwinkle was also found at Lastad at Søgne (131G) in 2023.

Table 1. Number of samples of blue mussel (pooled samples), cod (pooled for some liver main samples), common eider, dogwhelk, and common periwinkle. Dogwhelk at Farsund (15G) was not found in 2023, and Lastad (131G) was sampled for both dogwhelk and periwinkle. All snail samples were pooled. Bile was missing at three cod stations. The stations are ordered along the coastline starting north moving south. For common eider, samples for both 2022 and 2023 are included. *One extra blood sample was analysed. Station names in Vannmiljø are listed in **Table S4** in Appendix.

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

Species	Station code	Station name	Latitude	Longitude	Bile	Blood	Egg	Liver main	Liver siloxanes	Liver BEM	Fillet	Whole soft body
	43B2	Tromsø harbour	69.653	18.974				15	15		15	
	98B1	Lofoten	68.1858	14.7081				15	15		15	
	96B	Sandnessjøen	66.0444	12.5036				15			15	
	80B	Trondheim harbour	63.4456	10.3717				13	15		15	
	28B	Ålesund harbour	62.4678	6.0686				15	15		15	
	24B	Bergen harbour	60.3966	5.2707				6	7		7	
	53B	Inner Sørfjord	60.0973	6.5397	0	15		10		15	15	
	23B	Bømlo	59.8956	5.1086	0	16*		15	15	15	15	
	15B	Lista	58.0514	6.7469	15			15			15	
	13B	Kristiansand harbour	58.1328	7.9885				5	15		15	
	71B	Langesundfjord	59.0465	9.7028				11	15		15	
	36B	Tjøme, Outer Oslofjord	59.0405	10.4358				15	15		15	
	30B	Inner Oslofjord	59.8127	10.5518	0	16*		8	15	15	15	
	02B	Hvaler	59.0648	10.9735				4			7	
Dogwhelk (*Nucella lapillus*)	11G	Brashavn, Varangerfjord	69.8995	29.7419								1
	131G	Lastad, Søgne	58.0284	7.699								1
	15G	Ullerøy, Farsund	58.0493	6.9012								0
	227G	Mid Karmsund	59.3396	5.3122								1
	22G	Espevær, Bømlo	59.5837	5.1445								1
	36G	Færder, Outer Oslofjord	59.0278	10.5256								1
	76G	Risøya, Risør	58.728	9.2755								1
	98G	Svolvær airport	68.247	14.6664								1
Common periwinkle (*Littorina littorea*)	71G	Fugløyskjær, Langesundfjord	58.985	9.8046								1
	131G	Lastad, Søgne	58.0284	7.699								1
Common eider (*Somateria mollissima*)	19N	Kongsfjorden, Svalbard	79.004	12.11		15+15	15+15					

Table 2. List of parameters that will be shown and discussed in more detail in this report. Number of stations analysed in the species blue mussel *(Mytilus edulis)*, cod (*Gadus morhua*), common eider (*Somateria mollissima*) and snail (*Nucella lapillus* and *Littorina littorea*) are provided. An indication of 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	
	As	24	18	1	0		PROREF	
	Cd	24	18	1	0		PROREF	
	Co	24	18	1	0		PROREF	
	Cr	24	18	1	0		PROREF	
	Cu	24	18	1	0		PROREF	
	Hg	24	18	1	0	EQS	PROREF	
	Ni	24	18	1	0		PROREF	
	Pb	24	18	1	0		PROREF	
	Zn	24	18	1	0		PROREF	
PFAS	PFOA	6	11	1	0	EQS	PROREF	
	PFOS	6	11	1	0	EQS	PROREF	
	PFOSA	6	11	1	0		PROREF	
PBDE	BDE47	11	12	1	0		PROREF	
	BDE100	11	12	1	0		PROREF	
	BDE154	11	12	1	0		PROREF	
	sumBDE6[2]	11	12	1	0	EQS		no
PCB	CB118	23	18	1	0		PROREF	
	CB138	23	18	1	0		PROREF	
	CB153	23	18	1	0		PROREF	
	sumPCB7[3]	23	18	1	0	EQS		no
PAH	BAA	7	0	0	0	EQS	PROREF	
	BAP	7	0	0	0	EQS	PROREF	
	FLU	7	0	0	0	EQS	PROREF	
	PYR	7	0	0	0		PROREF	
	ANT	7	0	0	0	EQS		no
	NAP	7	0	0	0	EQS		no
Siloxanes	D5	0	13	1	0	EQS		
CP	MCCP	11	14	1	0	EQS		no
	SCCP	11	14	1	0	EQS		no
Pesticides	sumDDT	2	1	0	0	EQS		no
	HCB	2	1	0	0	EQS	PROREF	
	sumHCH	2	1	0	0	EQS		no
	QCB	2	1	0	0	EQS		no
Brominated	HBCDA	11	14	1	0	EQS	PROREF	
TBT-related	TBT	0	0	0	9	EQS		no
	TPhT	0	0	0	9	EQS		no

[1] Eider were analysed at one station, but in two tissues (blood and eggs). Data for exceedances of EQS and PROREF are reported in this report for both 2022 and 2023.

[2] Lower bound of sumBDE6, i.e. data below 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.

2.1.2. Detection frequencies of contaminants and history of Limit Of Quantifications (LOQs)

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 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 were increased somewhat (except CB118 which was lowered).

LOQ increased from 0.05 to 0.3 µg/kg. Also for cod livers with a high percentage of fat, the LOQ is higher with this method, and LOQs from 0.3 and up 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[4] (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).

[4] 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.

3 Summary of exceedances (EQS and PROREF) and time trends

Exceedances of EQSs, PROREF, 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 EQS 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

Assessment of exceedances of EQS have been done. The contaminants listed in **Table 3** have been determined in 2023, have an EQS in biota (Direktoratsgruppen vanndirektivet, 2018) and are therefore subject to assessment. A total of 329 assessments of EQSs have been done in 2023 (combination of contaminant × sample). The data also includes samples of common eider for 2022 and 2023 for both blood and eggs. Twenty contaminants determined in 2023 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**. EQSs were exceeded in 21 % of all selected contaminants in blue mussel and 36 % of all contaminants in cod, expressed as datapoints (contaminants x stations). For common eider the exceedances for 2022 and 2023 were 25 % of the datapoints. No exceedances were observed for contaminants determined in snails.

Table 3. List of contaminants determined in 2023 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

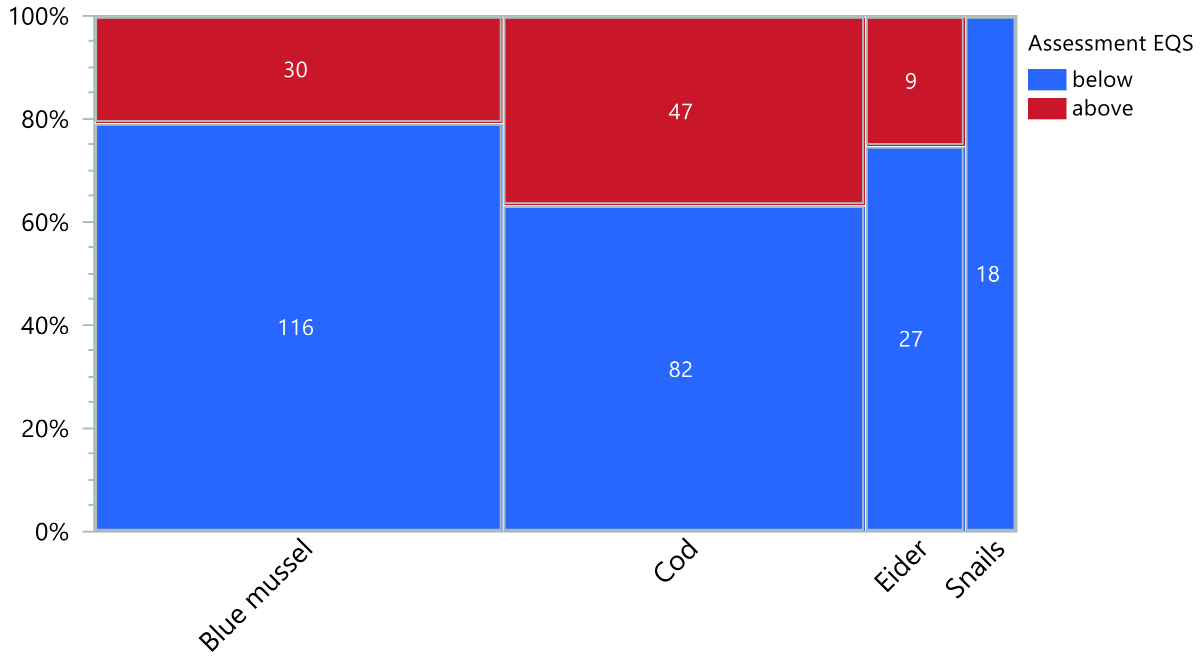

Figure 2. Exceedances of EQSs by species groups in a mosaic plot. The cells are labelled by the number of datapoints (contaminants x stations). The exceedances are considered by the median for each station and species. The colours represent below or above EQSs. Common eider for both 2022 and 2023 are included. The total area of the figures represents the 329 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** to **Figure 8** for blue mussel, cod and eider respectively.

In blue mussel (**Figure 3**), compounds with concentrations exceeding EQSs were mercury (at seven stations), sumBDE6 (all stations exceeded EQS), and sumPCB7 (12 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 sometimes exceeded also in freshwater trout from supposedly pristine rivers in Norway (Moe et al., 2018, 2019; Sandin et al., 2021; Thrane et al., 2020). Only one station did not exceed EQS for mercury.

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

In eider (**Figure 6**), mercury, sumBDE6, and sumPCB7 were the contaminants that exceeded EQS, mercury in both years and both tissues.

Contaminants often exceeding EQSs are therefore mercury, sumBDE6 and sumPCB7 for blue mussel and cod. MCCP exceeded EQS at one station for cod.

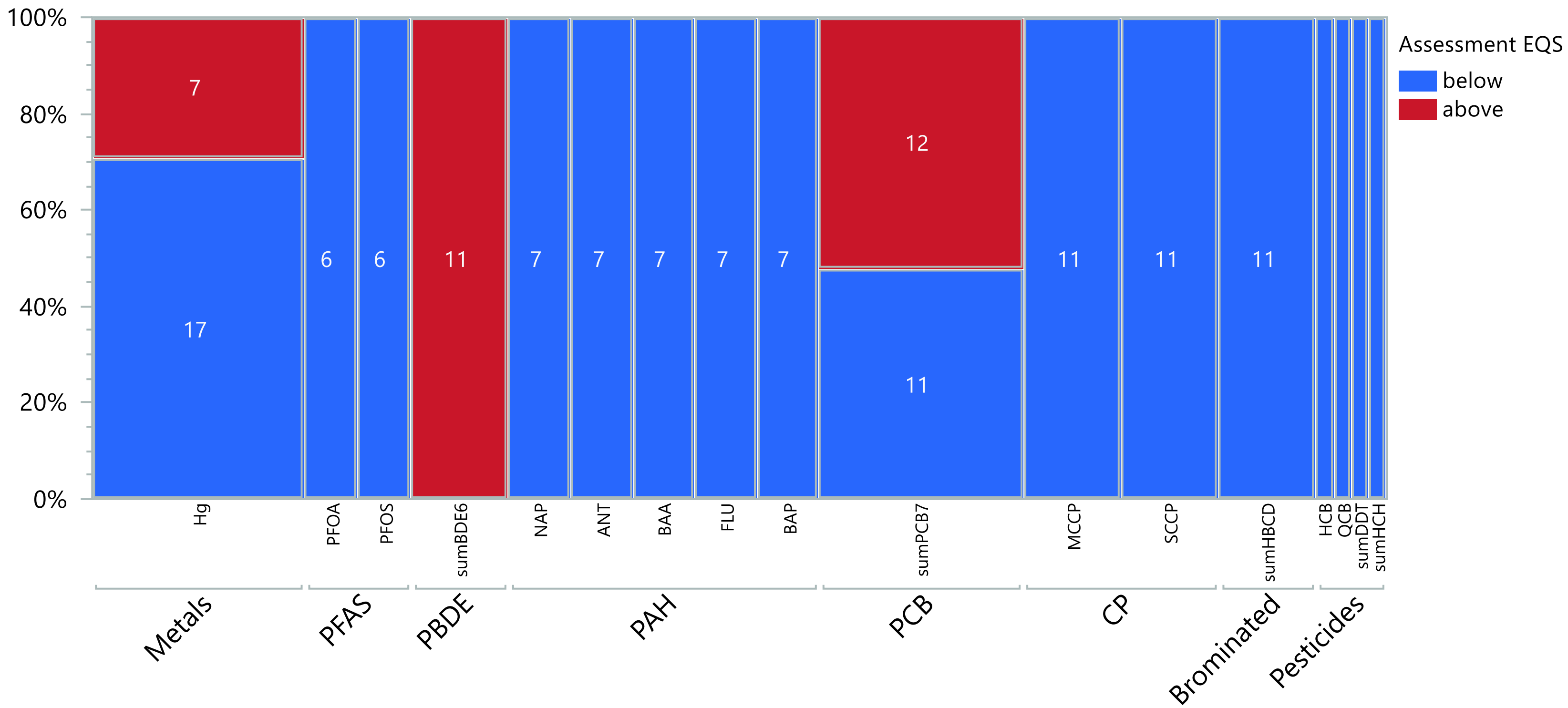

Figure 3. Exceedances of EQSs in blue mussel by contaminant and contaminant group. The cells are labelled by the number of stations in each category. The exceedances are considered by the median for each station. The colours represent below or above EQSs.

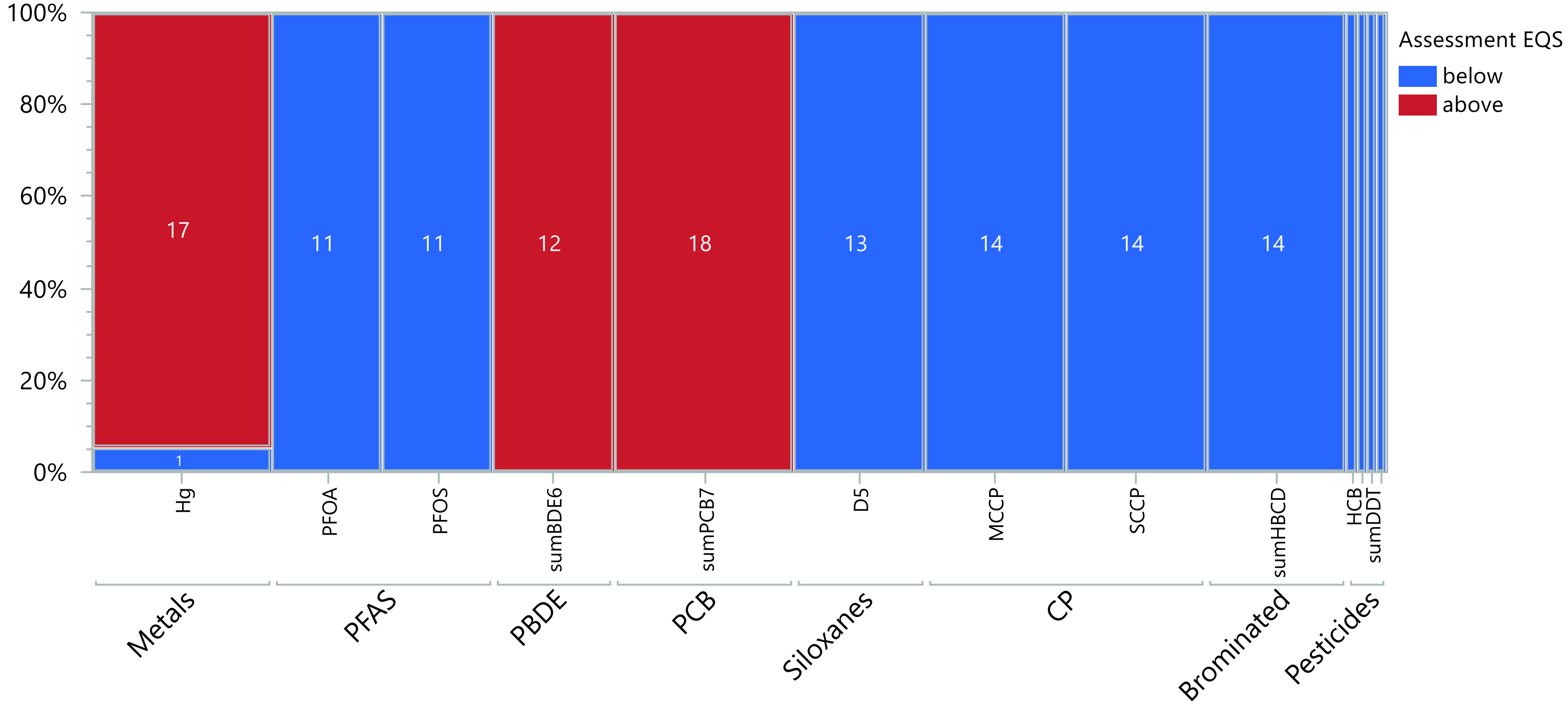

Figure 4. Exceedances of EQSs in cod by contaminant and contaminant group. The cells are labelled by the number of stations sampled. The exceedances are considered by the median for each station. The colours represent below or above EQSs.

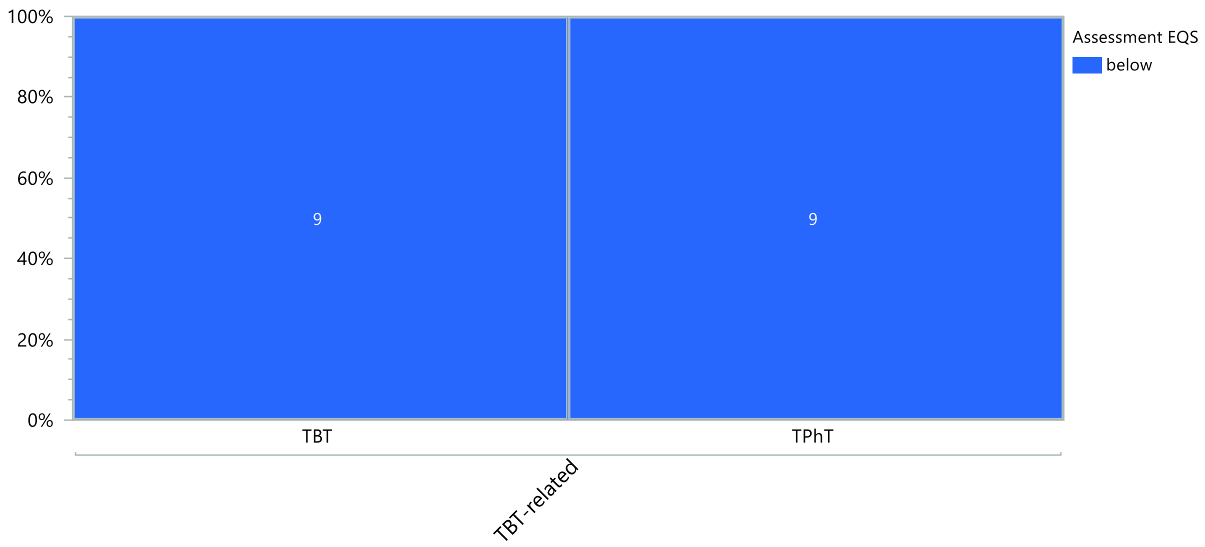

Figure 5. No exceedances of EQSs in snails (dogwhelk/common periwinkle) by contaminant. The number of stations in each group are labelled in the respective cell. The colour represents below EQSs.

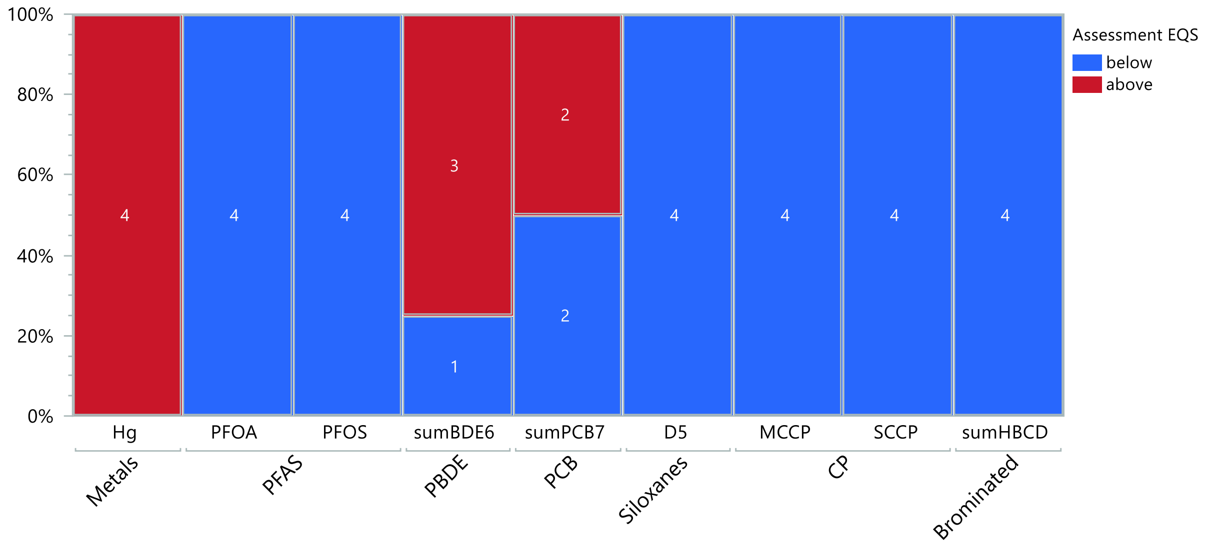

Figure 6. Exceedances of EQSs in eider in 2022 and 2023 in blood and eggs by contaminant and contaminant group. The cells are labelled by the number of years and tissues sampled. The exceedances are considered by the median for each year/tissue. The colours represent below or above EQSs.

3.1.2. Heatmaps for stations

To investigate potential pattern in stations exceeding EQSs, heatmaps for contaminants vs. stations are shown in **Figure 7** to **Figure 9**. No comments are made if we could not detect any special stations standing out compared to others.

In blue mussel, exceedances of mercury concentrations were observed at seven stations. This is an increase from 2022, where only three stations exceeded. Concentrations of sumBDE6 exceeded EQSs at all stations. For sumPCB7, half of the stations (12 of 23) showed exceedances of EQS.

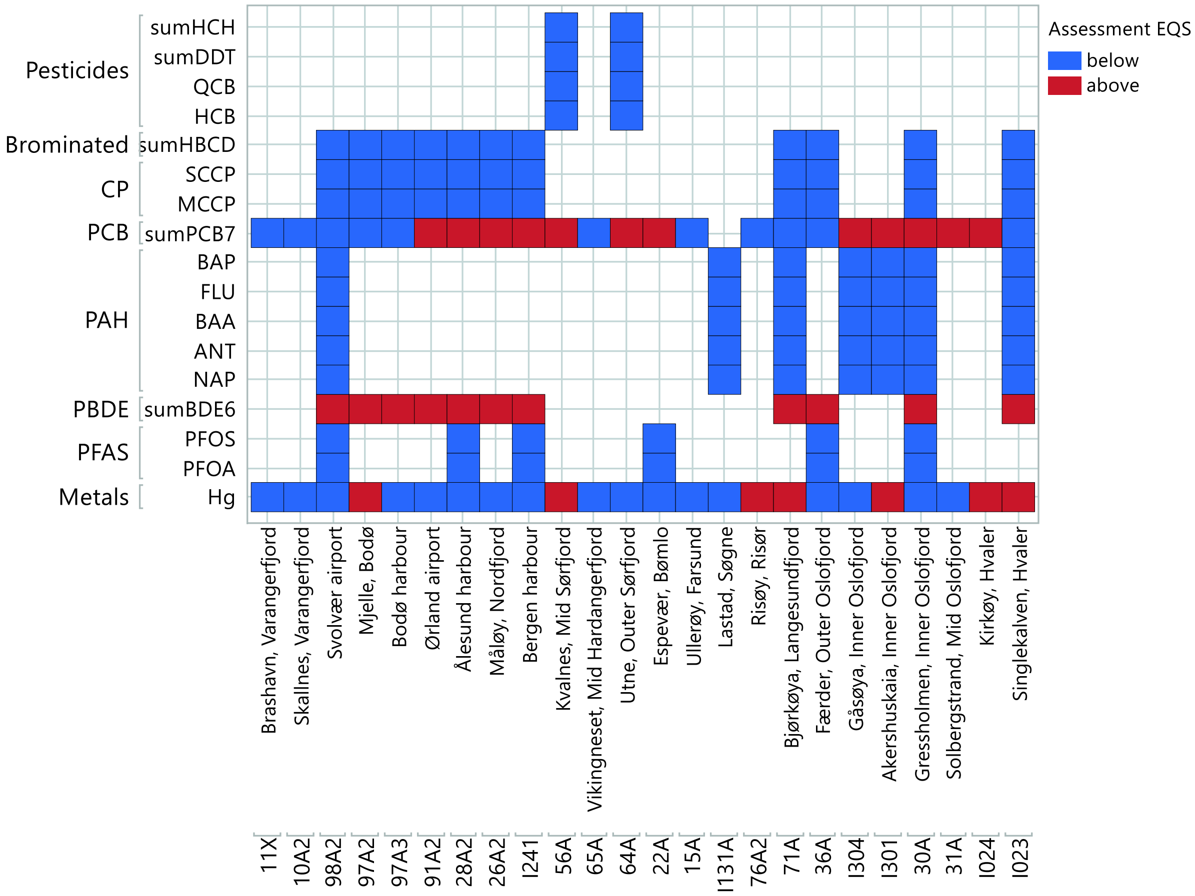

Figure 7. Heatmap of exceedances of EQSs in blue mussel. The exceedances are considered by the median for each station. The colours represent below or above EQSs. Empty "cells" mean that the contaminant was not analysed at the indicated station. Grey lines show the midpoint of each station and contaminant.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

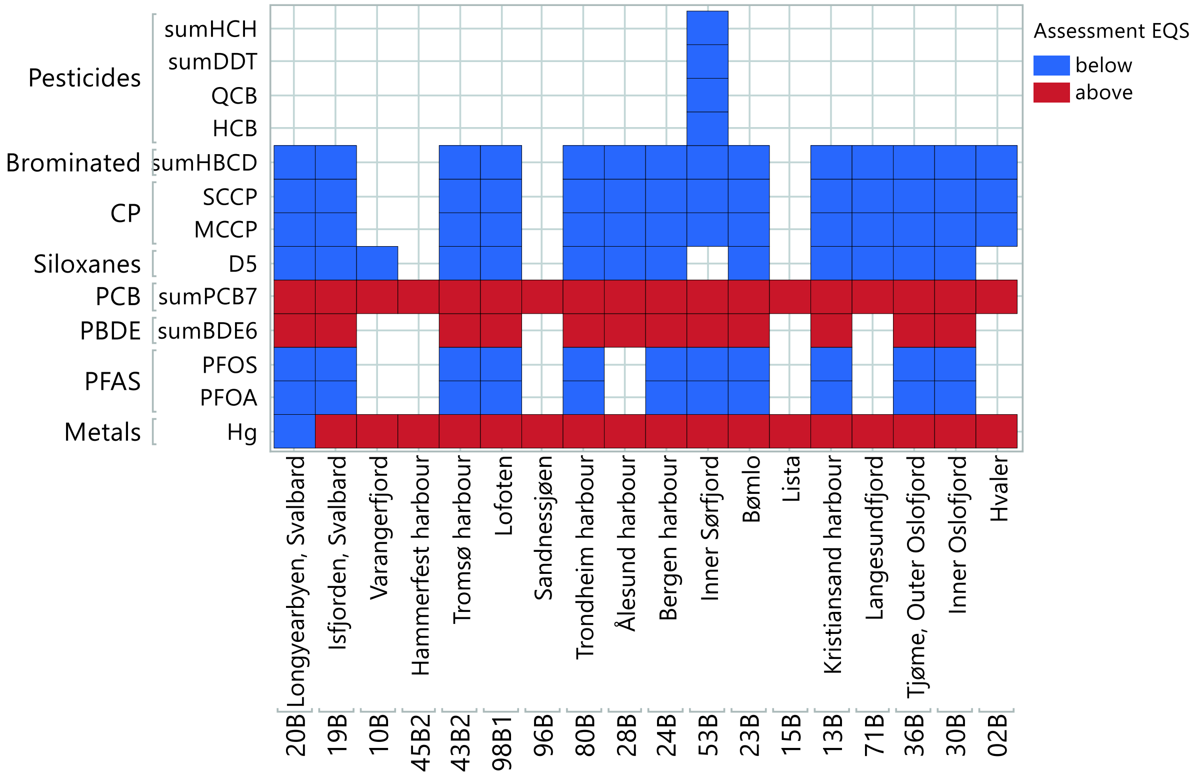

Figure 8. Heatmap of exceedance of EQSs in cod. The exceedances are considered by the median for each station. The colours represent below or above exceedance of EQSs. Empty "cells" mean that the contaminant was not analysed for at the indicated station. Grey lines show the midpoint of each station and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

For cod stations, mercury, sumBDE6, and sumPCB7 were the compounds where exceedances of EQSs mainly were observed. Mercury concentrations exceeded EQS at all stations but the one at Svalbard (Longyearbyen (20B).

Data for eider is presented for both 2022 and 2023 with data in both blood and eggs. Mercury, sumBDE6, and sumPCB7 were the contaminants exceeding EQSs also in eider. Blood samples in 2022 did neither exceed EQS for sumPCB7 nor sumBDE6. In 2023 sumPCB7 did not exceed EQS in blood.

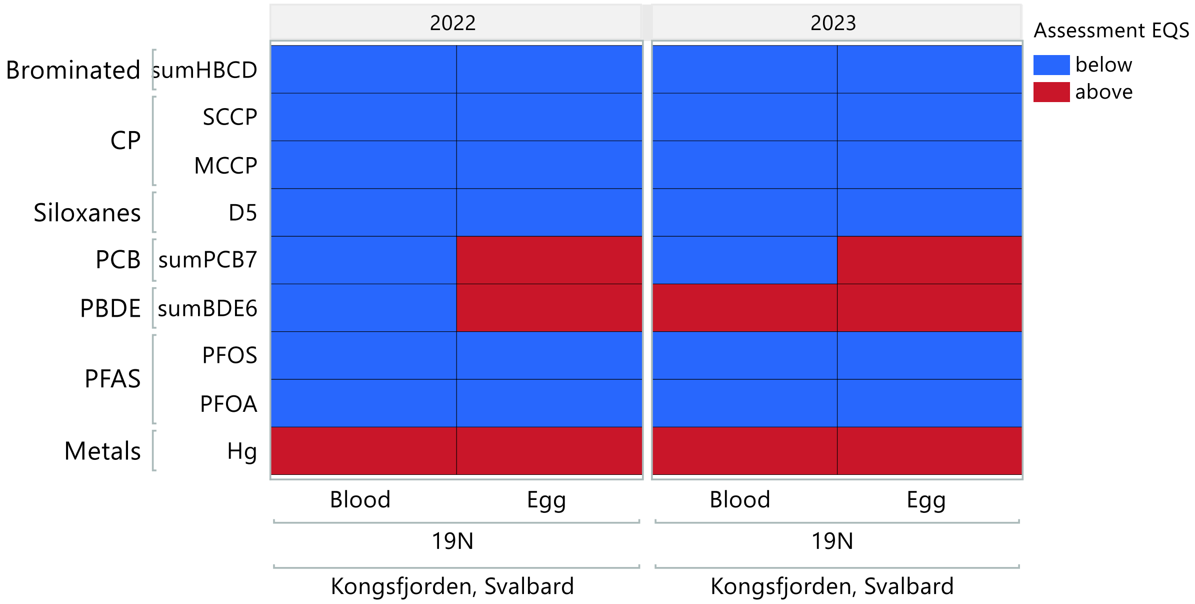

Figure 9. Heatmap of exceedance of EQSs in common eider for 2022 and 2023 in blood and eggs. The exceedances are considered by the median for each station. The colours represent below or above exceedance of EQSs. The stations are ordered along the coastline starting north moving south.

3.1.3. Sum of risk quotients (RQ) - comparison of stations

Based on a publication (Backhaus & Faust, 2012), we have developed the sum of risk quotients (sum RQ, see details in **chapter 6.7**) as an aid for comparison of levels between stations. The RQ is the measured concentration divided by the PNEC for the contaminant. For a given station, sum RQ is the sum of all measured contaminants divided by their PNEC. The fish and blue mussel have been normalised to a "standard fish" with 5 % lipid and 26 % dry weight for fish, and "standard mussel" with 1 % lipid and 8.3 % dry weight as described in the guidance document (European Commission, 2014). For more information of the normalisation process, please read **chapter 6.7**. The purpose of normalisation was to make a comparison between contaminants and stations less dependent of the lipidcontent. Also, the contribution to risk of compounds that do not bioaccumulate in lipids (e.g. mercury, PFOS, and PFOA) are more balanced.

A direct comparison of sum RQ is quite easy if the same contaminants have been analysed at all the stations. If the analytical repertoire is the same for all stations, the highest sum RQ identify the station(s) where the risks for environmental effects are highest. However, since the analytical repertoire was not the same at all stations, sum RQ is more difficult to use in our case. EQS for sumBDE6 was exceeded for all cod stations where it was analysed. However, PBDEs were not analysed at all cod stations. Therefore, it is challenging to compare sum RQ at stations where PBDEs have been analysed to stations where PBDEs have not been analysed. Potentially, the sum RQ at stations where PBDEs was not analysed in reality are higher than shown in our data.

Four compound groups exceeded EQSs in one or more stations: mercury, sumBDE6, sumPCB7, and PAHs (in mussels). Mercury was analysed at all stations, but the other compound groups exceeding EQSs were not analysed at all stations. Of these, sumBDE6 is less frequently analysed (11 of 24 mussel stations, and 12 of 18 cod stations). However, this also applies to some extent to sumPCB7 (analysed at 23 of 24 mussel stations and all cod stations). PAHs were analysed only in mussels, and at seven stations. In addition to these contaminants also CPs, HBCDA, PFAS, and pesticides made small contributions to sum RQ in a few stations. These contaminant groups are only analysed at a few stations. For a reference to which compounds that are analysed at each station, please refer to the heatmaps for mussel and cod respectively (**Figure 7** and **Figure 8**). Mentioning all the compounds not analysed at all stations would overcomplicate the figures. For example, pesticides were only analysed at two mussel stations and one cod station. We have chosen to present sum RQ in station categories for contaminant groups exceeding EQSs *not analysed* at that station. Stations marked with “none” indicate that the stations were analysed for all compounds that had any exceedance of EQS.

For mussel stations (**Figure 10**), the sum RQ varied between 23 and zero, with four stations not exceeding sum RQ ≥ 1 (10A2, 15A, I131A, 65A). Urban stations Bergen (I241), Mjelle Bodø (97A2), Ålesund (28A2), Gressholmen (30A), Bodø harbour (97A3), and (Akershuskaia (I301) had the highest RQs.

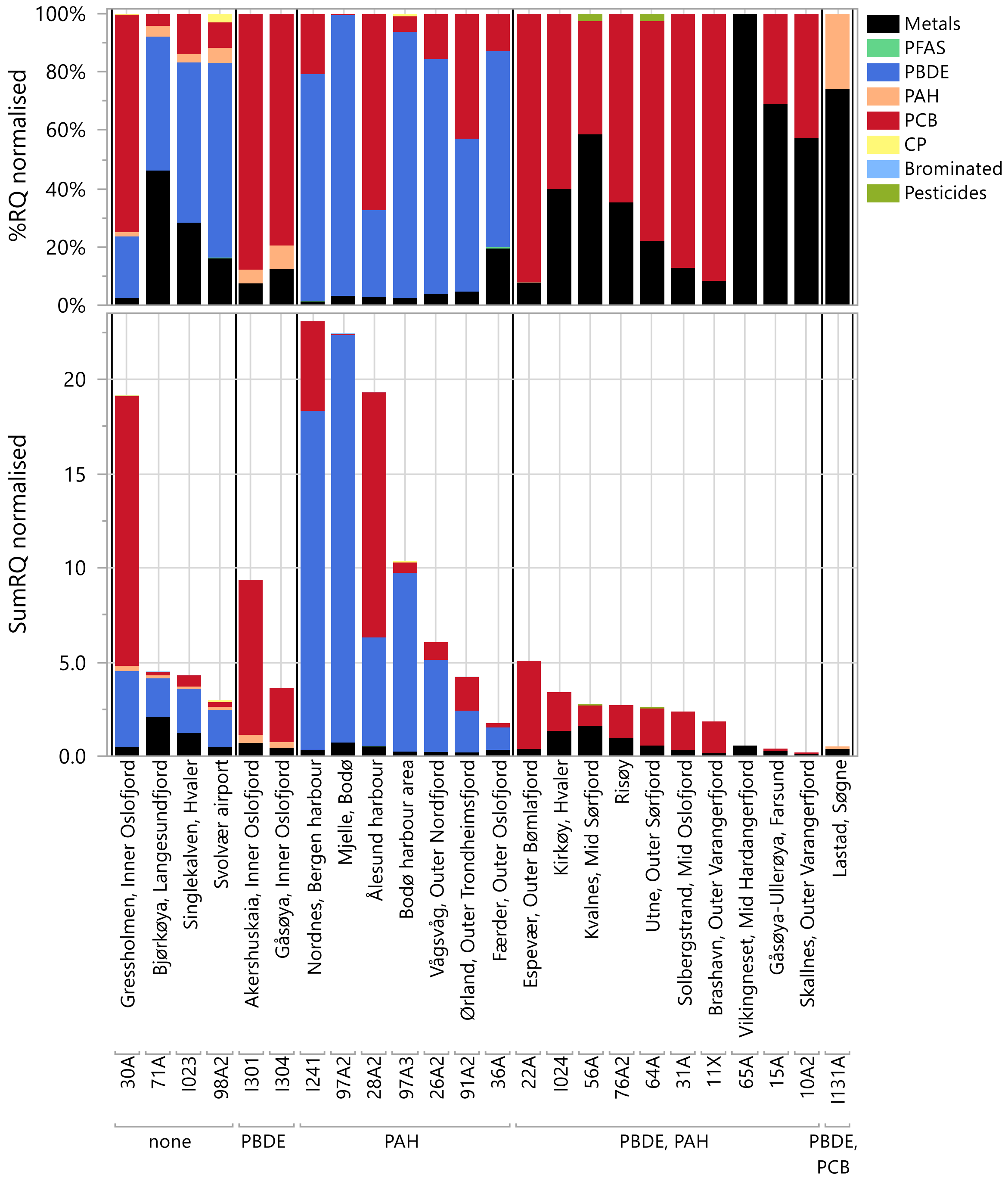

Figure 10. Stacked bar plot of sum RQ for blue mussel stations grouped by analyses of exceeding EQSs not performed for the stations (none: indicating that the stations were analysed for all compounds that had any exceedance of EQS). For a full view of which contaminants that were analysed at each station, please refer to the heatmaps for mussel (**Figure 7**). On the top, the % of sum RQ normalised for groups are shown, on the bottom the sum of RQ normalised.

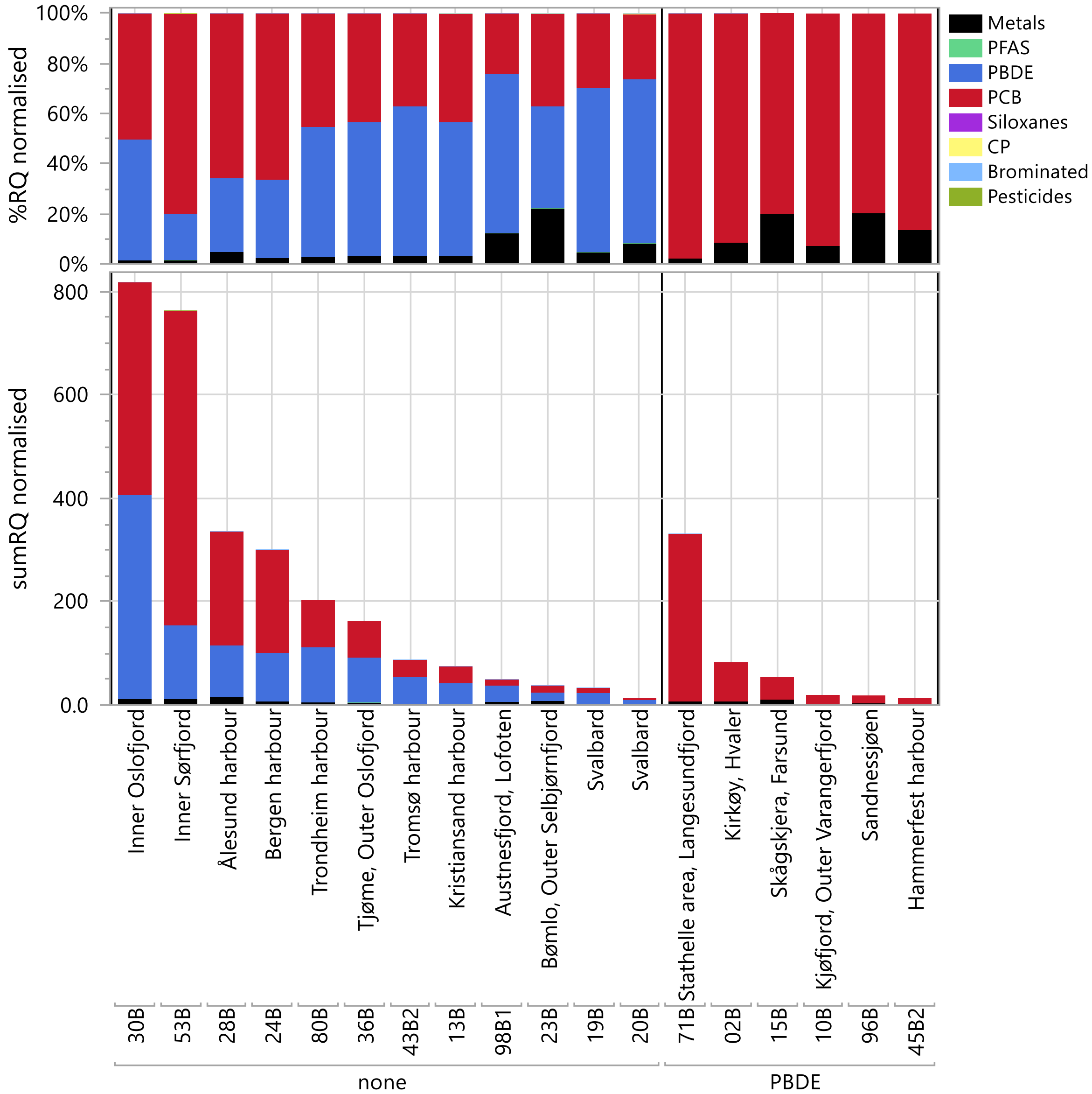

Figure 11. Stacked bar plot of sum RQ for cod stations grouped by analyses of exceeding EQSs not performed for the stations (none; indicating that the stations were analysed for all compounds that had any exceedance of EQS). For a full view of which contaminants that were analysed at each station, please refer to the heatmaps for cod (**Figure 8**). On the top, the % of sum RQ normalised for groups is shown, on the bottom the sum RQ normalised.

For cod stations (**Figure 11**), the sum RQ varied between 820 and 13, all stations exceed sum RQ ≥ 1. The two most important compounds contributing to exceedance were sumPCB7 and sumBDE6, but also mercury contributes. All these compounds are shown to biomagnify in cod, which is the reason why the sum RQ is so much higher in cod than in mussel. The urban stations (Inner Oslofjord, Bergen, Ålesund, and Trondheim harbour) were among those with the highest sum RQ. The Langesundfjord (71B) also had high RQ for sumPCB7, but the largest RQ contribution from sumPCB7 was observed in the Inner Sørfjord in 2023. This was a result of high PCB concentrations in cod from the Inner Sørfjord, compared to the last years. Especially high concentrations (> 10 000 ng/g ww) were observed in three samples from Sørfjorden, and these were the highest concentrations compared to all other specimens (all stations included) in 2023. In 2002, extreme concentrations of PCBs were also found in cod from the Inner

Sørfjord (N. Green et al., 2004), and this was attributed to renovation of the old power station of Tyssefaldene A/S, painted in the 1960s with a product containing an unknown PCB-mixture (Ruus et al., 2006). The paint/plaster from the power station, and the fish with the highest PCB-concentrations, exhibited PCB congener patterns where relative concentrations of CB153 were lower than of CB138, together with generally low relative concentrations of CB180 and high of CB101(Ruus et al., 2006). This was also the case for the samples from the Inner Sørfjord in 2023 with the highest PCB-concentrations (**Figure 12)**.

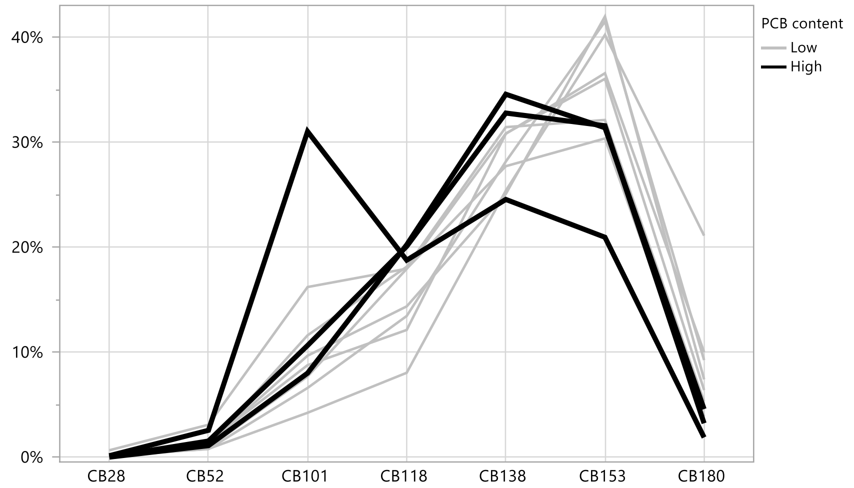

Figure 12. Percent of PCB isomers of sumPCB7. Samples of cod with high content of PCB are shown in black, while samples with low content in grey.

3.2 PROREF

Concentrations of contaminants were compared to PROREF reference levels. PROREF (provisional high reference contaminant concentrations) is a NIVA-developed method intended to determine reference values for classifying whether the concentrations for a given contaminant at a given station is close to low/background concentration (either natural concentration or resulting from only diffuse exposure). More specifically, the method has four main principles: 1) the survey must include stations far from point sources of contaminants (i.e. potential background stations), 2) stations are classified into background or non- background stations for each contaminant, species, tissue and basis, 3) the classification of stations is done by finding a set of stations with significantly lower values than other stations, using purely objective statistical criteria, and 4) the PROREF value is set so that most observed concentrations on the background stations are below PROREF. Thus, a station can be background for contaminant X in c--od liver, but not for contaminant Y in the same matrix, or contaminant X in a different matrix. We consider PROREF to provide a valuable method for assessing contaminant levels in addition to the risk based EQS. For a more thorough description, see **chapter 6.8**. We have calculated Norwegian PROREF values based on MILKYS-results for the period 1992-2016. We assessed the 25 contaminants selected for presentation for 2023 data based on the ratio between the 2023 median concentration and PROREF (**Table 4**). Results for other contaminants with PROREF values, but not selected for presentation in 2023, are given in **Supplementary** data.

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**). PAHs are metabolised by cod and therefore PROREFs have not been developed for PAHs in cod.

Table 4. List of contaminants selected in 2023 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.

Contaminant group	Contaminant	Unit	PROREF blue mussel	PROREF cod
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
	Nickel (N)i		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
	Perfluorooctanesulfonic acid (PFOS)		Not developed yet	10
	Perfluorooctanesulfonamide (PFOSA)		Not developed yet	6.2
PBDEs	PBDE congener 47 (BDE47)		0.17	16
	PBDE congener 100 (BDE100)		0.050	2.6
	PBDE congener 154 (BDE154)		0.050	1.5
PAHs	Benzo(a)anthracene (BAA)		1.5	
	Fluoranthene (FLU)		5.4	
	Pyrene (PYR)		1.0	
	Benzo(a)pyrene (BAP)		1.2	
PCBs	PCB congener 118 (CB118)		0.070	100
	PCB congener 138 (CB138)		0.20	160
	PCB congener 153 (CB153)		0.26	190
Brominated	HBCDA		0.027	2.6
Pesticides	Hexachlorobenzene (HCB)		0.10	14

Exceedances of PROREF in different species are shown in **Figure 13**. Blue mussel exceeded PROREF for 42 % of the samples, and 10 % of the datapoints could not be classified vs. PROREF since LOQ was higher than PROREF. In cod, 15 % of the samples were exceeding PROREF, and the highest exceedances were lower for cod (5-10x PROREF) than for mussel (up to >20x PROREF).

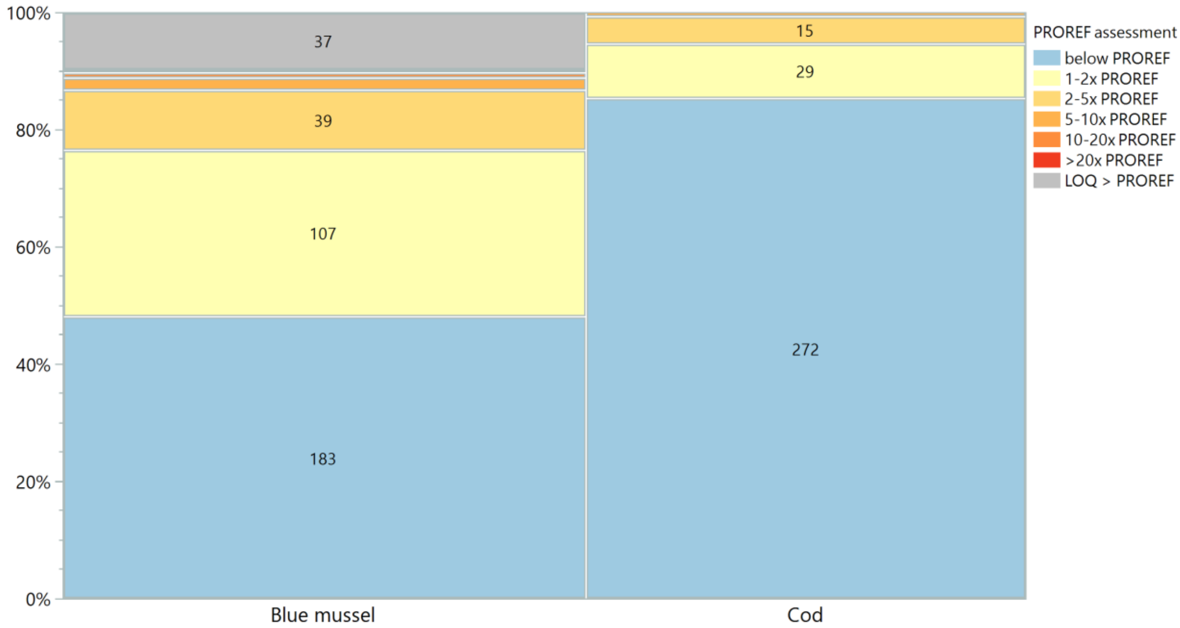

Figure 13. Assessment of PROREF ratios in a mosaic plot. The cells are labelled by the number of datapoints (contaminants x stations). The assessments are considered by the median for each station and species and are represented by colors in the figure. In cases where LOQs were higher than PROREF (grey) no assessments could be made.

For mussels, all metals except silver had stations where concentrations exceeded PROREF (**Figure 14**). For silver, the LOQ was equal to PROREF, and therefore no assessment could be made. Among the metals, the highest exceedances were observed for lead (10-20x PROREF). The highest exceedances were seen for PCBs, with > 20xPROREF for CB118. PAHs were analysed in mussels from seven stations, and exceedances above PROREF were observed for benzo(a)anthracene, fluoranthene, and pyrene.

In cod, mercury was the contaminant exceeding PROREF the most (**Figure 15**). Several stations exceeded PROREFs, most notably silver and cadmium at 4 stations. PFOSA, BDE47, and BDE100 exceeded at one station each. PCBs exceeded PROREF at 3-5 stations.

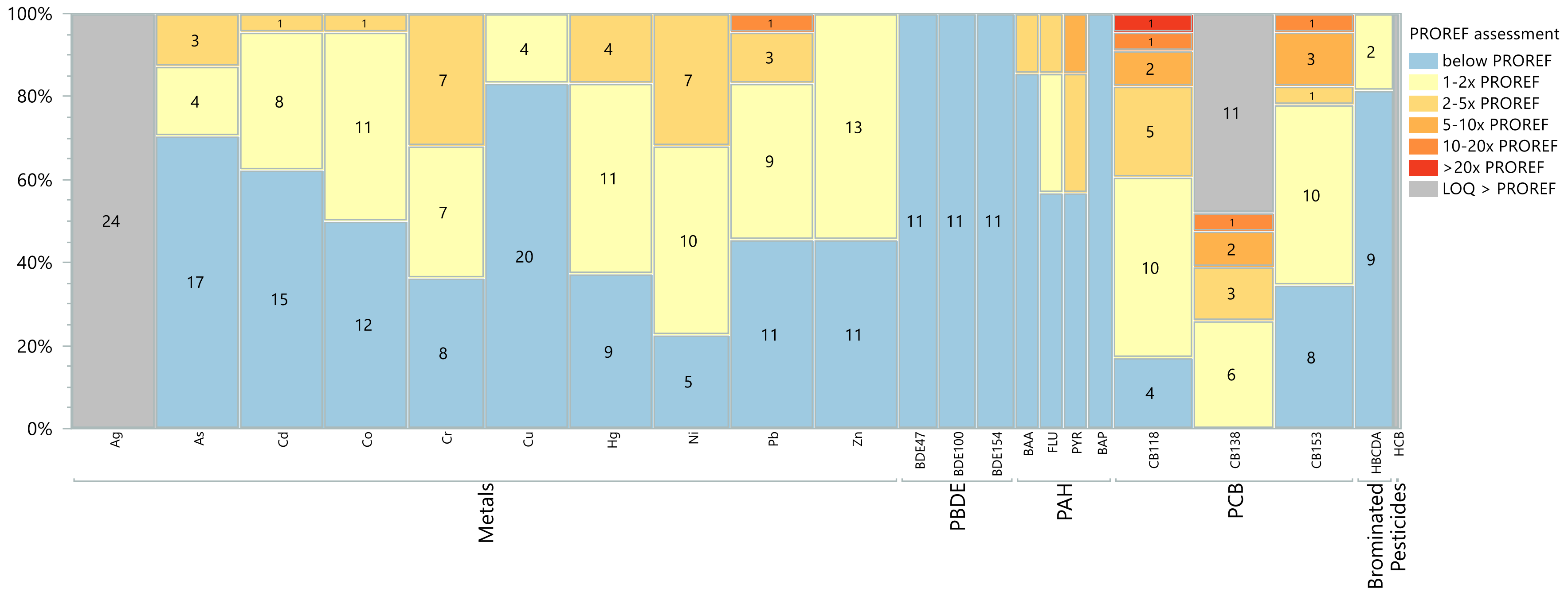

Figure 14. Assessment of PROREF ratios in blue mussel by contaminant and contaminant group. The cells are labelled by the number of datapoints (contaminants x stations). The assessments are considered by the median for each station and are represented by colours in the figure. In cases where LOQs were higher than PROREF (grey) no assessments could be made.

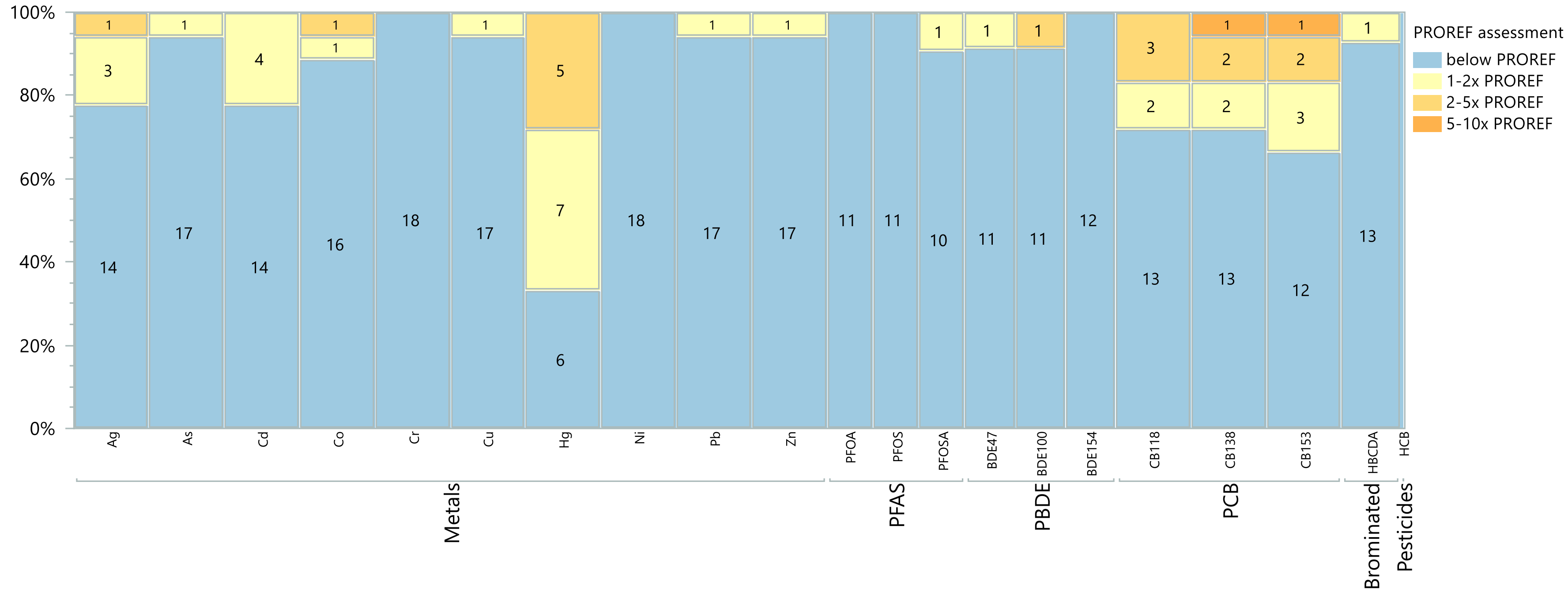

Figure 15. Assessment of PROREF ratios in cod by contaminant and contaminant group. The assessments are considered by the median for each station and are represented by colours in the figure. In cases where LOQs were higher than PROREF (grey) no assessments could be made.

3.2.2. Heatmaps for stations

Blue mussel stations in the Inner Oslofjord (**Figure 16**) had many 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)). In contrast to last year where one mussel station had no exceedances of PROREF, all stations had exceedances of PROREF in 2023. All samples from stations Solbergstrand (31A) in the Mid Oslofjord and Bjørkøya (71A) in the Langesundfjord were suspected to have been contaminated by nickel and chromium during sample preparation, and results were therefore withdrawn.

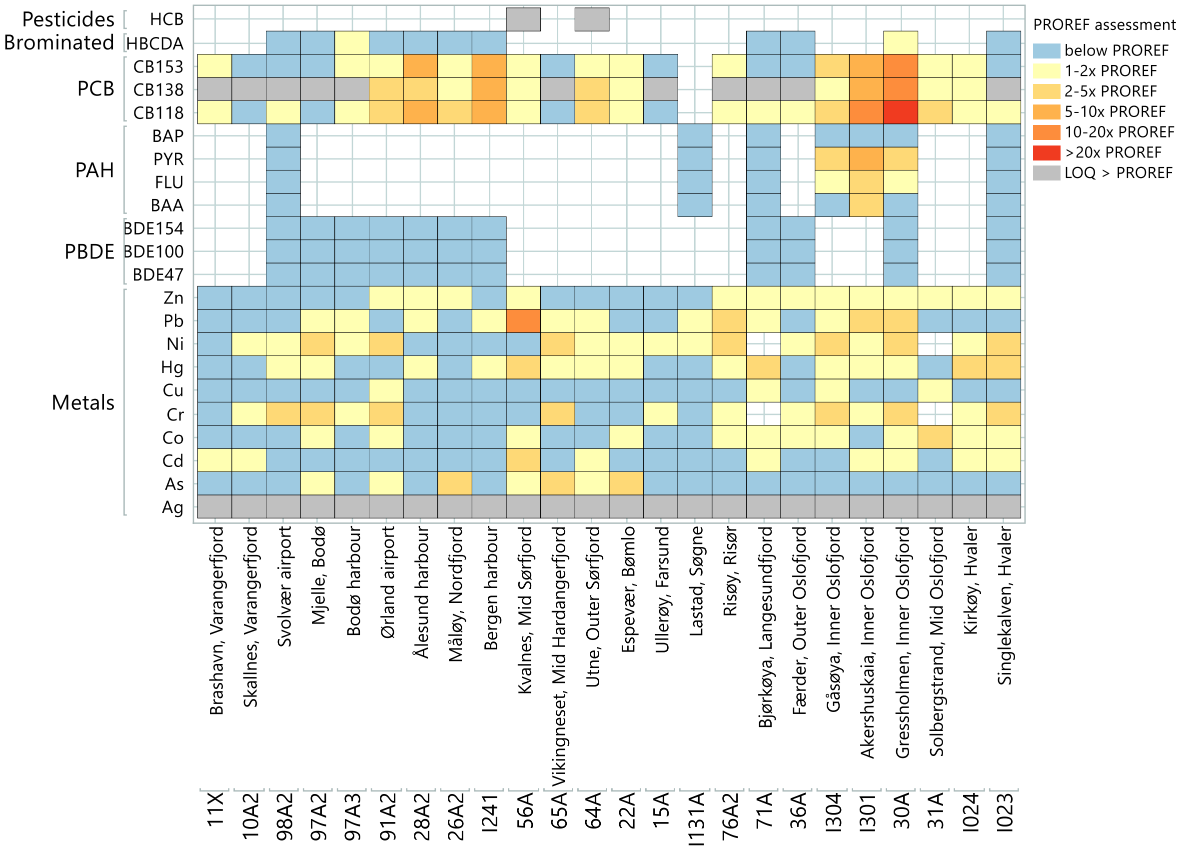

Figure 16. Heatmap of assessment of PROREF ratio in blue mussel. The assessments are considered by the median for each station and are represented by colours in the figure. In cases where LOQs were higher than PROREF (grey) no assessments could be made. Empty "cells" mean that the contaminant was not analysed for 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 17**) were most often observed at the stations in the Inner Oslofjord (30B) followed by Bergen (24B) harbour, Sørfjorden (53B), and Ålesund (28B). For Sørfjorden please note that the heatmap is based on median concentrations which is less influenced than mean concentrations on outlier (high) concentrations. Three stations did not have exceedances of PROREF for any compounds investigated in mussels from Hammerfest (10B), Tromsø harbour (43B2), and Kristiansand harbour.

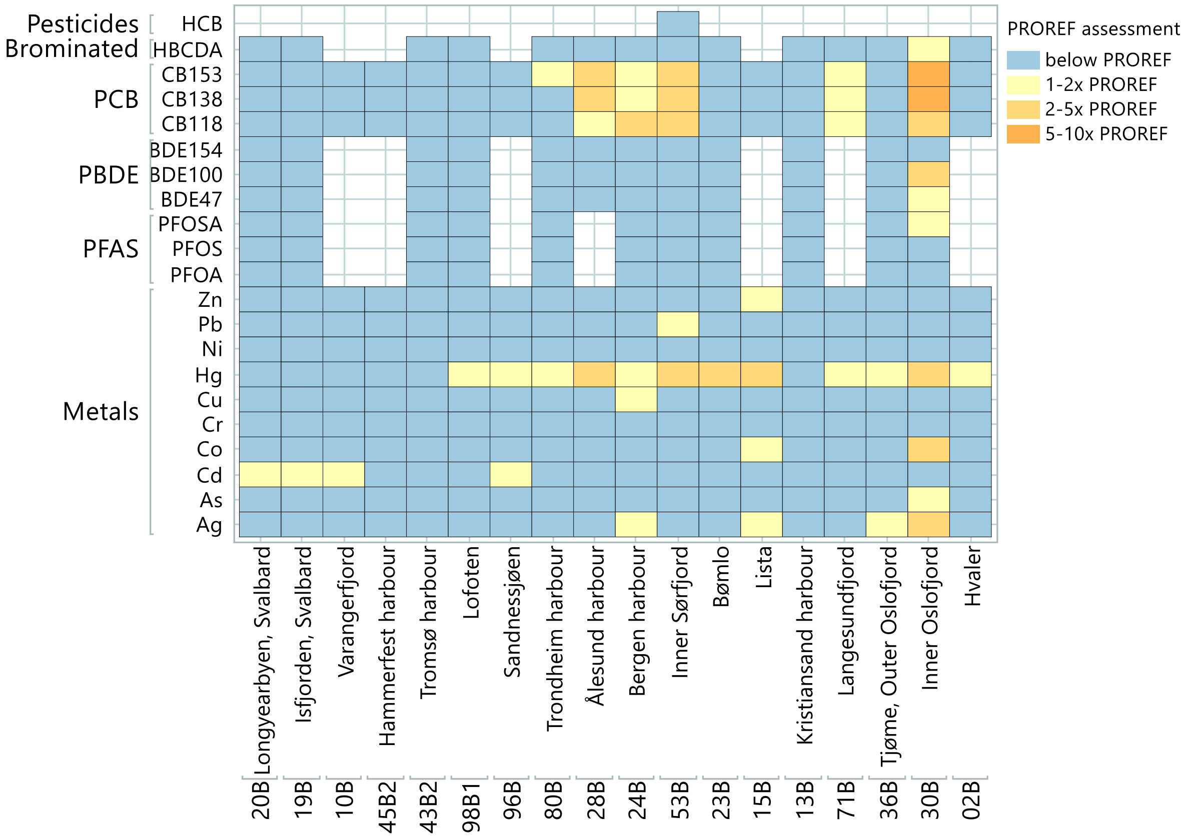

Figure 17. Heatmap of assessment of PROREF ratios in cod. The assessments are considered by the median for each station and are represented by colours in the figure. In cases where LOQs were higher than PROREF (grey) no assessments could be made. Empty "cells" mean that the contaminant was not analysed for 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.

3.2.3. Sum of PROREF-ratios above background level

As with sum RQ, we did a similar assessment of stations for PROREF. For sum PROREFratio, we only included contaminants above background levels (i.e. PROREF>1). As for sum RQ, the comparison between stations was hampered by different contaminant groups being analysed at each station. Stations are therefore grouped by the compounds exceeding PROREF>1 *not analysed* at the station. The contaminant groups that exceeded PROREFratio 1 and that were not analysed at all stations were PAHs, HBCDA (brominated), and PCB for blue mussel. For cod, HBCDA, PBDEs and PCBs exceeded PROREFratio 1, and was not analysed at all stations.

The sum of PROREFratio above background levels for blue mussel varied from 75 to 2.2 (Lastad, Søgne (I131A)). Gressholmen (30A) in the Inner Oslofjord had the highest sum PROREFratio. Also, other urban stations in Oslofjord, Bergen, and Ålesund harbour had high sum PROREFratio (> 20). In addition, Sørfjorden (56A, Kvalnes) had the third highest sumPROREF > 1 (32). For most of the stations the percentage contribution came mostly from metals.

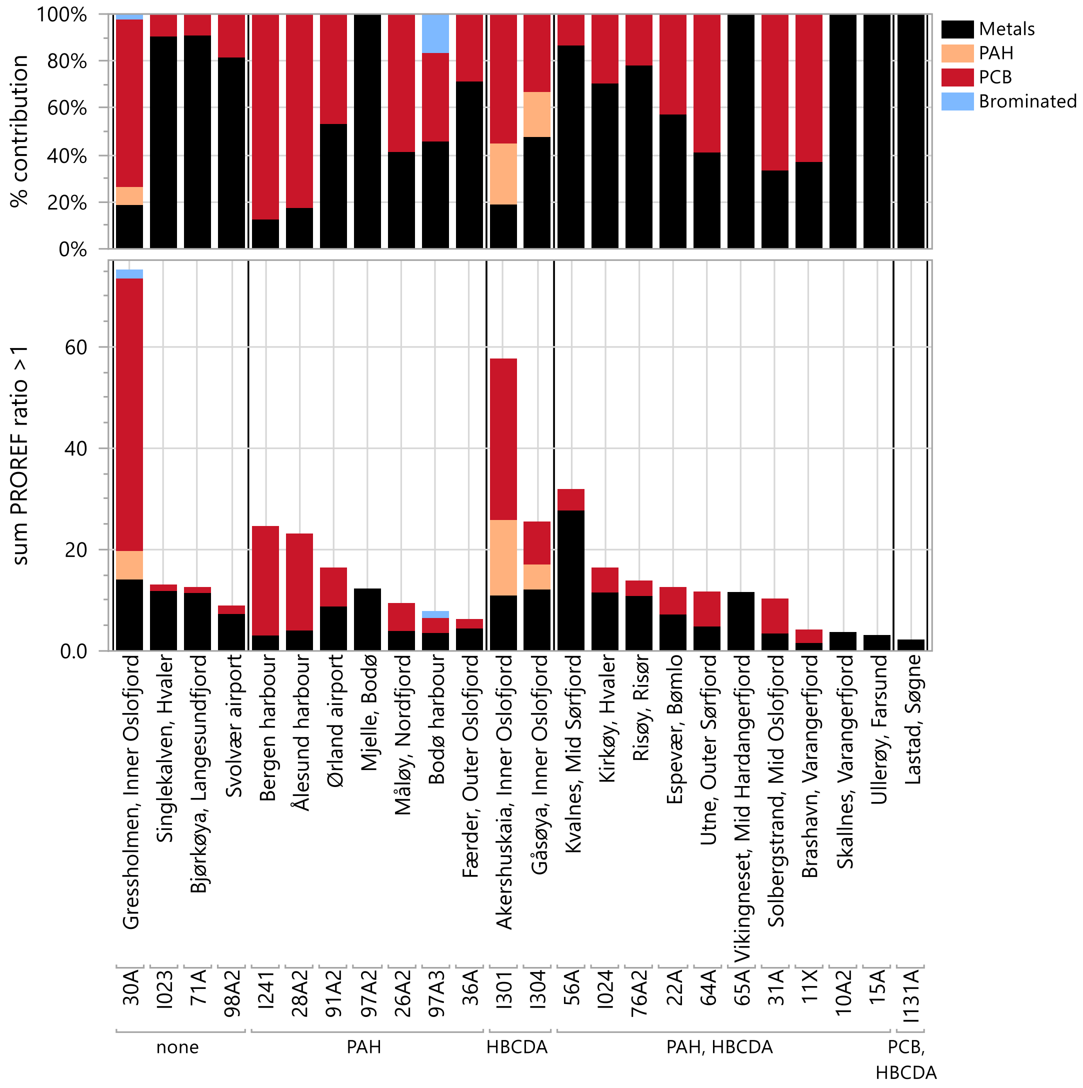

Figure 18. Stacked bar plot of sum PROREFratio above background levels for blue mussel stations grouped by analyses not performed for the stations (the group Brominated only contains HBCDA). On the top, the contribution (in % of sum PROREFratio>1) for individual groups is shown, on the bottom the sum PROREFratio>1.

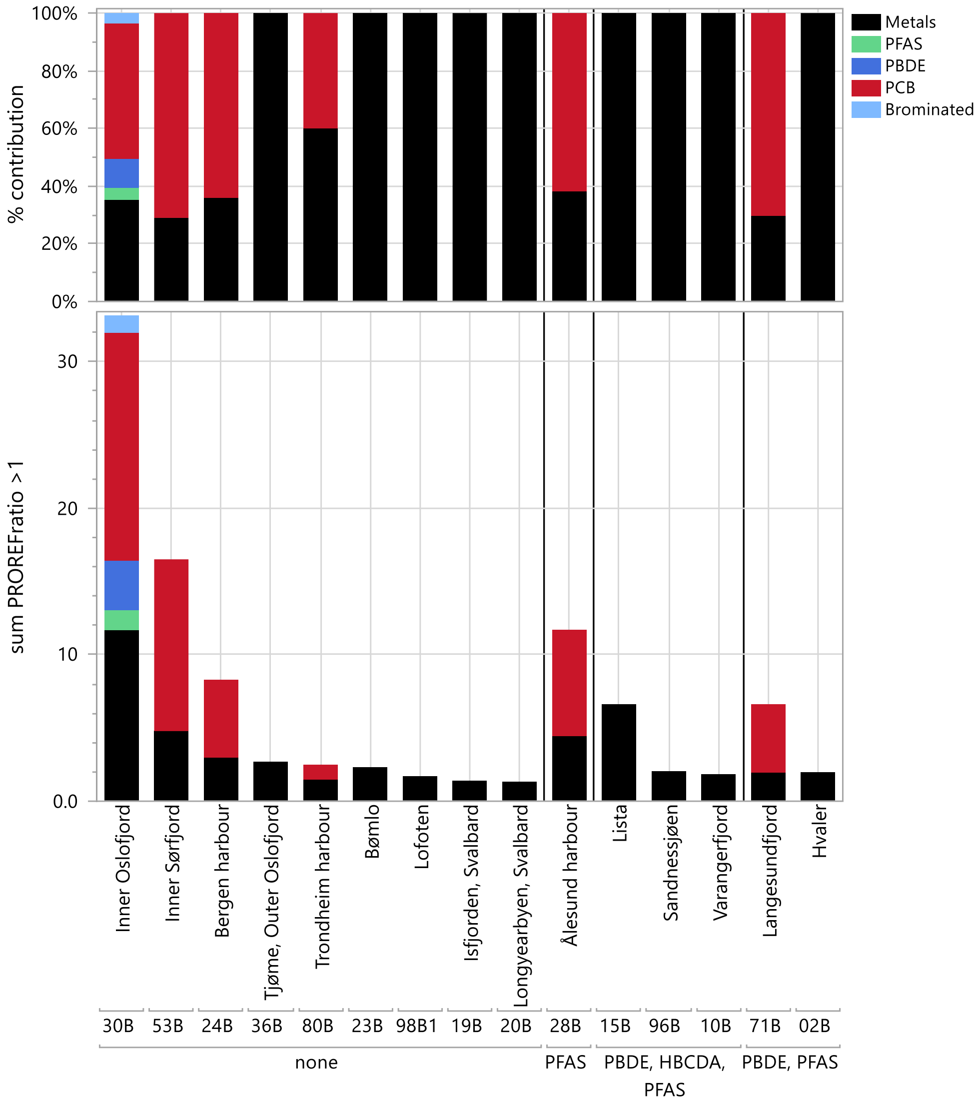

Figure 19. Stacked bar plot of sum PROREFratio above background levels for cod stations grouped by analyses not performed for the stations (the group Brominated only contains HCBDA). On the top, the % contribution (of sum PROREF>1) for individual groups is shown, on the bottom the sum PROREFratio>1.

Three cod stations (Hammerfest (45B2), Tromsø harbour (43B2), and Kristiansand harbour (13B) had no exceedances of PROREF background levels and are therefore not in **Figure 19**. The sum PROREFratio above background levels varied from 33 to 1.3. The Inner Oslofjord (30B) had sum PROREFratio higher than other stations, with contributions from metals, PFAS, PBDE, PCB, and HBCDA.

3.3 Time trends

3.3.1. Species and contaminants

In 2023, the OSPAR method of estimating time trends, HARSAT, was implemented for MILKYS (**chapter 6.9**). 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. The final choice of time trend (linear vs. non-linear) depends on model fit (based on AIC_c values). HARSAT also takes into consideration both the error of the chemical analysis **(chapter 6.3**) and also treats values under LOQ correctly as left-censored data (**chapter 6.5**). For more details on the trend analysis, see **chapter 6.9**. 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 774 time trends in each of two time span 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.

Table 5. Contaminants selected for describing time trends.

Group	Contaminant	Number of stations with trends (whole and recent)		
		Blue mussel	Cod	Eider[1]
Metals	Ag	24	18	2
	As	24	18	2
	Cd	24	18	2
	Co	24	18	2
	Cr	24	18	2
	Cu	24	18	2
	Hg	24	18	2
	Ni	24	18	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
Brominated	HBCDA	11	14	2
Pesticides	HCB	2	1	0
All	All	401	331	42

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

Time trends (recent (≤ 10 years) and whole period) for species are shown in **Figure 20**. More detailed view of time trends for contaminants in blue mussel, cod, and eider are shown in **Figure 21** to **Figure 23**. Heatmaps of time trends (stations vs. contaminants) are shown in **Figure 24** and **Figure 25**. 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". For examples of this distinction, please refer to examples in **chapter 6.9**.

A part (10-20 %) 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 20**). However, also upward trends were observed (5-10%). For blue mussels more upward trends for recent trends (10%) than whole trends (6%), were observed.

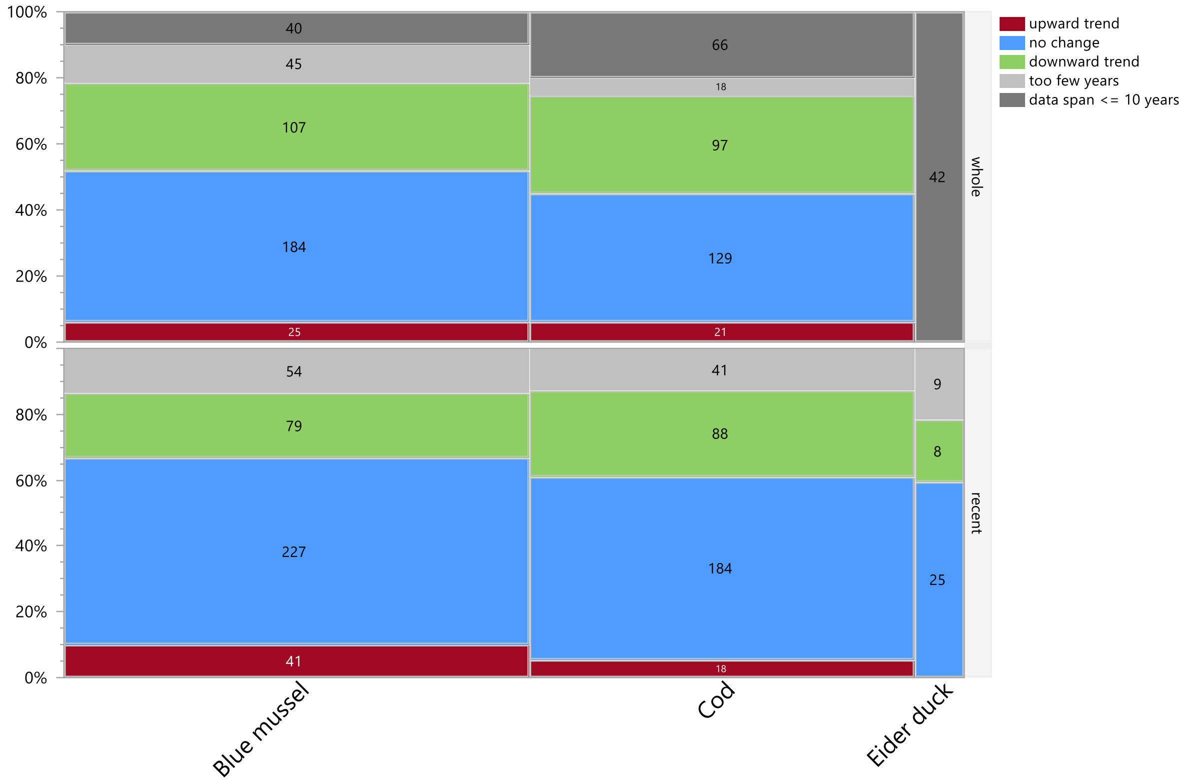

Figure 20. Mosaic plot of time trends for blue mussel and cod. Upper panel shows the whole trends, while lower panel shows recent trends. The number of trends (stations × contaminants) are indicated in the respective cells.

In blue mussel, downward trends in the whole period were more frequent than upward trends (27% vs. 6%) and was found for many contaminants. Upward whole trends were found for all metals except silver, and were also found for PCBs (CB118, CB138 and CB153).

The overall picture was roughly the same for recent trends, but more upward trends for PCBs were found. 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.

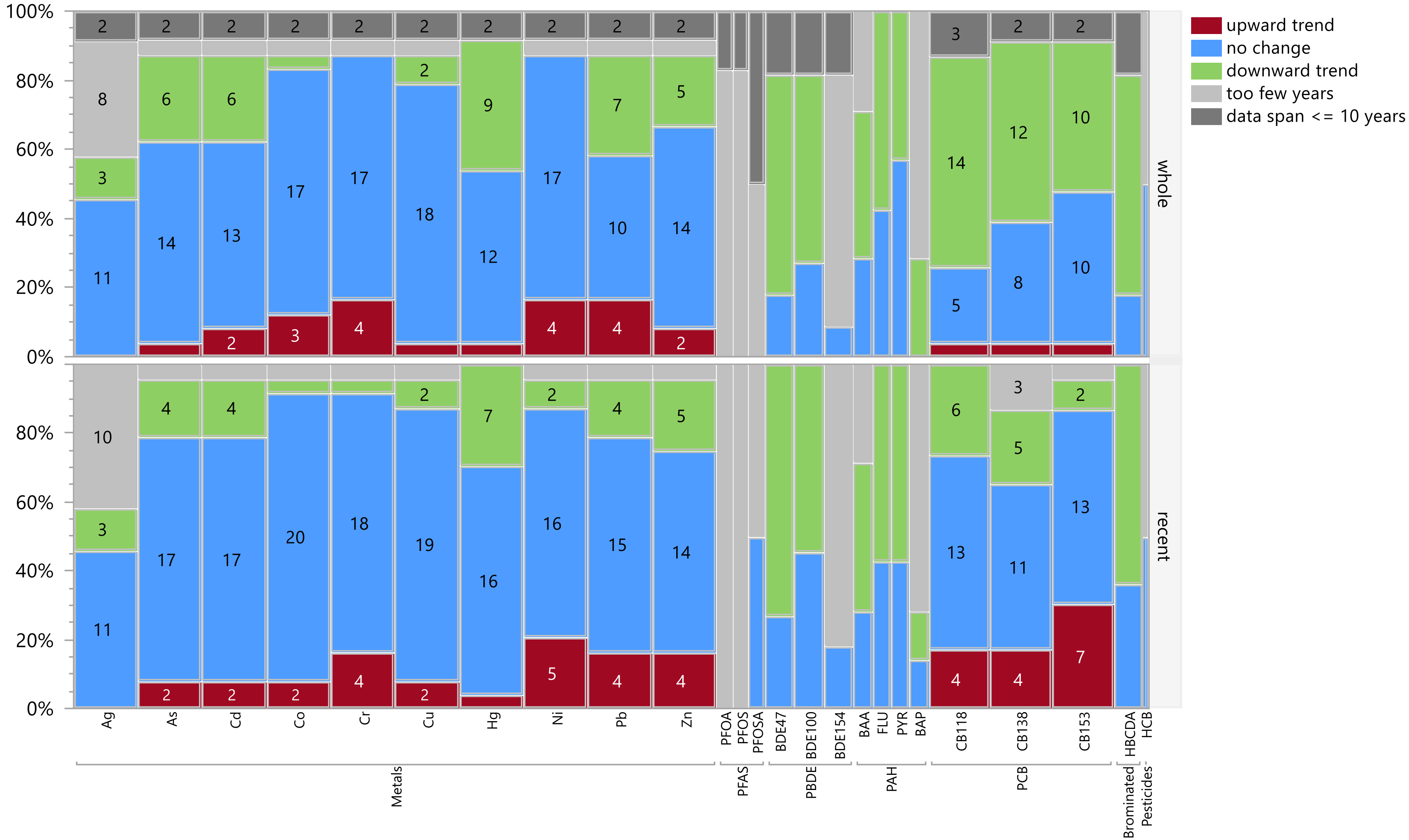

Figure 21. Time trends for blue mussel. Upper panel shows the whole trends, while lower panel shows recent trends. The numbers of stations are indicated in the respective cells.

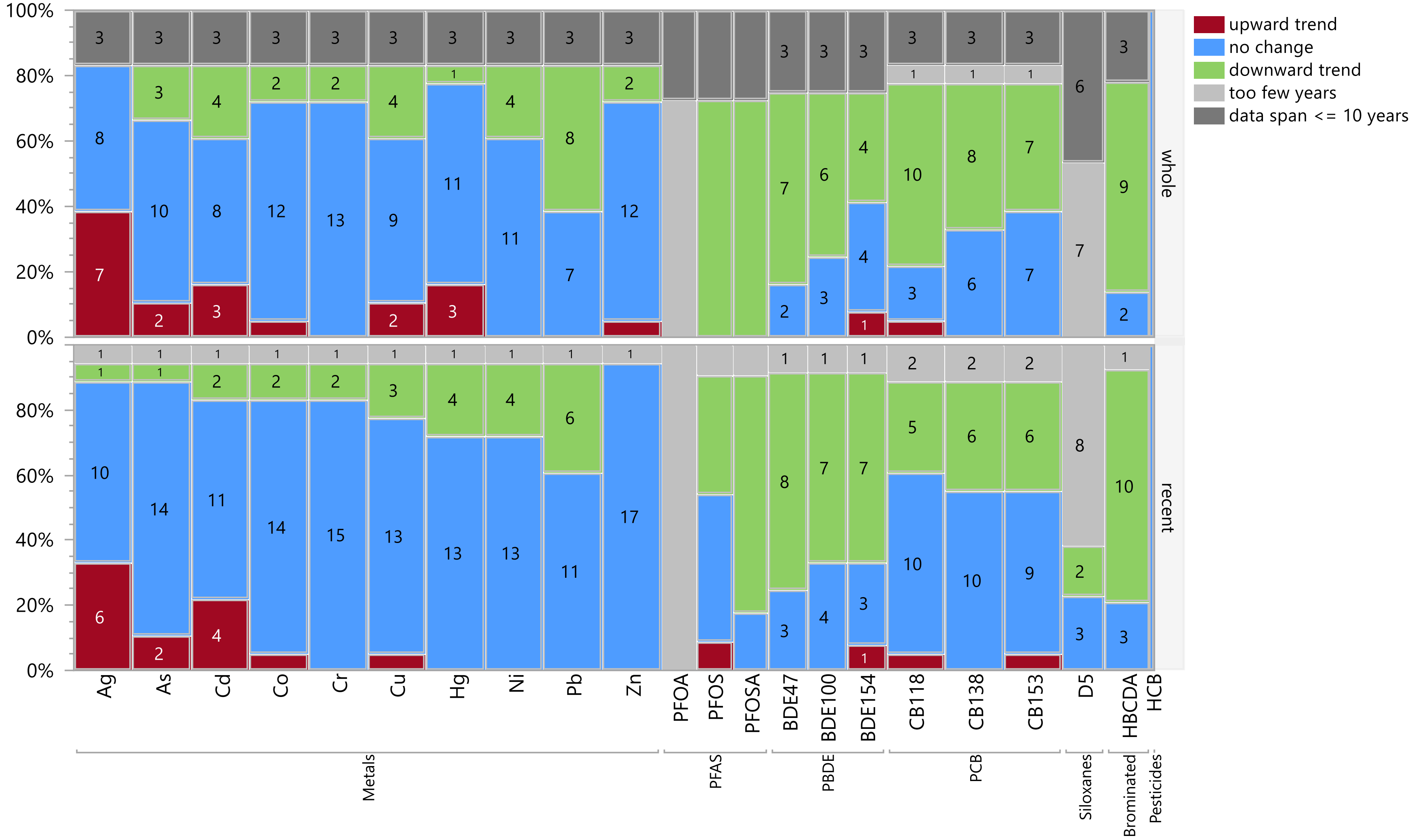

Figure 22. Time trends for cod. Upper panel shows the whole trends, while lower panel shows recent trends. The number of stations is indicated in the respective cells.

Downward time trends for the whole period in cod were more frequent than upward trends (**Figure 22**). Silver, cadmium and mercury had the highest percentages of upward time trends for whole trends, but silver and cadmium had most upward time trends in recent years. No upward recent time trend for mercury was observed. However, one upward recent time trend for PFOS was observed.

Time trends for eider are shown in **Figure 23**. A few downward recent time trends were observed in blood and eggs, but apart from PFOS they were not the same contaminants in the two tissues.

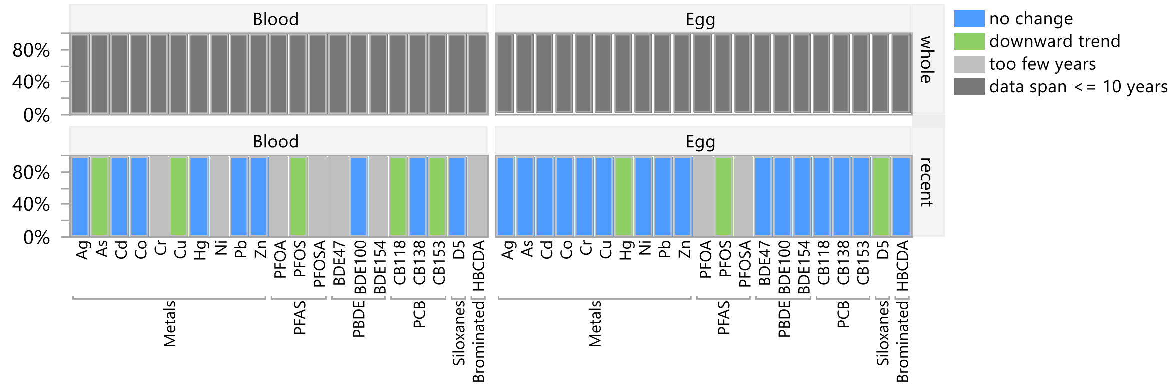

Figure 23. Time trends for eider. Upper panel shows the whole trends, while lower panel shows recent trends. The number of stations is indicated in the respective cells.

3.3.2. Heatmaps for stations

The upward whole and recent trends for metals in blue mussel (**Figure 24**) were mostly found at stations in the Oslofjord; Gåsøya (I304), Gressholmen (30A), Akershuskaia (I301), Tjøme (36A1) and Hvaler (I024), but to a less extent also at other stations. Mercury had an upward time trend only at Akershuskaia (both recent and whole trends). A few stations had upward recent time trends for PCBs, and most notably stations Måløy (26A, both whole and recent) and Gressholmen (30A, only recent). A few other stations had upward recent time trends for one or two PCB isomers.

Also in cod, a few upward recent and whole trends for metals were observed **(Figure 25**). Lista and Sandnessjøen (stations 15B and 96B respectively) had the most upward time trends. Time trends at Svalbard (19B) could also be estimated, and a single upward recent trend was found for PFOS, in this pristine area. Long range transport of PFAS to Svalbard has been shown, and several PFAS compounds can be formed from the atmospheric degradation of precursors (Hartz et al., 2023). However, the source of the PFAS found here, in cod from Svalbard, is unknown. A few upward trends for BDEs and PCBs were also observed, both whole and recent periods.

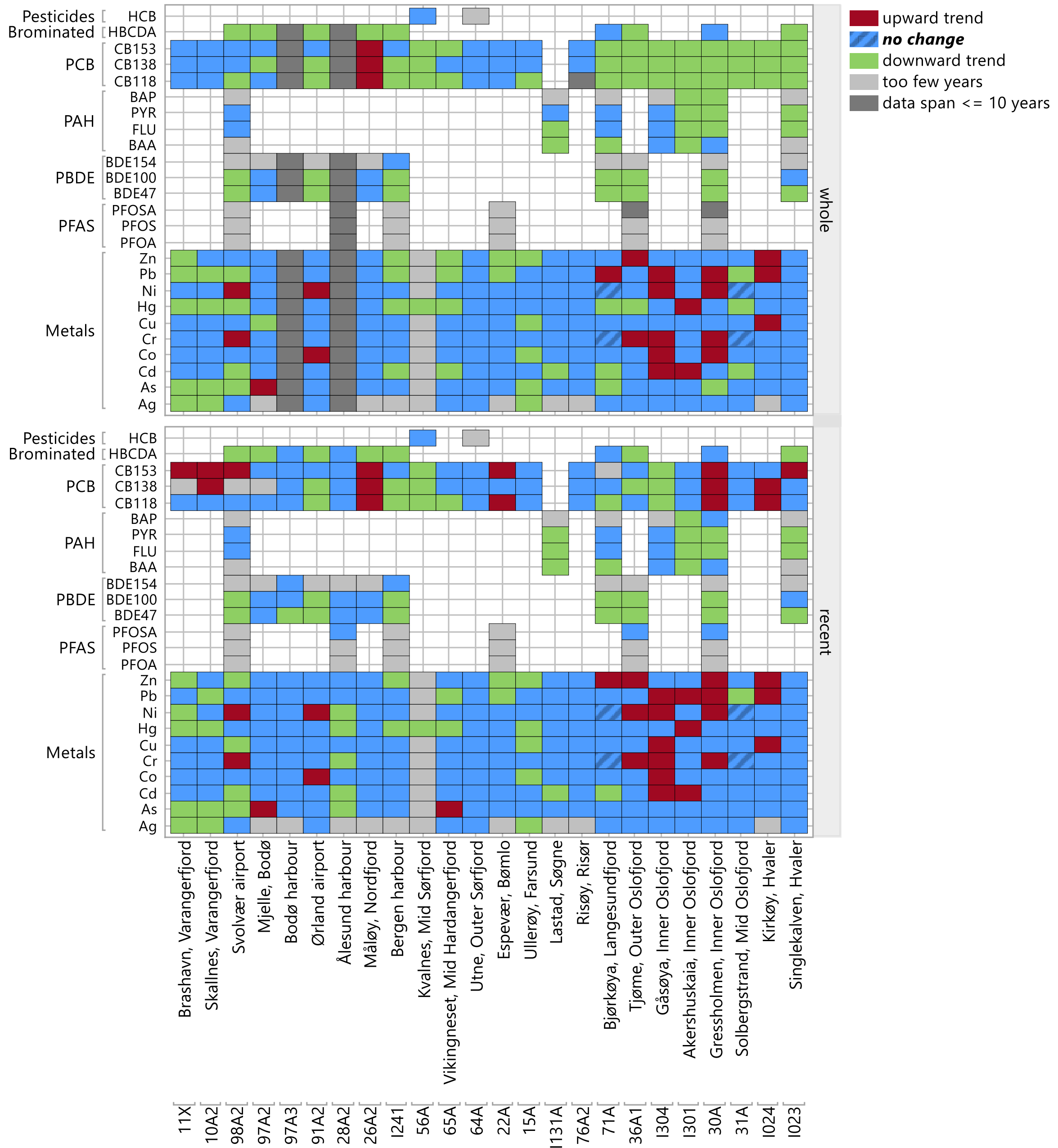

Figure 24. Heatmap of the whole trend and recent time trends in blue mussel. The colours represent time trends observed at stations. Empty "cells" mean that the contaminant was not analysed. Grey lines show the midpoint of each station and contaminant. The stations are ordered along the coastline starting north moving south. Time trends for chromium and nickel for stations Solbergstrand (31A) and Bjørkøya (71A) are shown for trends in 2022 (cells are hatched) since data from 2023 were suspected to be contaminated during sample preparation.

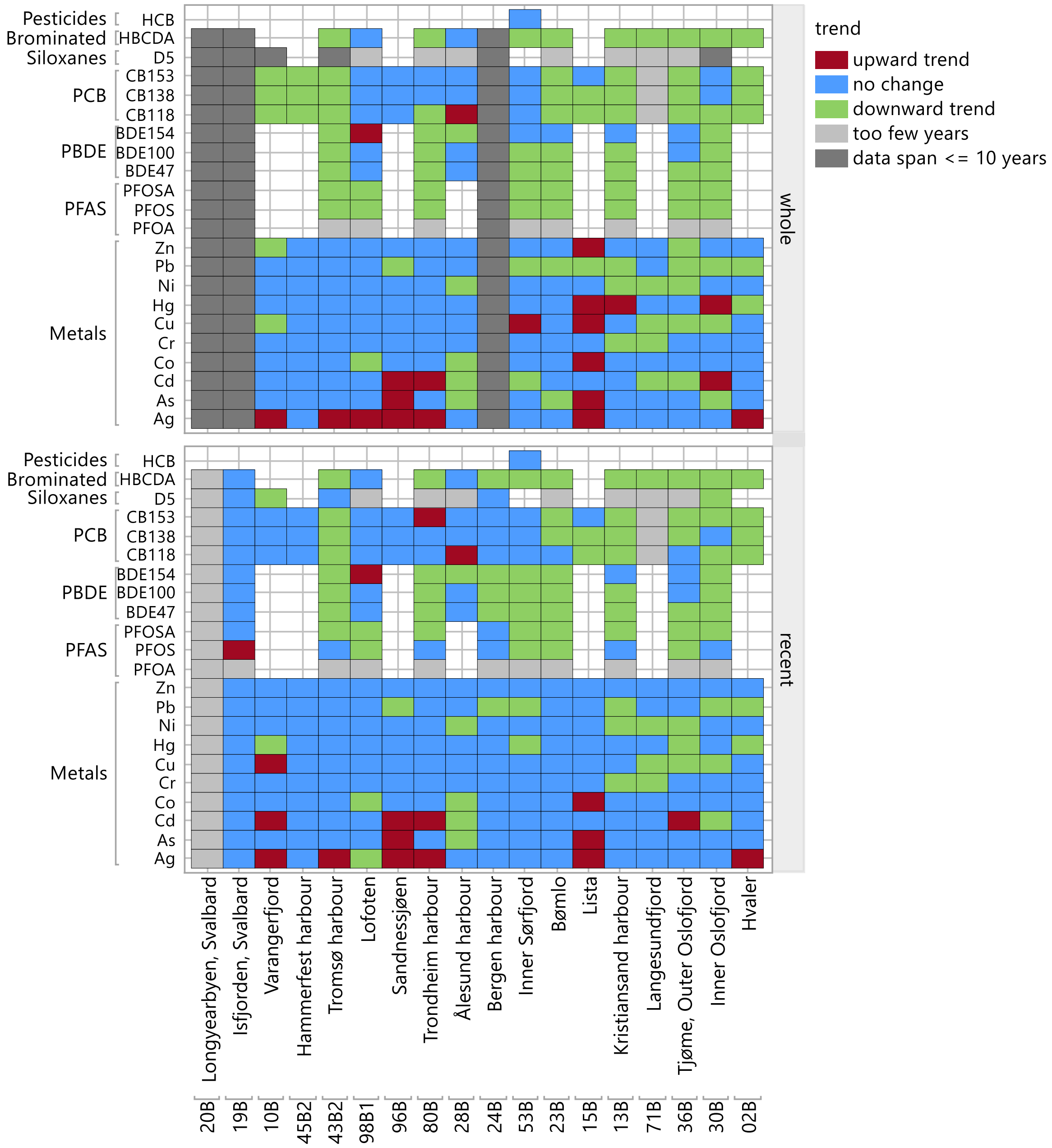

Figure 25. Heatmap of the whole trend and recent time trends in cod. The colours represent time trends observed at stations. Empty "cells" mean that the contaminant was not analysed. Grey lines show the midpoint of each station and contaminant. For mercury, cod have been length adjusted. The stations are ordered along the coastline starting north moving south.

3.3.3. Upward time trends for stations that exceeded EQS and/or PROREF

Special attention needs to be paid for stations and contaminants with upward trends which at the same time are exceeding EQS. This was the case for 7 combinations of contaminants, stations and species for the selected contaminants which are listed in **Table 6**. Note that EQS for sumPCB7 and sumBDE6 was exceeded in all cod stations, and all but one for mercury. Also, the highest exceedances of PROREF were investigated, and for blue mussel we included exceedance higher than or equal to 5xPROREF, while in cod higher than or equal to 2xPROREF (**Table 6**). The figures of the corresponding trends and relation to EQS are shown in

Figure 27 and **Figure 28**. Significant trends have a statement in the upper right corner of the figure indicating the annual percentage change pr. year.

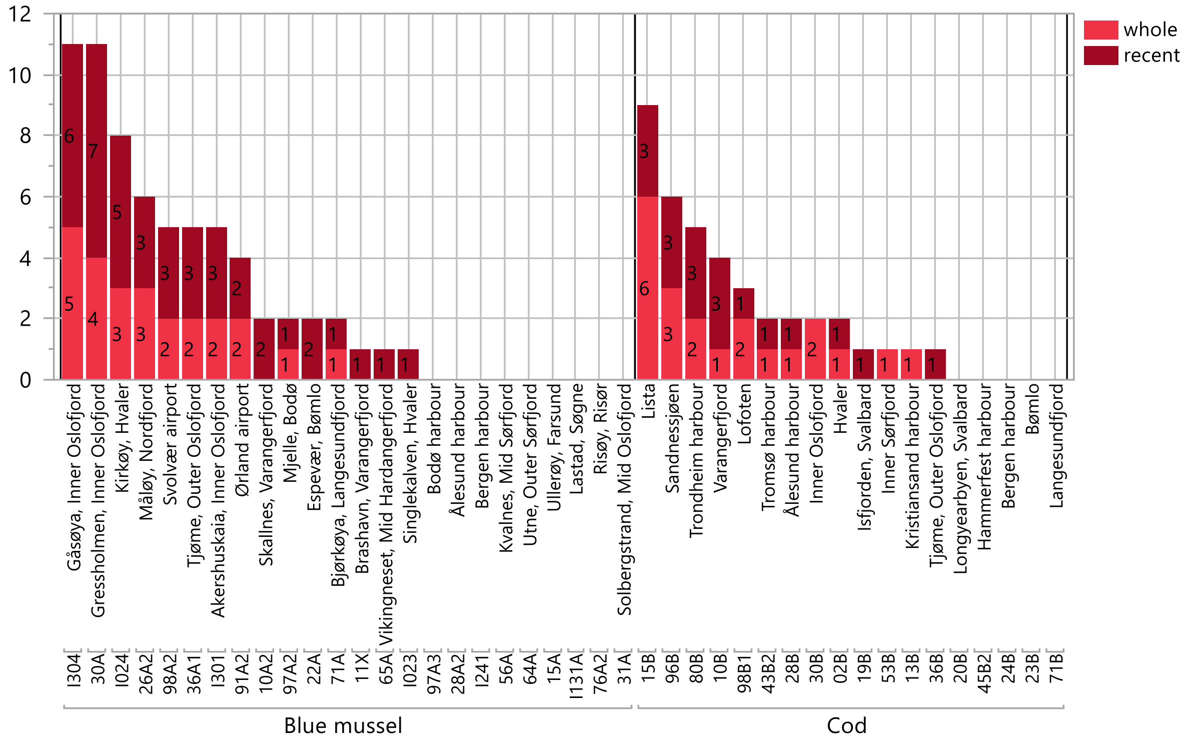

Figure 26. Number of upward time trends for blue mussel and cod stations. Recent and whole trends are shown in different red colors, and the number of contaminants for the two types of time trends are shown. If a contaminant has increasing time trends for both recent and whole period, it is not counted twice since the underlying data are different. Please refer to the heatmaps for time trends for specific contaminants overview (**Figure 23**-**Figure 25**)

It is difficult to pinpoint the reasons for the observed time trends. New uses of PCBs were banned in Norway in 1980, and discharges of mercury are generally reduced, following the agreement (2013) and entering into force (2017) of the Minamata Convention. However, still, we observe increasing trends. MILKYS is not designed to investigate the reasons for upward time trends, only to investigate the existence of such trends. However, there is reason to believe that climate change, increased precipitation, and runoff/washout from land lead to more contaminants (such as mercury and PCBs) along the coast.

Table 6. Overview of contaminants with upward trends and exceedance of EQS (RQ) and/or PROREF (>5 for mussel and >2 for cod). RQ and exceedance of PROREF are given with two significant digits.

Species	Contaminant	Station	Station name	RQ (concentration/EQS)	PROREFratio (concentration/ PROREF)	Shown in Figure
Cod	**Hg**	15B[1]	Lista	8.5	3.0	**Figure 27**
		13B[1]	Kristiansand harbour	1.9	<1	
		30B[1]	Inner Oslofjord	9.0	3.2	
Blue mussel	**CB118**	30A	Gressholmen, Inner Oslofjord		24	**Figure 28**
	CB138	30A	Gressholmen, Inner Oslofjord		15	
	CB153	30A	Gressholmen, Inner Oslofjord		14	
	Hg	I301	Akershuskaia, Inner Oslofjord	1.1	1.8	

[1] Note that the upward trend is the whole trend, not the recent trend.

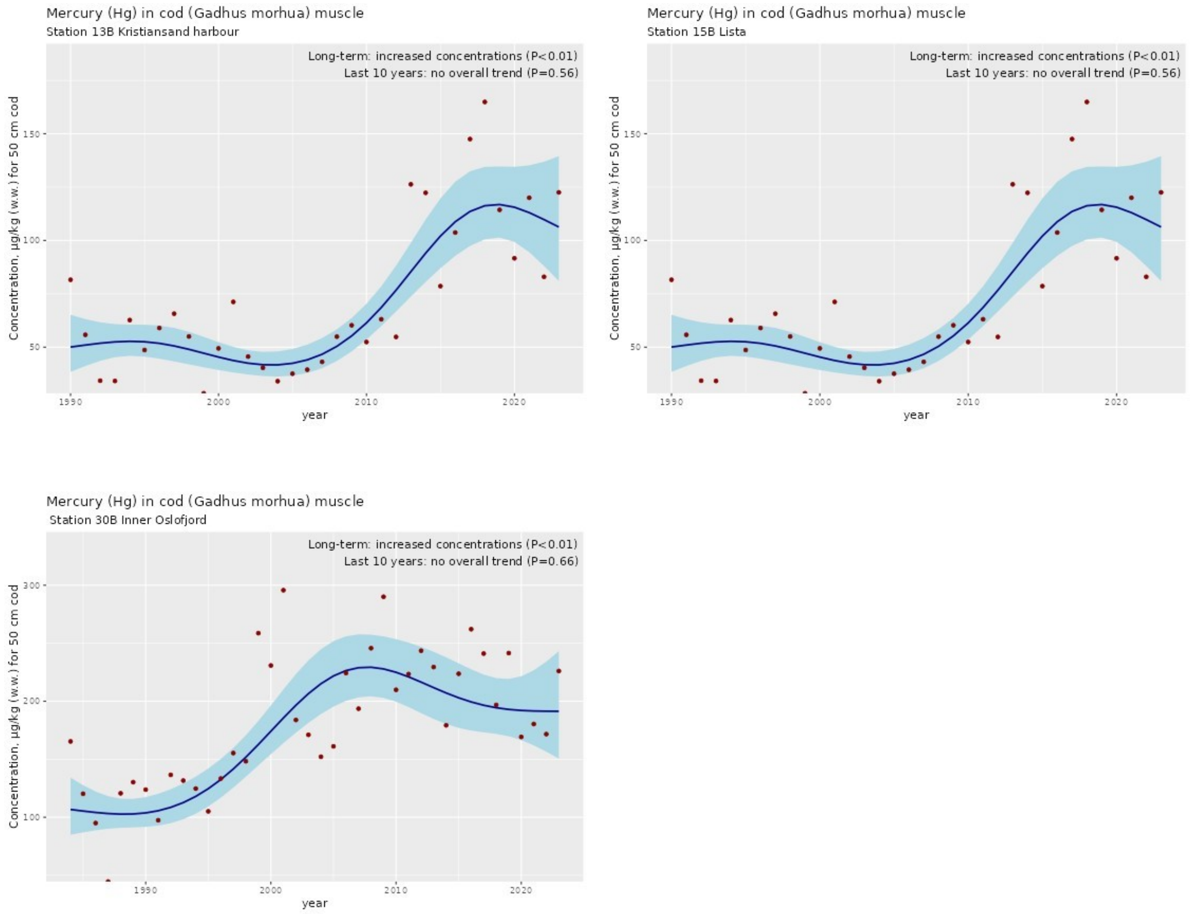

Figure 27. Cod stations with upward time trends for length adjusted mercury concentrations: Kristiansand harbour (13B), Lista (15B), and Inner Oslofjord (30B). The 2023 concentrations exceeded EQS and for two stations also PROREFs more than two times. Median concentrations are shown as red circles. The 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. Note that scales on the axes varies. Trends are based on all data, but only medians are shown here.

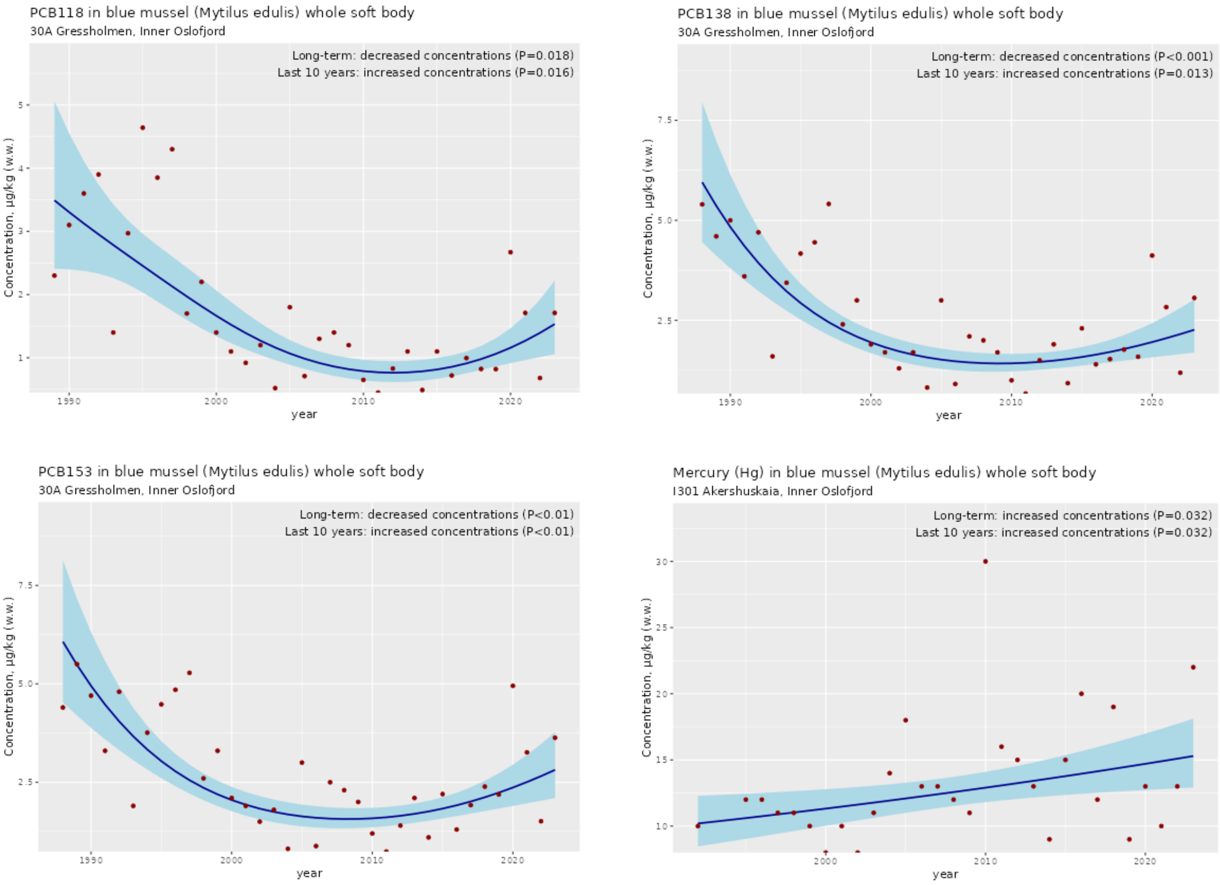

Figure 28. Blue mussel station with upward time trends for PCBs (PCB118, PCB138 and PCB153) in the Inner Oslofjord: station 30A Gressholmen. The 2023 concentrations exceeded PROREFs more than five times. Since the data from 2020 was higher than the other years, we confirmed that the data were significant when excluding year 2020 in linear trend analyses of the latest 10 years. Blue mussel station with upward time trend for mercury: I301 Akershuskaia, where the 2023 concentrations exceeded EQS.

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). 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 analysed in dogwhelk at seven stations (dogwhelk at Farsund (15G) was not found in 2023) and common periwinkle at two stations (Fugløyskjær in Langesund (71G) and Lastad at Søgne (131G). 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 (<2.7 µg/kg ww) and common periwinkle (<0.92 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 (<0.83 µg/kg ww) and common periwinkle (<0.5 µg/kg ww), all TPhT-concentrations were below EQS.

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 were 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 29** and **Figure S13**). Significant downward whole trends were found at Færder

(36G) in the Outer Oslofjord (**Figure 29**), Risøya (76G) at Risør, Lastad (131G) at Søgne, Espevær (22G) by Bømlo, and at Svolvær in Lofoten (98G)

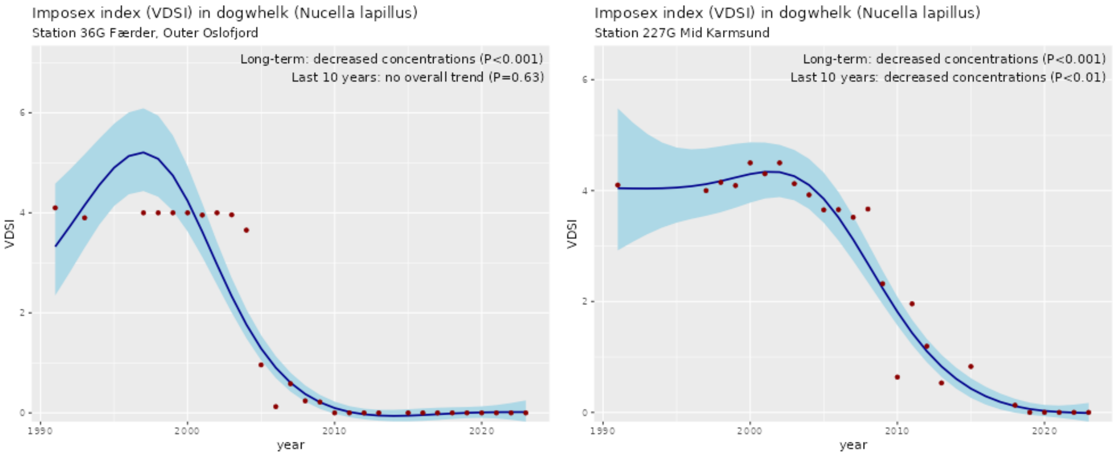

Figure 29. VDSI from 1991 to 2023 for dogwhelk from Færder (36G) in the Outer Oslofjord (left) and in the Mid Karmsund (227G) (right). For full explanation of figure see example in **Figure 27.**

Selected time trends

Two time trends for VDSI in dogwhelk are shown in **Figure 29**. VDSI in dogwhelk at Færder (36G) showed downward whole trend. In the Mid Karmsund (227G), there were both downward whole and recent trends.

The 2023 data confirmed the results since 2017 of no effects of TBT on dogwhelk (VDSI=0) (Schøyen et al., 2019).

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 a significant downward whole trend (**Figure 30**).

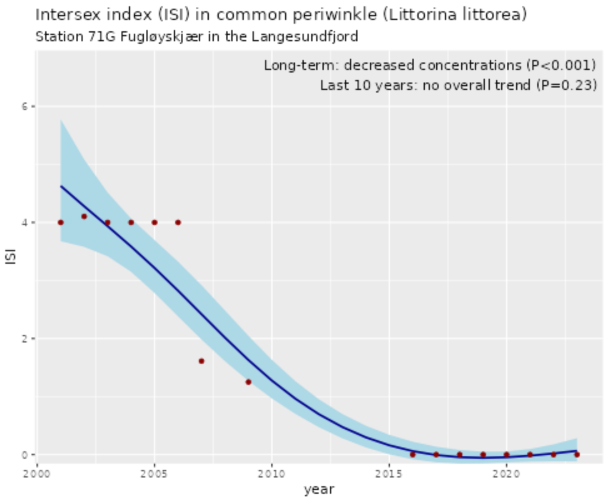

Figure 30. ISI from 2001 to 2023 for common periwinkle from Fugløyskjær in the Langesundfjord (71G). For full explanation of figure see example in **Figure 27**.

Dogwhelk versus common periwinkle

At Lastad in Søgne (131G), both dogwhelk and common periwinkle were collected and analysed for comparison between the two species and assessment of the possibility of using common periwinkle instead of dogwhelk. TBT concentrations in both dogwhelk (<0.83 µg/kg ww) and common periwinkle (<0.5 µg/kg ww) were below LOQ. The effects of TBT were zero for both dogwhelk (VDSI) and common periwinkle (ISI).

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 methods applied to cod (including analyses of degradation products of PAH in bile). Each method is in theory specific for 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). In 2023, however, results of OH-pyrene metabolites in bile could only be obtained from station 15B (Lista).

OH-pyrene metabolites in bile

Analysis 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 2023 the median (non-normalised [5]) concentration of OH-pyrene metabolites in bile from cod at station 15B was below the ICES/OSPAR assessment criterion (background assessment criteria, BAC; 21 ng/ml), however, with large variation (range: <1 – 129 ng/g).

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 2023 appeared similar as in as most years, since 2013. The median activity in the Inner Oslofjord (30B) in 2023 was similar as at Bømlo (23B; reference station), while in the Inner Sørfjord (53B), the median ALA-D activity was significantly lower (than both Bømlo and the Inner Oslofjord; Tukey-Kramer HSD). The largest variation in ALA-D activity was also observed in the Inner Sørfjord. 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 2023, the highest (among all stations) hepatic concentrations of lead were found in cod from the Inner Sørfjord (53B), and these were significantly higher than in both in the Inner Oslofjord (30B) and 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 2023, the median EROD activity appeared lower at Bømlo (23B, reference station), than in the Inner Oslofjord (30B) and Inner Sørfjord (53B), however the difference was only statistically significant (Tukey-Kramer HSD) from the Inner Oslofjord (the activity in the Inner Sørfjord was neither different from Bømlo, nor the

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

Inner Oslofjord). Median EROD activities were below the ICES/OSPAR assessment criterion (background assessment criteria, BAC; 145 pmol/min/mg microsomal protein), at all stations.

It must be mentioned that the cod specimens accumulating very high PCB concentrations in the Sørfjord (**chapter 3.1.3**) did not show any elevated EROD activity. This corresponds with findings in 2002, when extreme PCB concentrations were observed in cod from the same site (Ruus et al., 2006), indicating limitations for this assay as a biomarker for this combination of PCB congeners (Kennedy et al., 2003). Besselink et al. (1998) showed inhibition of dioxin (TCDD)-induced EROD activity by PCBs in flounder.

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 increase per trophic level can be expressed as:

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

Then:

TMF = 10^b

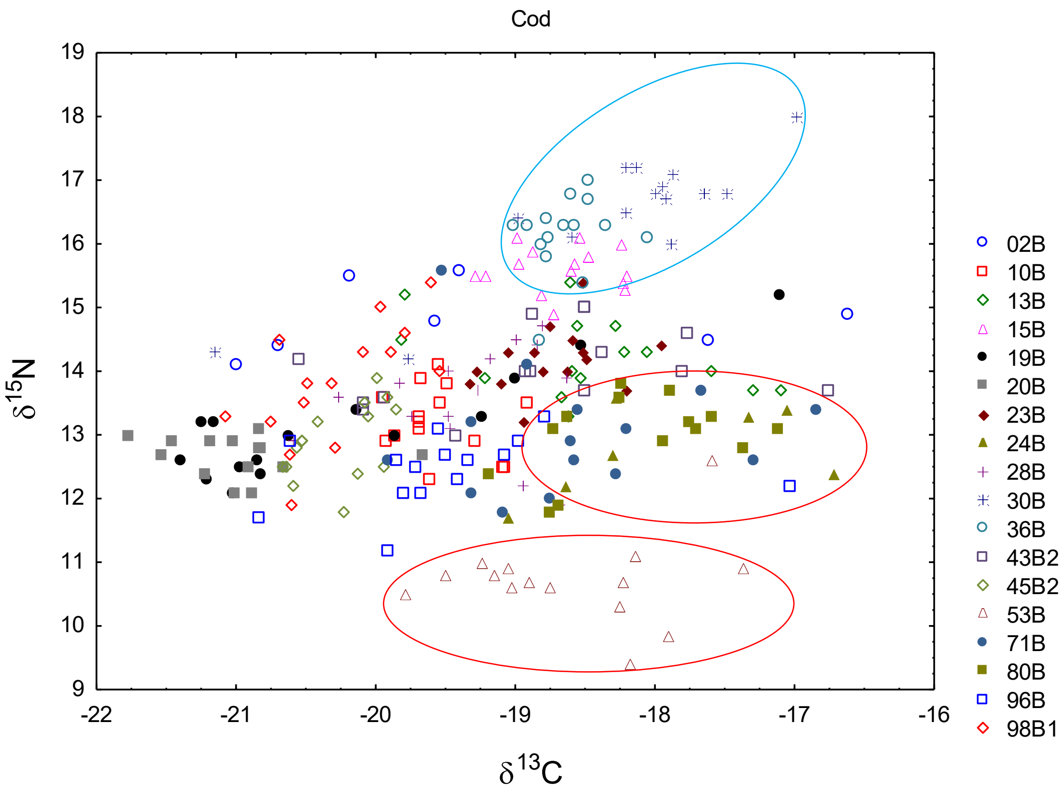
The TMF has been amended to Annex XIII of the European Community Regulation on chemicals and their safe use (REACH) for possible use in weight of evidence assessments of the bioaccumulative potential of chemicals as contaminants of concern.

The results of the stable isotope analysis in 2023 generally show the same pattern as observed in previous years i.e., a continual geographical pattern, indicating a spatial trend persistent in time (**Figure 31**).

As previously, cod from the Sørfjord (53B) and (partly also) Bergen harbour (24B; both in Vestland County) stand out with low $\delta^{15}N$ signature (**Figure 31**). The same is shown for mussels from the Sørfjord (56A) and Bergen harbour (I241), indicating that the $\delta^{15}N$ 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 31**) indicating a high baseline.

The isotopic signatures in cod from Svalbard appear similar at the two stations (19B and 20B; **Figure 31**), apparently with the lowest $\delta^{13}C$-values.

In 2019, the $\delta^{15}N$ 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; (Schøyen, Grung, Lund, Hjermann, Ruus, Øxnevad, Beylich, et al., 2024). 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.



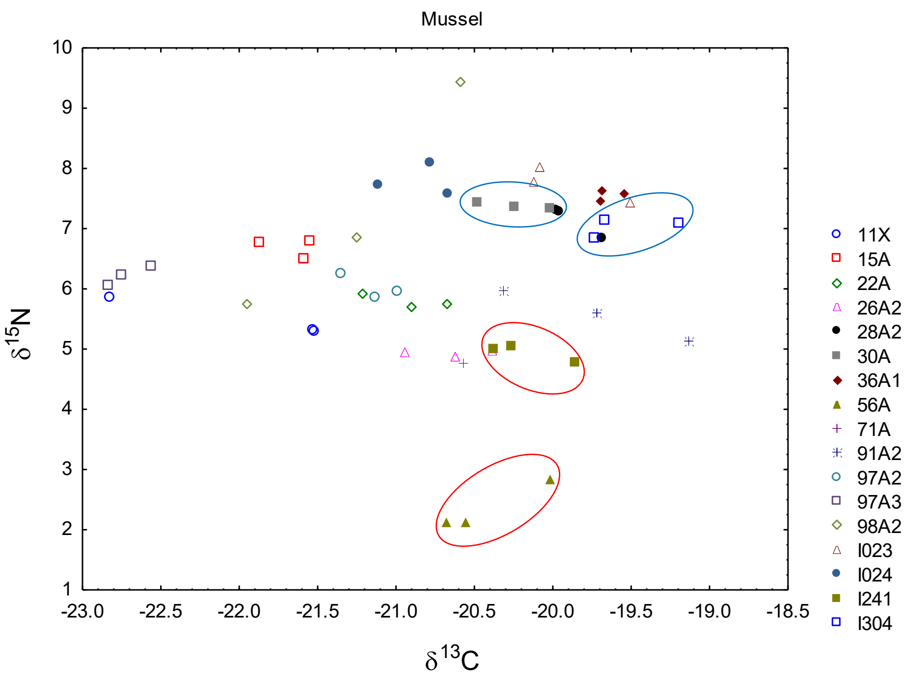


Figure 31. $\delta^{13}C$ plotted against $\delta^{15}N$ for cod (top) and blue mussel (bottom). Blue ellipses indicate the position of (most of) the samples of cod and blue mussel from the Inner Oslofjord, while red ellipses indicate the position of the samples of (most of) the cod and blue mussel from the Sørfjord and Bergen harbour.

The δ15N values in eiders from Svalbard (blood and egg) resembled those previously observed (Schøyen, Grung, Lund, Hjermann, Ruus, Øxnevad, Beylich, et al., 2024). This is illustrated in **Figure 32**, where δ15N is plotted against δ13C for blood and egg, all years, in a bag plot (a bivariate box plot; Rousseeuw et al., 1999a). Also as previously, the δ13C values in the eiders differed between the two matrices (blood and egg; **Figure 32**), likely related to different lipid content (also recognized by a higher C:N weight ratio in eggs), as lipids are δ13C-depleted relative to proteins (Sweeting et al., 2006). Samples were not treated to remove carbonates or lipid prior to stable isotope analysis. Similar as for cod, the blood of eiders from Svalbard appeared slightly lower in δ13C, compared to blood of eiders from the Inner Oslofjord (sampled in May 2022; (Ruus et al., 2023); Mean: -21.72; ±0.65 σ; n=15,). Furthermore, the eider blood displayed lower δ13C in 2019, compared to the other sampling years (**Figure 32**). In 2019 the blood was sampled in July (8th), while the other years' sampling was conducted in June (4th - 9th , or 23rd). Eider females brood alone for 25-28 days, and during incubation, they rarely leave the nest. They fast during the breeding period, losing much of their body weight. Stored lipid reserves are mobilized while fasting (Korschgen, 1977). The reduced δ13C in 2019 is most likely due to mobilized lipid reserves (the C:N-ratio in the blood of the eiders was also significantly higher in 2019, than the other years; Tukey-Kramer HSD), due to longer fasting, which could also affect contaminant dynamics (Thorstensen et al., 2021).

In 2023, eggs and bird blood samples were collected from the same nest, and the isotopic signatures were correlated; significant linear regressions were found between isotopic signatures in blood and eggs for both δ13C (R^2=0.66) and δ15N (R^2=0.41).

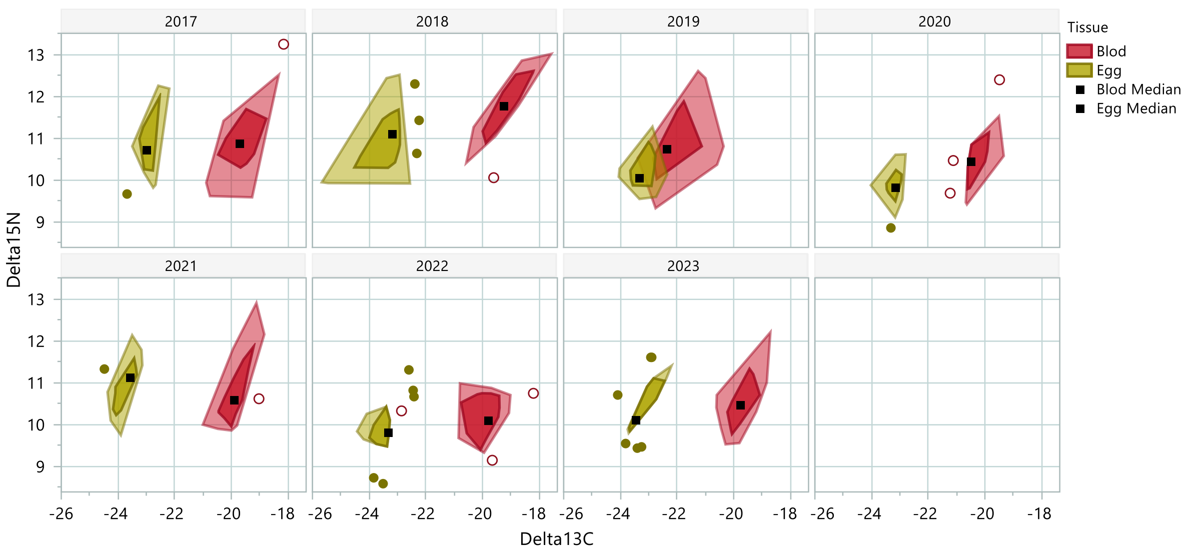


Figure 32. Bag plot: δ13C plotted against δ15N in blood and egg of eider from Svalbard (19N), each of the years 2017 to 2023.

5 Cod health parameters

Several cod parameters were measured, most of which are listed in **Table 7**. In addition to the parameters listed, gonad weight was measured at cod stations where biological effect markers were measured. Also, liver colour has been noted but are not shown.

Table 7. Overview of cod parameters for each station (minimum, median and maximum). The statistical parameters are given with two significant digits.

St. code	Station name	N	Sex[6]		Age			Length (cm)			Weight (g)			Liver weight (g)		
			F	M	Min	Med	Max	Min	Med	Max	Min	Med	Max	Min	Med	Max
20B	Longyearbyen, Svalbard	15	9	6	2	3	6	39	46	72	480	860	3,900	13	22	180
19B	Isfjorden, Svalbard	15	7	8	3	4	7	43	58	70	880	1,700	2,300	10	39	67
10B	Varangerfjord	27	11	16	3	4	7	33	41	56	350	650	1,800	3.1	11	100
45B2	Hammerfest harbour	21	6	12	2	4	6	35	43	56	360	750	1,600	3.6	26	77
43B2	Tromsø harbour	15	6	9	3	5	12	41	58	80	700	2,100	5,200	22	60	260
98B1	Lofoten	15	9	6	4	5	9	55	60	78	1,700	2,400	4,800	57	92	360
96B	Sandnessjøen	21	8	13	2	3	7	33	46	60	370	980	2,600	2.6	18	59
80B	Trondheim harbour	16	5	11	2	4	6	47	55	65	970	1,500	2,600	9.3	27	140
28B	Ålesund harbour	15	6	9	2	4	8	47	53	81	1,100	1,600	4,600	13	100	320
24B	Bergen harbour	7	3	4	2	3	5	35	49	61	450	1,300	2,300	11	31	53
53B	Inner Sørfjord	15	8	7	2	2	6	33	48	60	350	1,100	2,200	5.5	19	51
23B	Bømlo	16	10	6	2	3	5	50	65	74	1,300	3,100	5,100	24	120	400
15B	Lista	17	8	7	2	3	5	47	59	73	1,100	2,100	3,900	18	31	80
13B	Kristiansand harbour	18	5	13	1	1	2	27	34	47	190	360	1,100	1.6	7.6	17
71B	Langesundfjord	31	15	16	1	1	2	30	34	49	240	360	940	3.9	7.3	30
36B	Tjøme, Outer Oslofjord	26	13	13	2	3	4	44	49	58	1,000	1,300	2,700	8.1	22	65
30B	Inner Oslofjord	34	13	16	1	2	4	30	37	51	200	470	1,300	2	5.4	56
02B	Hvaler	7	3	4	1	2	3	38	42	46	490	650	1,000	5.9	13	23

From the data, several health based indices can be calculated, in our case we used Fulton condition index (Fulton CI), heptatosomatic index (HSI) and weight and length at age (Dale et al., 2019; Marteinsdottir & Begg, 2002)(**Table 8)**. Higher values for the condition indices indicate better condition and thereby health. It has been shown that young cod grow faster the two first years, and slower at age >9 years (Marteinsdottir & Begg, 2002). Therefore, the length at age has been divided into three age groups, 1-2, 3-8 and >9 years.

A comparison of all cod parameters between stations was done by ANOVA followed by Tukey post-hoc tests. The results of the Tukey statistics are shown in **Figure S14** and details of the statistics given in **Table S3** (both in supplementary data). All ANOVAs were <0.0001.

Ranking of the means of cod parameters are shown in **Figure 33**. A ranking of 18 means that the station was highest, but not necessarily statistically different from station with rank 17. Details for the ranking and statistical differences between stations for all investigated parameters are listed in **Table S3**. Stations with high ranking include stations Lofoten (98B1), Bømlo (23B) and Ålesund (28B), while low ranking stations were Inner Oslofjord (30B), Kristiansand harbour (13B) and Langesundfjord (71B) (see heatmap in **Figure 33**). A principal component analysis (PCA) of the same parameters for cod except length at age are shown to the right in **Figure 33**. The PCA shows which parameters correlate to each other (arrows point in the same direction), and which parameters that are not correlated (arrow points in orthogonal direction, i.e. ca. 90° to each other). A negative correlation occurs if the arrows point in the

[6] Sex and age were not determined for more than 15 fish at each station

opposite direction of each other. The PCA shows that weight at age and Fulton CI were correlated, while age and HSI were correlated, but were orthogonal (not correlated) to Fulton CI and weight at age. Weight, length, and liver weight were intercorrelated since they point in almost the same direction and correlate somewhat with all 4 other parameters. The two first axes of the PCA explained 77 % of the variation in the dataset.

Table 8. Overview of median concentrations for calculated health parameters for cod. Data is given with two significant digits.

St. code	Station name	Fulton CI	HSI	Weight at age*	Length at age*		
					Age 1-2	Age 3-8	Age >9
20B	Longyearbyen, Svalbard	0.86	2.7	320	21	15	
19B	Isfjorden, Svalbard	0.86	2.6	400		15	
10B	Varangerfjord	0.93	2.1	190		10	
45B2	Hammerfest harbour	0.96	4.1	240	18	13	
43B2	Tromsø harbour	1.1	2.6	440		12	6.7
98B1	Lofoten	1	4	540		14	8.7
96B	Sandnessjøen	1	1.7	370	22	15	
80B	Trondheim harbour	0.98	2.4	430	25	13	
28B	Ålesund harbour	1.1	3.9	500	25	12	
24B	Bergen harbour	1	2.3	420	18	16	
53B	Inner Sørfjord	1	1.8	330	21	15	
23B	Bømlo	1.1	4	940	27	18	
15B	Lista	1	1.6	720	25	19	
13B	Kristiansand harbour	1	1.8	360	33		
71B	Langesundfjord	1	2.1	390	32		
36B	Tjøme, Outer Oslofjord	1.1	1.7	540	24	17	
30B	Inner Oslofjord	0.86	1.2	260	20	13	
02B	Hvaler	0.91	1.8	370	22	14	

* Weight/length at age is the weight/length divided by the age.

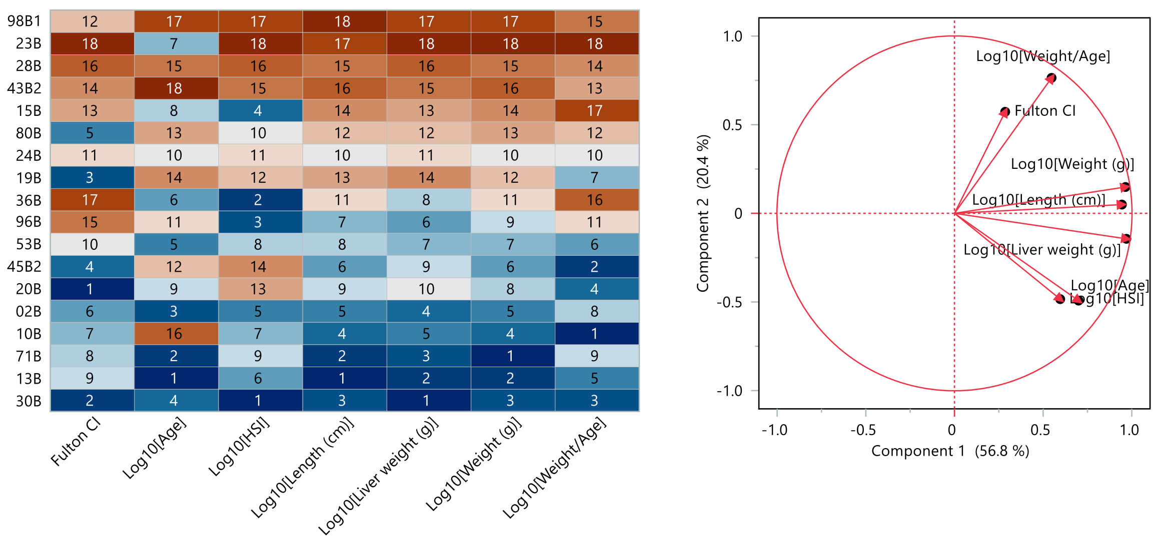


Figure 33. Ranking of means for cod parameters. Each ranking for each parameter and station are shown in the heatmap to the left where cell coloring is according to rank (high to low: dark brown to dark blue). The stations are ordered by the geometric mean of ranking for all parameters. To the right, a PCA (loading plot) of the same parameters. The principal components 1 and 2 at each axis shows how much of the variation that was explained by the PCA.

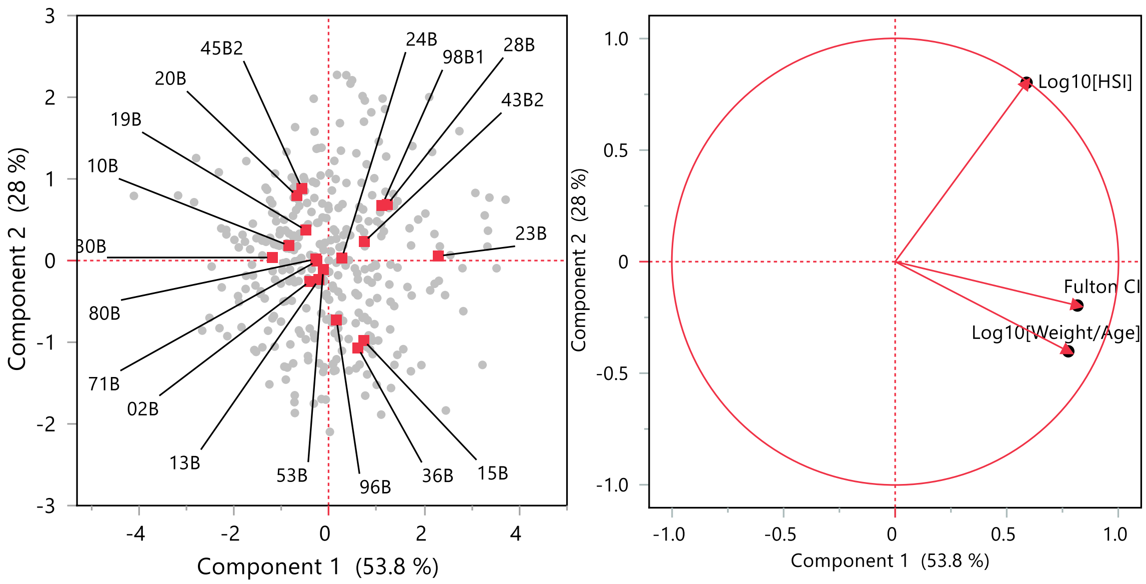
Three of the parameters are related to the health of the cod: Fulton CI, HSI and weight at age. Although length at age is also related to the health of the cod, the length at age varies with the age of the cod and was therefore not included in the PCA and in assessment of health parameters. The health-related parameters are shown in **Figure 34**. The PCA can be interpreted by the loading-plot of the PCA shown at the upper right of **Figure 34**. The score plot is shown at the upper left. The station rankings are illustrated in a heatmap while the PCA shows the relationship between the parameters. The rankings show that stations with high health-related parameters were stations Bømlo (23B), Ålesund harbour (28B), and Lofoten (98B), while lower health were found at stations Inner Oslofjord (30B) and Varangerfjord (10B). The PCA explained 82 % of the variation and shows that HSI and Fulton CI were not correlated. However, weight at age and Fulton were closely correlated. These parameters were generally higher in stations to the right in the score plot and lower at stations to the left in the score plot. Stations 23B and 30B, respectively, represent the extreme points on this scale (as can also be read from the heat map of station rankings).

To further scrutinize this, a bagplot[7] (Rousseeuw et al., 1999) of the scores for the two first principal components are shown in **Figure 35** for each station. Fish that have high scores for age and Fulton CI are located to the right in the bagplots, while high scores for HSI are in the upper right corner. Stations centering to the right had high Fulton CI and weight at age. Stations centering near the upper right corner had high HSI. Stations such as Langesundfjord (71B) and Inner Oslofjord (30B) had a large spread of datapoints. Other stations had a much smaller spread of the data, e.g. Lofoten (98B1), Bergen harbour (24B), Lista (15B), Isfjorden (19B) and Longyearbyen (20B).

In conclusion the fish from different stations had varying health-related conditions. There was a correlation between Fulton CI and weight at age, while HSI was not correlating with Fulton CI or weight at age. A ranking of fish health by stations showed that generally the highest indices were found in cod from Bømlo (23B), Ålesund harbour (28B), Lofoten (98B1) and Tromsø harbour (43B2). The lowest rank of fish health was generally found in cod from the Inner Oslofjord (30B).

The indices investigated are general and are affected by many factors in the environment such as availability of food and other potential factors/stressors. Caution should therefore be exercised in relating the observed differences in physiological data merely to contaminant burden.

[7] *A bagplot is a two-dimensional equivalent to a (one-dimensional) boxplot.*



	Fulton CI	Log10[HSI]	Log10[Weight/Age]
23B	18	18	18
28B	16	16	14
98B1	12	17	15
43B2	14	15	13
24B	11	11	10
15B	13	4	17
71B	8	9	9
80B	5	10	12
36B	17	2	16
96B	15	3	11
53B	10	8	6
13B	9	6	5
19B	3	12	7
02B	6	5	8
45B2	4	14	2
20B	1	13	4
10B	7	7	1
30B	2	1	3

Y

Figure 34. The health-related cod parameters; the score plot (upper left) and loading plot (upper right) of the PCA of the health-related parameters. In the bottom a heatmap of the station ranking ordered from highest to lowest by geometric means.

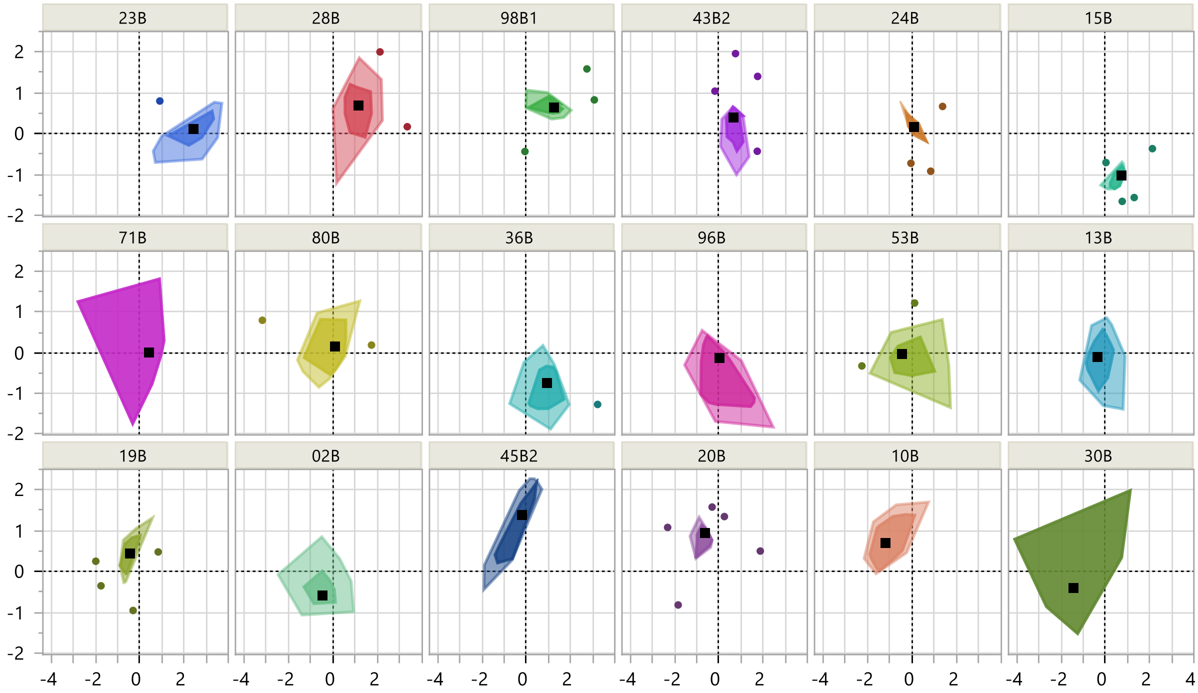


Figure 35. Bagplot of scores on principal components 1 and 2 from the PCA in **Figure 35**. This means that the means here corresponds to those in the score plot in **Figure 34**. The station order of the bagplots is the same as the heatmap in **Figure 34** (read from upper left corner to the right, then next row etc.). The medians at the centre of the data are indicated with black squares. The inner polygon (the bag) contains 50 % of the datapoints, while the outermost polygon (the fence) contains all datapoints that are not considered to be outliers. Statistical outliers are shown with coloured points.

6 Materials and methods appendix

6.1 Sampling and matrices

6.1.1. 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**).

Samples were collected during 2023 (early 2024 for some cod) and analysed according to OSPAR guidelines (OSPAR, 2021)[8] 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 2023 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, Beylich, 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)[9] and cod for The Environmental Specimen Bank[10] (ESB Norway, Miljøprøvebanken).

6.1.2. 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 36**). The stations were chosen to represent highly polluted, or reference stations distributed along the Norwegian coast. It has been shown that the collected 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.

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

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

[10] *The Environmental Specimen Bank « Miljøprøvebanken*

Figure 36. Blue mussel (photo: Janne Gitmark, NIVA, right) and blue mussel sampling at st. I301 Akershuskaia in the Oslo harbor area (photo: Marijana Stenrud Brkljacic, NIVA, center and left).

The blue mussel samples were collected from 15th July to 17th November 2023. 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.

6.1.3. 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 37**). 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 37. Dogwhelk (photos: Lise Tveiten, left, and Jarle Håvardstun, NIVA, center) 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 21st August to 13th November 2023.

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).

6.1.4. Atlantic cod

Atlantic cod was caught from 18 stations (**Table 1**, **Figure 38**). 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 15th December 2023, except for cod collected until January 2024 in Bergen (24B) and March 2024 in Sandnessjøen (96B). 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 38**). 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 38. 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 center 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.

6.1.5. Common eider

Contaminants in the common eider were investigated at one station in the Kongsfjord at Svalbard (19N), which the present study considered as a reference station (**Table 1**, **Figure 39**). Blood samples were collected from 15 individuals (two subsamples from each) and eggs from 15 other individuals 4th June 2023. All samples are from adult nesting females. Data for 2022 and 2023 are presented in this report due to financial cuts for 2022 data. 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.

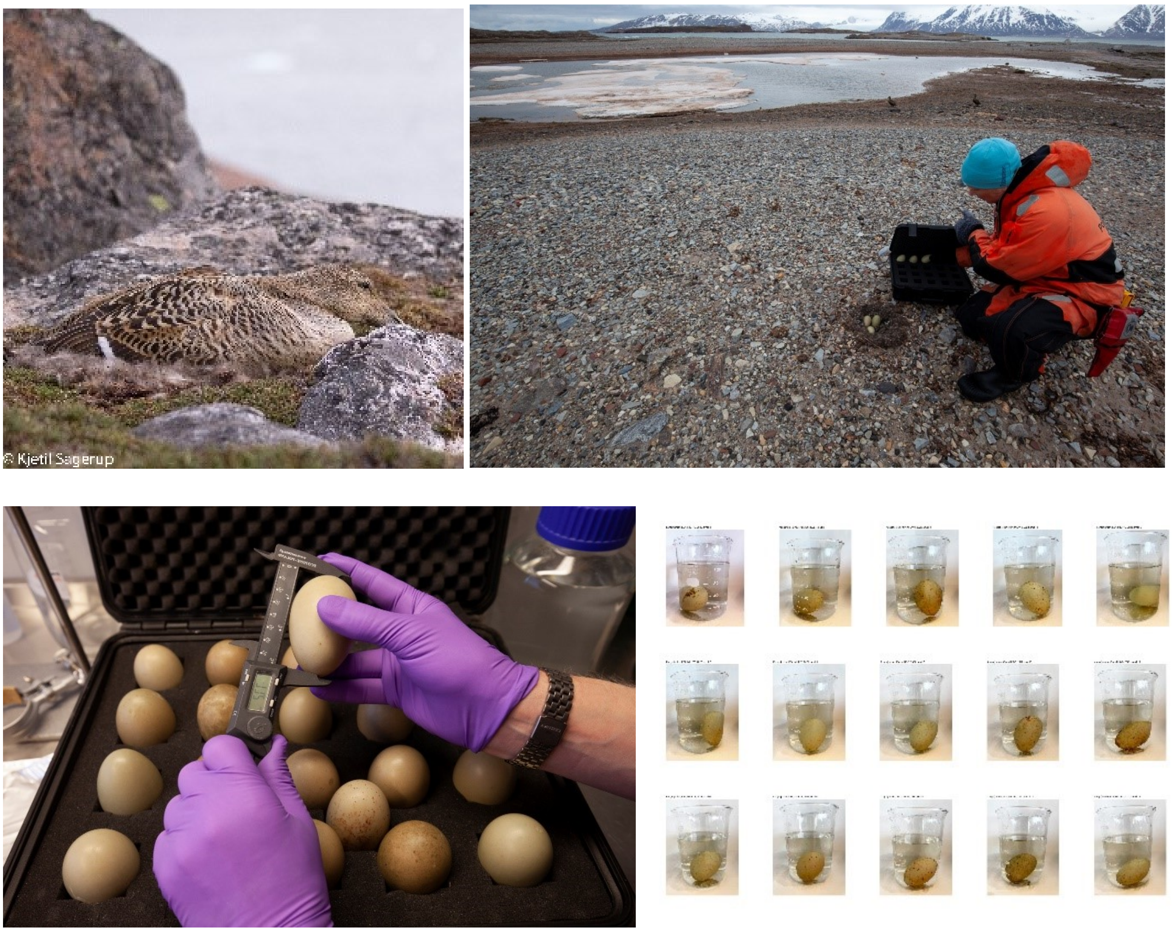


Figure 39. Common eider at Svalbard (photos: Kjetil Sagerup, Akvaplan-niva, top left and bottom right and Oddgeir Sagerup top right and bottom left).

6.1.6. Flat fish

Flat fish (*Platichthys flesus*) was sampled at Sande (33F), but the samples were not analysed due to financial cuts since 2021.

6.2 Storage of samples

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

6.3 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 tissue 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 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' values are automatically highlighted.

The laboratories used for the chemical testing are accredited according to ISO 17025[11].

Summary of quality control results

Standard Reference Materials (SRM) as well as in-house reference materials were analysed regularly (**Table 9**), and PAHs in blue mussel, as well as BDEs and HBCDDs in liver, was an internal reference (fish oil). Fish reference material was used as SRM for the quality assurance of PCBs in blue mussel and fish liver, and for tin organic compounds the reference material ZRM 81 was used as SRM mussel tissue. For the determination of the pesticides trans-nonachlor and DDTs in mussel and liver, internal reference materials provided by EF GfA Lab services were used, these consisted of fish meal and feeding stuff. For the quality assurance of chlorinated paraffines spiked fish was used as an in-house reference material, and spiked fish liver was used for quality control of per- and polyfluorinated chemicals (PFAS).

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

Table 9. Summary of the quality control of results for the 2023 biota samples analysed in 2023-2024. The SRM, in-house reference materials and quality assurance standards were analysed in series with the MILKYS samples and measured several times (N) over a number of 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), PFAS (% recovery) and trans-nonachlor (ng/g). Tissue types were: mussel soft body, snail (SB), fish liver (LI), and fish fillet (MU).

Code	Contaminant	Tissue type	SRM type	SRM value condence interval	N	W	Mean value	Standard deviation
Ag	Silver	-	-	-	-	-		-
As	Arsenic	SB/LI	Apple juice	109 ± 22	45	8	108	9.80
Cd	Cadmium	SB/LI	Apple juice	95 ± 29	45	8	94.3	5.40
Cr	Chromium	SB/LI	Apple juice	103 ± 30	45	8	107	7.97
Co	Cobalt	-	-	-	-	-		-
Cu	Copper	SB/LI	Apple juice	4796 ± 1439	45	8	4716	259
Hg	Mercury	SB/MU	Apple juice	18.4 ± 4.8	45	8	17.0	1.10
Ni	Nickel	SB/LI	Apple juice	112 ± 34	45	8	108	11.1
Pb	Lead	SB/LI	Apple juice	95 ± 20	45	12	97.8	6.20
Zn	Zinc	SB/LI	Apple juice	5163 ± 1549	45	8	5160	299
Sn	Tin	-	-	-	-	-		-
BDE28	2,2,4' Tribromodiphenylether	SB	Internal RM (fish oil)	102 ± 178	8	21	110.0	5.4
BDE47	2,2,4,4',- Tetrabromodiphenylether	SB	Internal RM (fish oil)	1030 ± 84	8	21	991.3	40.5
BDE100	2,2',4,4',6- Pentabromodiphenylether	SB	Internal RM (fish oil)	296 ± 52	8	21	279.5	14.1
BDE99	2,2',4,4',5- Pentabromodiphenylether	SB	Internal RM (fish oil)	138 ± 16	8	21	133	4.8
BDE154	2,2',4,4',5,6'- Hexabromodiphenylether	SB	Internal RM (fish oil)	353 ± 54	8	21	316.9	13.1
BDE153	2,2',4,4'5,5'- Hexabromodiphenylether	SB	Internal RM (fish oil)	174 ± 23	8	21	169.3	7.7
BDE209	Decabromodiphenylether	SB	Internal RM (fish oil)-	415± 254-	8	21	624.7	182.7
BDE49	2,2',4,5'- tetrabromodiphenyleter	SB	Internal RM (fish oil)	323 ± 60	8	21	319.3	22.8
BDE66	2,3',4,4'- Tetrabromodiphenyleter	-	Internal RM (fish oil	79.1 ± 16.2 -	8	21	72.2	3.5
BDE119	2,3',4,4',6- Pentabromodiphenyl ether	SB	Internal RM (fish oil)	91 ± 18	8	21	88.4	7.6
CB77	PCB congener CB77	-	-	-	-	-	-	-
CB52	PCB congener CB52	SB/LI	Internal RM (fish)	426 ± 128	18	14	446.3	33.7
CB28	PCB congener CB28	SB/LI	Internal RM (fish)	255 ± 76	16	14	279.4	32.2
CB189	PCB congener CB189	-	-	-	-	-	-	-
CB180	PCB congener CB180	SB/LI	Internal RM (fish)	4555 ± 1367	18	14	4713.6	394.7
CB169	PCB congener CB169	-	-	-	-	-	-	-
CB167	PCB congener CB167	-	-	-	-	-	-	-
CB157	PCB congener CB157	-	-	-	-	-	-	-
CB156	PCB congener CB156	-	-	-	-	-	-	-
CB153	PCB congener CB153	SB/LI	Internal RM (fish)	4839 ± 1452	18	14	5642.2	760.8
CB138	PCB congener CB138	SB/LI	Internal RM (fish)	3578 ± 1073	18	14	3669	311.4
CB126	PCB congener CB126	-	-	-	-	-	-	-
CB123	PCB congener CB123	-	-	-	-	-	-	-
CB118	PCB congener CB118	SB/LI	Internal RM (fish)	832 ± 250	18	14	873.6	47.4
CB114	PCB congener CB114	-	-	-	-	-	-	-
CB105	PCB congener CB105	-	-	-	-	-	-	-

Code	Contaminant	Tissue type	SRM type	SRM value confidence interval	N	W	Mean value	Standard deviation
CB101	PCB congener CB101	SB/LI	Internal RM (fish)	1501 ± 450	18	14	1645.9	107.5
DDEOP	o,p'-DDE	SB/LI	Internal RM (feed)	0.11 ± 0.03	2	1	0.07	0.005
TDEOP	o,p'-DDD	SB/LI	Internal RM (feed)	0.267 ± 0.08	2	1	0.21	0.001
DDTOP	o,p'-DDT	SB/LI	Internal RM (feed)	0.259 ± 0.08	2	1	0.19	0.03
DDEPP	p,p'-DDE	SB/LI	Internal RM (feed)	5.01 ± 1.50	2	1	3.75	0.4
TDEPP	p,p'-DDD	SB/LI	Internal RM (feed)	1.73 ± 0.50	2	1	1.10	0.09
DDTPP	p,p'-DDT	SB/LI	Internal RM (feed)	0.613 ± 0.20	2	1	0.49	0.02
SCCP	Short-chain chlorinated Paraffins (C10-C13)	SB/LI	Internal RM (spiked fish)	10000	22	24	10889	793
MCCP	Medium-chain chlorinated Paraffins (C14-C17)	SB/LI	Internal RM (spiked fish)	10000	22	24	10504	1252
α-HBCDD	α-Hexabromocyclododecane	SB	Internal RM (fish oil)	1.3 ± 0.3	n.a.	21	1.26	0.055
β-HBCDD	β-Hexabromocyclododecane	SB	Internal RM (fish oil)	0.5 ±0.1	n.a.	21	0.51	0.023
γ-HBCDD	γ-Hexabromocyclododecane	SB	Internal RM (fish oil)	0.5 ± 0.1	n.a.	21	0.49	0.016
BGHIP	Benzo[ghi]perylene	SB	Internal RM (fish oil)	46 ± 23	3	17	39.8	4.8
ICDP	Indeno[1,2,3-cd]pyrene	SB	Internal RM (fish oil)	53 ± 64	3	17	33.2	0.9
BBJF	Benzo[b+j]fluoranthene	SB	Internal RM (fish oil)	93 ± 65	3	17	79.0	12.7
DBA3A	Dibenzo[ac,ah]anthracene	-	-	-	-	-	-	-
BKF	Benzo[k]fluoranthene	SB	Internal RM (fish oil)	54 ± 50	3	17	48.1	11.5
ACNLE	Acenaphthylene	SB	Internal RM (fish oil)	38 ± 11	3	17	29.0	4.7
ANT	Anthracene	SB	Internal RM (fish oil)	49 ± 26	3	17	34.1	3.3
BAA	Benzo[a]anthracene	SB	Internal RM (fish oil)	49 ± 15	3	17	49.7	13
BAP	Benzo[a]pyrene	SB	Internal RM (fish oil)	42 ± 23	3	17	40.2	14
CHR	Chrysene	SB	Internal RM (fish oil)	49 ± 23	3	17	47.9	6.3
FLU	Fluoranthene	SB	Internal RM (fish oil)	42 ± 13	3	17	42.2	3.1
FLE	Fluorene	SB	Internal RM (fish oil)	58 ± 38	3	17	52.9	13.7
NAP	Naphthalene	SB	Internal RM (fish oil)	61 ±32	3	17	34.4	6.6
PA	Phenanthrene	SB	Internal RM (fish oil)	47 ± 21	3	17	44.1	6.2
PYR	Pyrene	SB	Internal RM (fish oil)	42 ± 12	2	17	40.5	5.2
ACNE	Acenaphthene	SB	Internal RM (fish oil)	41 ± 14	3	17	30.6	2.1
TBBPA	Tetrabromobisphenol-A	-	-	-	-	-	-	-
BPA	Bisphenol-A	-	-	-	-	-	-	-
BPA	Bisphenol-A	-	-	-	-	-	-	-
BPA	Bisphenol-A	-	-	-	-	-	-	-
APO	4-tert-oktylfenol	-	-	-	-	-	-	-
APO	4-n-oktylfenol	-	-	-	-	-	-	-
APO	4-n-nonylfenol	-	-	-	-	-	-	-
MBT	Monobutyltin (MBT)	SB	ZRM 81 (mussel)	1.3 ± 0.2	-	1	2.0	-
DBT	Dibutyltin (DBT)	SB	ZRM 81 (mussel)	1.6 ± 0.3	1	1	1.7	-
TBT	Tributyltin (TBT)	SB	ZRM 81 (mussel)	2.1 ± 0.12	1	1	1.4	-
TPhT	Triphenyltin (TPhT)	SB	ZRM 81 (mussel)	-	-	-	-	-

Code	Contaminant	Tissue type	SRM type	SRM value confidence interval	N	W	Mean value	Standard deviation
PFBS	Perfluorobutane sulphonate	LI	In-house spiked liver	100 %[1)]	7	20	90.6	8.2 %
PFHxA	Perfluorohexane acid	LI	In-house spiked liver	100 %[1)]	7	20	90.7	8.6 %
PFHpA	Perfluoroheptane acid	LI	In-house spiked liver	100 %[1)]	7	20	92.5	6.4 %
PFOA	Perfluorooctane acid	LI	In-house spiked liver	100 %[1)]	7	20	98	7 %
PFNA	Perfluorononane acid	LI	In-house spiked liver	100 %[1)]	7	20	97.6	8.1 %
PFOS	Perfluorooctane sulphonate	LI	In-house spiked liver	100 %[1)]	7	20	100	7.9 %
PFOSA	Perfluorooctane sulphone amide	LI	In-house spiked liver	100 %[1)]	7	20	97.5	4.9 %
PFHxS	Perfluorohexane sulphonate	LI	In-house spiked liver	100 %[1)]	7	20	86.5	3.9 %
PFDA	Perfluorodecanoic acid	LI	In-house spiked liver	100 %[1)]	7	20	92.8	10.3 %
PFUDA	Perfluoroundecanoic acid	LI	In-house spiked liver	100 %[1)]	7	20	100.6	7.9 %
PFTrDA	Perfluorotridecanoic acid	LI	In-house spiked liver	100 %[1)]	7	20	103.4	8.1 %
PFDS	Perfluorodecanesulphonate	LI	In-house spiked liver	100 %[1)]	7	20	82.6	2.3 %
	Dieldrin	SB	Internal RM (feed-	2.05 ± 0.6	2	1	1.4	0.15
	Trans-Nonachlor	SB	Internal RM (feed)	1.39 ± 0.40	2	1	1.09	0.19

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, 2023) and Food Analysis Proficiency Testing Services (FOOD 2022/2023) 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, 2021).

A priority list of chemical analysis is listed in **Table 10**.

Table 10. 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

6.4 QA/QC

Additional to the general quality assurance (QA) done by the individual laboratory, 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, see **chapter 6.9**) to make this control easier and more efficient. Here trends from the last years will appear and deviating results are marked (example in **Figure 40**). 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 are registered to NIVAs internal control system, and a complaint are reported to the relevant laboratory. For the 2023 data, one mussel samples showed high results for arsenic (As) and a deviation was sent to the subcontractor. There were mistakes found in the evaluation and new results were reported. All activity is recorded in NIVAs deviation/control system. One deviation is also made due to suspect high levels of chromium and nickel in a blue mussel sample. No reanalysis was performed as the suspect reason is that it is due to contamination of the sample during preparation. An information e-mail was sent to everyone that work with preparation of the samples to be extra careful when the samples are in contact with stainless steel.

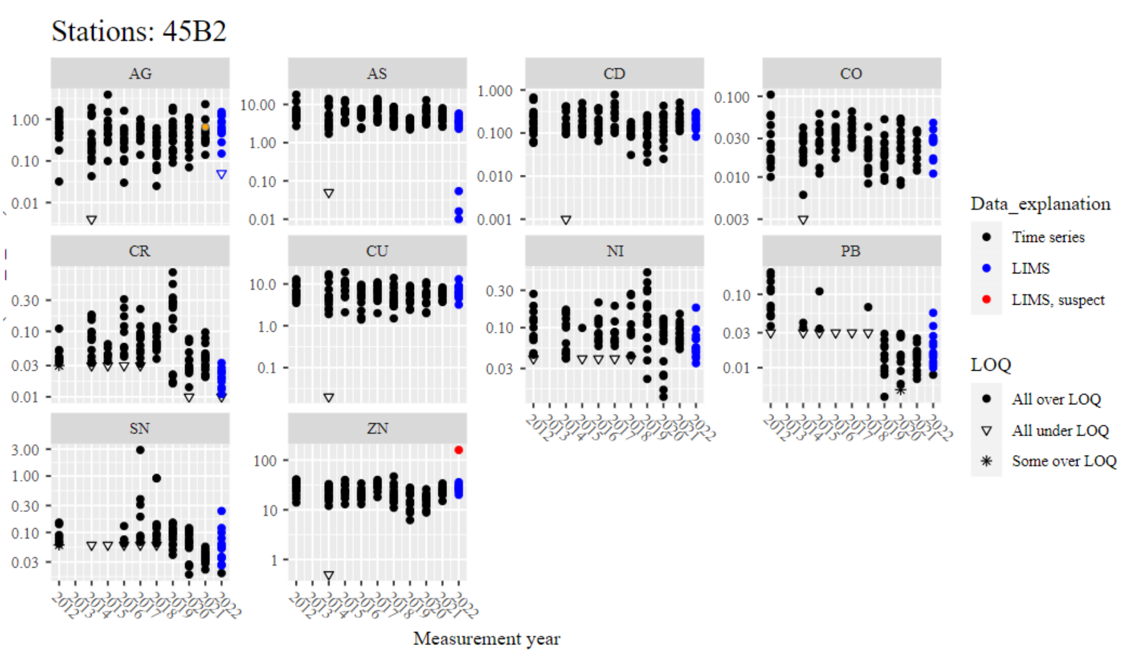


Figure 40. Screenshot of QA app used for manual assessment of chemical concentrations every year. The screenshot shows the results for a single station and for one substance group. The concentrations to perform QA on (last year's results, red and blue dots) are shown together with previous year's results (black dots) in order to make it easier to identify 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 or not the flagged results should be treated as a deviation and a complaint should be sent to the relevant laboratory.

6.5 LOQ

The proportion over LOQ (detection frequency, in %) of the various compounds for each tissue is given in **Figure 41** gives the observed LOQ (median values) in blue mussel in the various compounds since 2002.

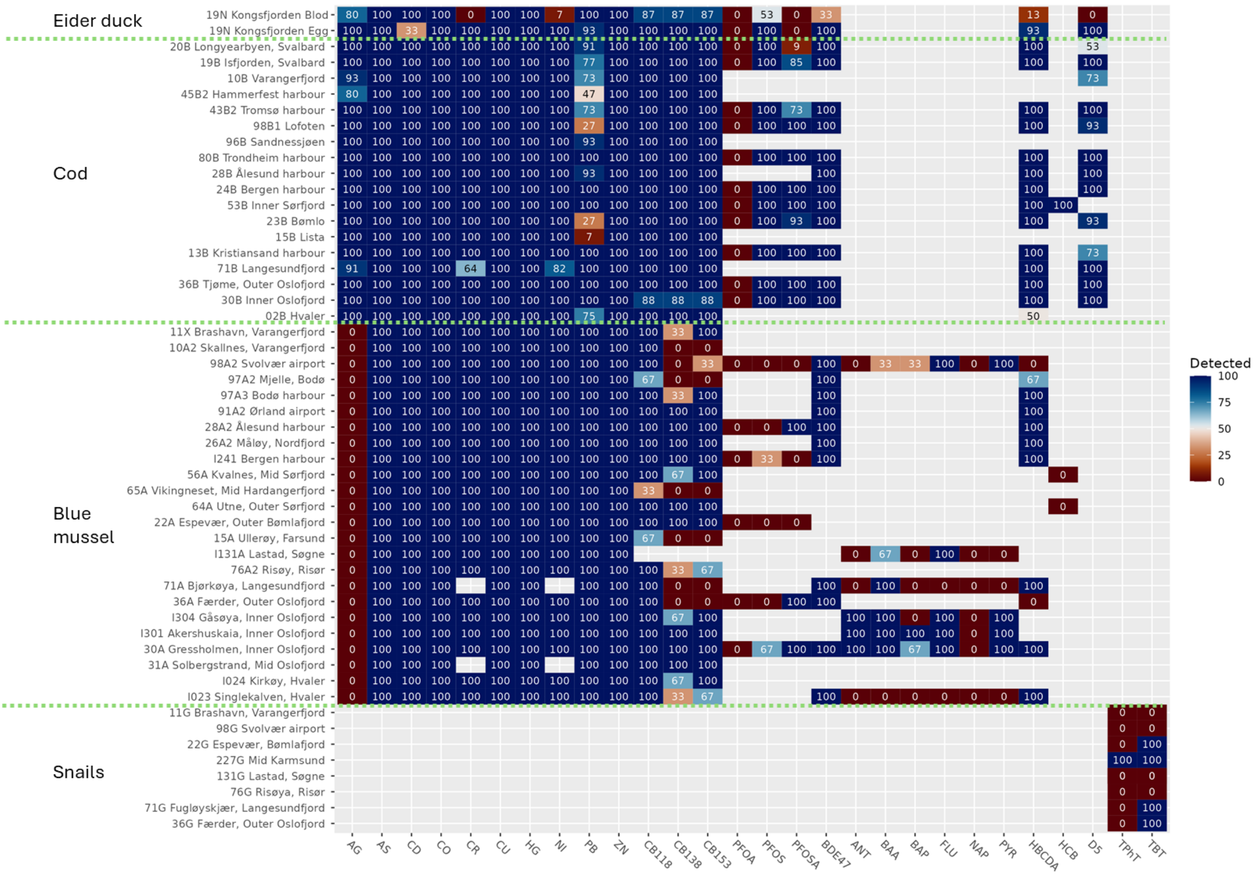


Figure 41. Proportion over LOQ (detection frequency, in %) of the compounds for each tissue in 2023. Within each species, the stations are ordered along the coastline starting north moving south.

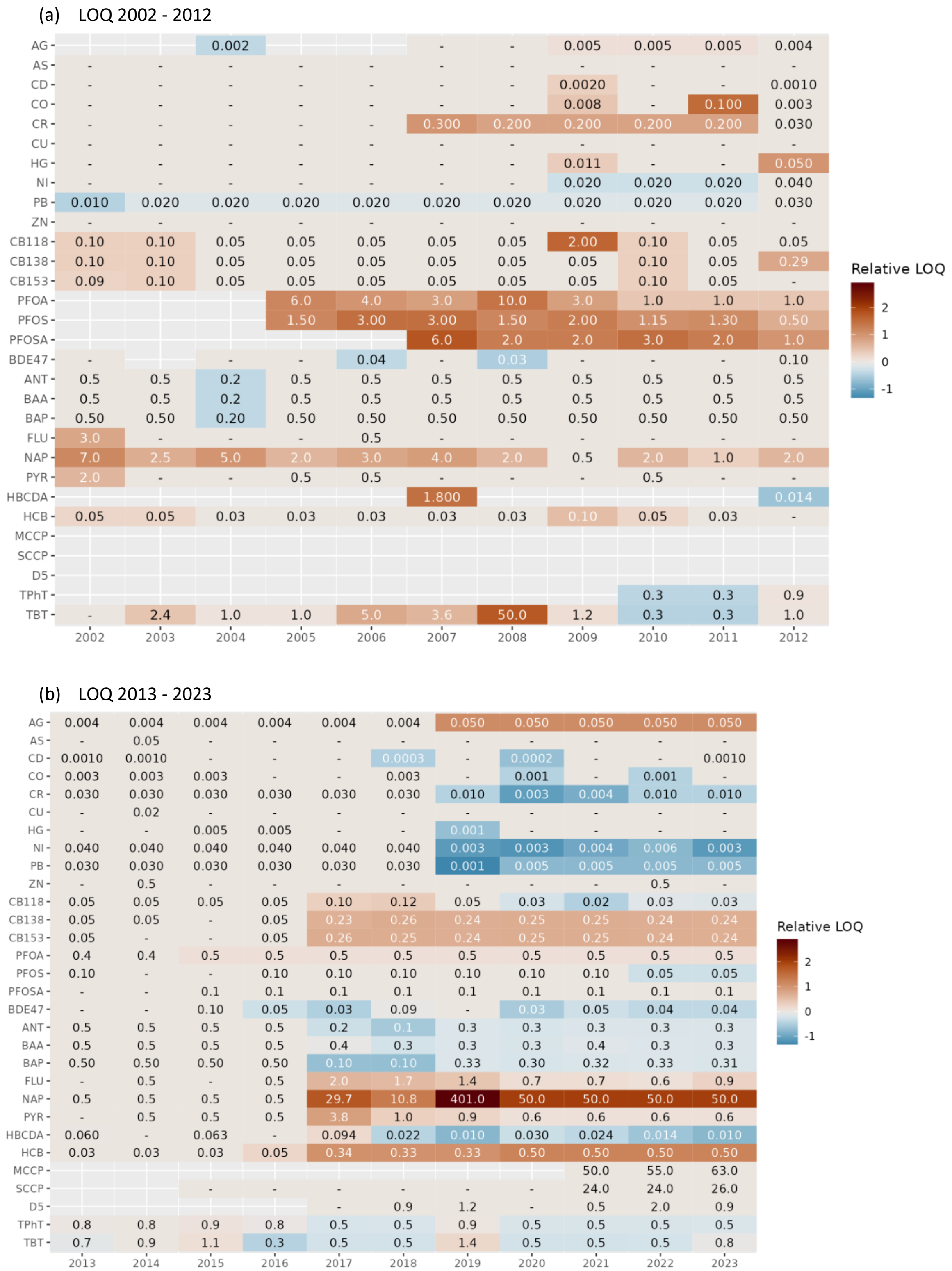


Figure 42. Changes in LOQ values over time. The numbers in the table show observed LOQ (median values, mg/kg ww for metals incl. Hg, and ug/kg ww for others). In blue mussel for various compounds in the periods 2002-2012 (a) and 2013-2023 (b). The colors indicate the "relative LOQ" compared to a reference period defined as 2013-2015 (median LOQ versus the median LOQ during the years 2013-2015). Blue colors show lower (better) LOQ and red colors 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).

6.6 Classification of environmental 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 programme 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 of the European Parliament and of the Council of 12 August 2013 Amending Directives 2000/60/EC and 2008/105/EC as Regards Priority Substances in the Field of Water Policy, 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 apply 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 EQS 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 not otherwise accounted for by the EU directives (Direktoratsgruppen vanndirektivet, 2018).

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 of the European Parliament and of the Council of 12 August 2013 Amending Directives 2000/60/EC and 2008/105/EC as Regards Priority Substances in the Field of Water Policy, 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.

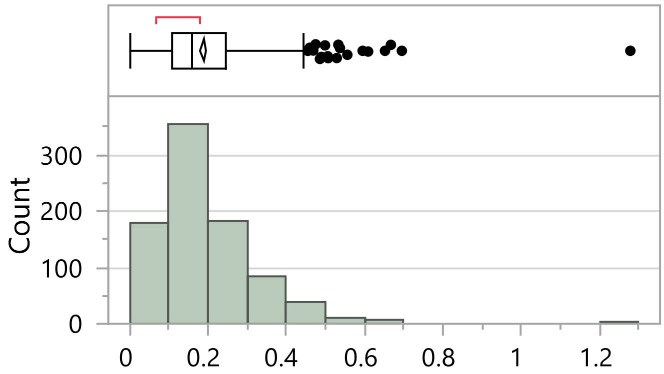
The EQS and PROREF as well as time trend analyses use concentrations on a wet weight (ww) basis. The choice of basis (i.e. concentrations on a wet weight, dry weight, or fat weight basis) follows the OSPAR approach aimed at meeting several considerations: scientific validity, uniformity for groups of 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 EQS 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 states 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 43** 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 require 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 43. 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.

6.7 Sum RQ and sum PROREFratio>1

For each station and species, the measured environmental concentration (MEC) was divided by the EQS (or predicted no-effect concentration PNEC). In ecotoxicology, this ratio is denoted RQ (risk quotient (Eq 1).

$$RQ_i = \frac{MEC_i}{EQS_i}$$

Furthermore, a sum of RQ for each station and species is estimated as a sum of each RQ at the given station for the specific species (Eq. 2) (Backhaus & Faust, 2012).

$$\text{sum RQ} = \sum_{i=1}^{n} RQ_i$$

The sum RQ can be used to assess which stations are “worst”. However, the analytical repertoire varied between stations, therefore it is difficult to compare all stations with each other. However, we believe that this is a start for evaluating mixture toxicity. However, it must be kept in mind that the EQSs are based on different protection measures, and as such do not necessarily describe toxicity to the same organism. Sum RQ is often a tier 1 of assessing mixture toxicity, followed by more refined assessments.

Most of the contaminants with an EQS in this study accumulate in lipids of organisms (except mercury, PFOS, and PFOA). For cod, the fatty rich liver is analysed, and therefore the results of assessment vs. EQS are very conservative. For these substances, the implementation strategy for WFD (European Commission, 2014) recommend that measured concentrations in fish should be normalised to fish with 5 % lipid content. We have chosen to do this normalization only for the sum RQ-approach. Also for blue mussels the sum RQ was normalised to a 1 % lipid content to make the sum RQs comparable between stations with different lipid% in blue mussel.

For mercury, PFOS, and PFOA that do not accumulate in lipids, the recommended practice is to normalize against another parameter such as dry weight. The default dry weight content for fish is approximately 26 % while for blue mussels a suggested default dry weight content is 8.3 %. In MILKYS, the lipid content of mussel and livers of cod and the dry weight of mussel are measured. However, the dry weight of cod has not been done since 2020. But based on historic measurements (1981-2020) of dry weight of cod livers, a good correlation between lipid% and dry weight of cod liver was found. The correlation is presented in **Figure 44**. For cod fillet, the median dry weight% was 20, see **Figure 44**. The median dry weight of 20 % for cod fillet was therefore used for normalization of data to 26 % dry weight. Mussel samples were also normalised to a dry weight of 8.3 %.

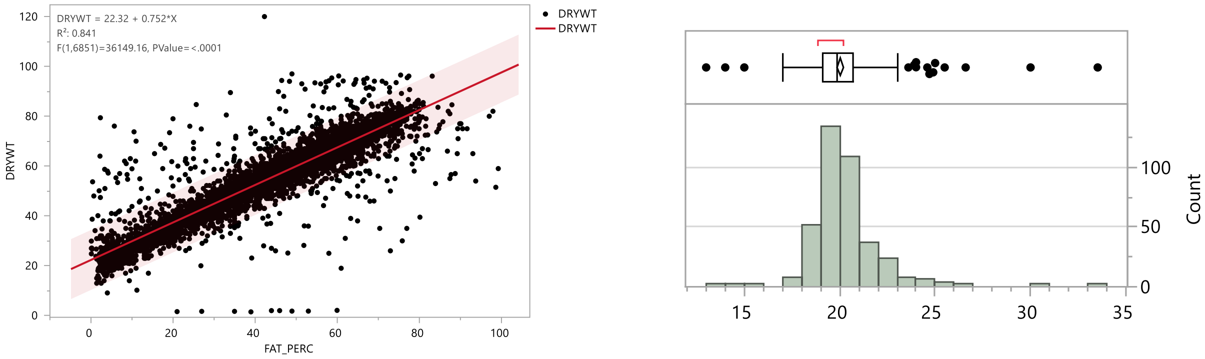


Figure 44. To the left: correlation between lipid% and dry weight% of cod liver in the period 1981-2020. The linear regression line is shown in red, while the uncertainty of the prediction is shown in transparent red colour. The prediction formula, the R^2 and F-test is shown in the upper left corner. The number of data points for lipid% and dry weight % was 6,853. **To the right**: histogram of dry weight% of cod fillet in the period 1981-2020. The median and mean dry weight% was 20 % with upper and lower 95 % mean from 19.89 to 20.23 %. The number of fillet samples was 378.

Based on the sum RQ-approach, we also calculated sum PROREFratio. PROREF is an estimation of concentrations above background levels when PROREF exceeds 1. Sum PROREFratio was calculated the same way as RQ and sum RQ *with one important difference*. Only PROREFratio >1 was included in the sum PROREFratio. Therefore, the sum PROREFratio for a station with only background concentrations will be 0.

6.8 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 criterias 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 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". The method has four main principles: 1) the survey must include stations far from point sources of contaminants (i.e. potential background stations), 2) stations are classified into background or non-background stations for each contaminant, species, tissue and basis, 3) the classification of stations is done by finding a set of stations with significantly lower values than other stations, using purely objective statistical criteria, and 4) the PROREF value is set so that most observed concentrations on 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 which stations that are reference stations, and secondly, to 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 (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).

6.9 Statistical time trend analysis

We have used the HARSAT tool version 1.0.2 (Arctic Monitoring and Assessment Programme et al. 2024) 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 [12]. 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[13]:

- 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 only 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 below LOQ (given a proposed model and coefficients).

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. 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.

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[12] https://dome.ices.dk/ohat/trDocuments/2022/help_methods_biota_contaminants.html
[13] https://dome.ices.dk/ohat/trDocuments/2022/help_methods_less_thans.html

Analyses were performed using R version 4.3.2.

When there is a significant non-linear time trend, we classified the trend results for a given period (i.e., either the whole series or the last 10 years) by comparing the height of the time series curve at only the start and end of the period (taking into account the uncertainty of these two times). If there is a non-linear trend, these two points may not differ even if the time trend in itself is significantly different (**Figure 45**). 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 (OSPAR 2022c).

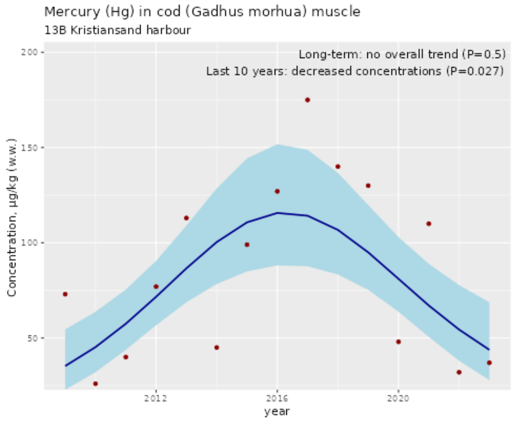

Figure 45. Example of time series (station 13B, Kristiansand harbour) classified for whole trend as "no change". The time series has a non-linear trend for the whole period, but there is no significant difference between the start point and last point of the curve. The recent trend was, however, significant downwards.

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

6.10 Sum parameters

In MILKYS, we have changed the practice for reporting sum parameters including the reporting of data for the survey in 2021 (Schøyen, Grung, Lund, Hjermann, Ruus, Øxnevad, Beylich, et al., 2024). 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[14] (LB) and upper bound[15] (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 of 31 July 2009 Laying down, Pursuant to Directive 2000/60/EC of the European Parliament and of the Council, Technical Specifications for Chemical Analysis and Monitoring of Water Status., 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

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

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

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).

6.11 Cod health parameters

Several health-based indices were calculated based on the parameters measured: Fulton condition index (CI, Eq. 1), hepatosomatic index (HSI, Eq 2), length at age (weight/age) and weight at age (weight/age).

$$\text{Fulton CI} = \frac{\text{Weight (g)}}{\text{Length (cm)}^3} \times 100 \qquad \text{Eq. 1}$$

$$\text{HSI} = \frac{\text{Liver weight (g)}}{\text{Weight (g)}} \times 100 \qquad \text{Eq. 2}$$

Statistical treatments were as follows: all data except Fulton CI were log10-transformed. Statistical differences between stations means were investigated by ANOVA followed by Tukey post-hoc analysis. The significance was set at $p<0.05$. Not all results of the ANOVA abided the normality criterion for the residuals (log10 Weight at age, Fulton CI and age). However, visual inspection of the QQ-plots showed only small deviations at the lower end for all, and for Fulton CI also a few points on the upper end. It was therefore deemed that the ANOVA was valid.

Results of the means (log10-transformed and for Fulton CI non-transformed) were used for ranking the data. The ranking was done on the means and did not take into consideration the Tukey statistic (i.e. a ranking of 1 was given to the lowest mean, irrespective if the station was significantly different to the next-lowest mean or not). This means that the highest mean was assigned a rank of 18, while the lowest rank was assigned a value of 1. Principal component analysis (PCA) was used to investigate relationships between the parameters. The same data as previously mentioned was used (i.e Fulton CI was not log-10-transformed, while other data was log10-transformed). JMP v. 18.0.1 was used for statistical treatment.

6.12 Data treatment and figures

JMP[16] statistical software (version 18.0.1) was used for data treatment after initial treatment in R. Mosaic plots, heatmaps, stacked bar plots, bagplots and PCA used in this report were produced using JMP.

[16] https://www.jmp.com/

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Supplementary data

Assessments of exceedances of PROREF for contaminants not selected for presentation in 2023 are given here. The contaminants are listed in **Table S1**.

Table S1. List of contaminants not selected in 2023 for which a PROREF exist. 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 (AN)T		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	β-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**.

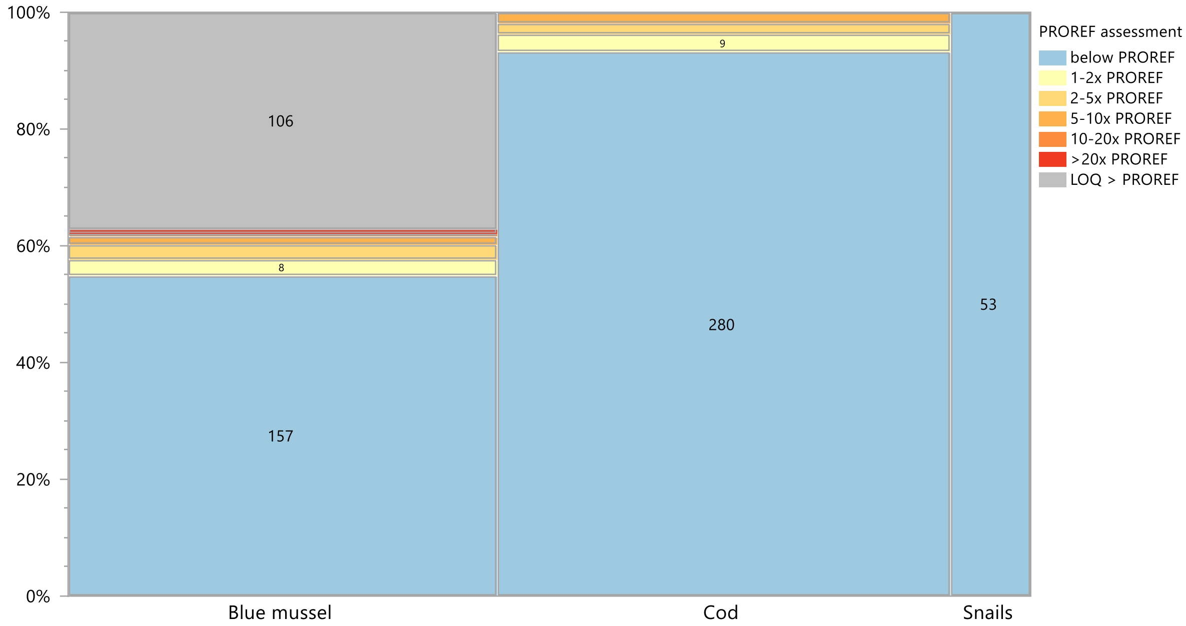

Figure S1. Exceedances of PROREF for contaminants not selected in 2023 in a mosaic plot. The cells are labelled by the number of stations and parameters. The exceedances are considered by the median for each station and species. The colours represent below or above exceedance of PROFEF (darker yellow to red), or that the PROREF was below LOQ, and therefore could not be classified (grey).

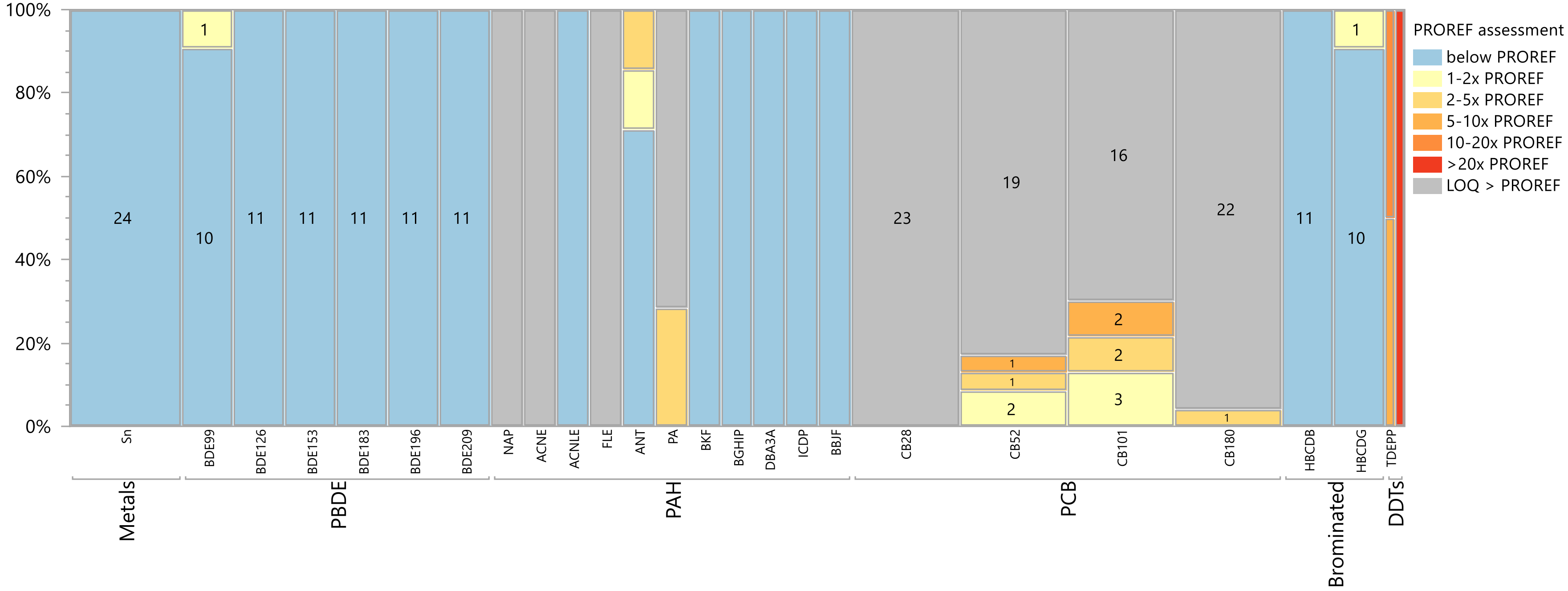

Figure S2. Exceedances of PROREF for contaminants not selected in 2023 in blue mussel by contaminant and group of contaminants. The cells are labelled by the number of stations sampled. The exceedances are considered by the median for each station. The colours represent below or above exceedance of PROFEF (darker yellow to red), or that the PROREF was below LOQ, and therefore could not be classified (grey).

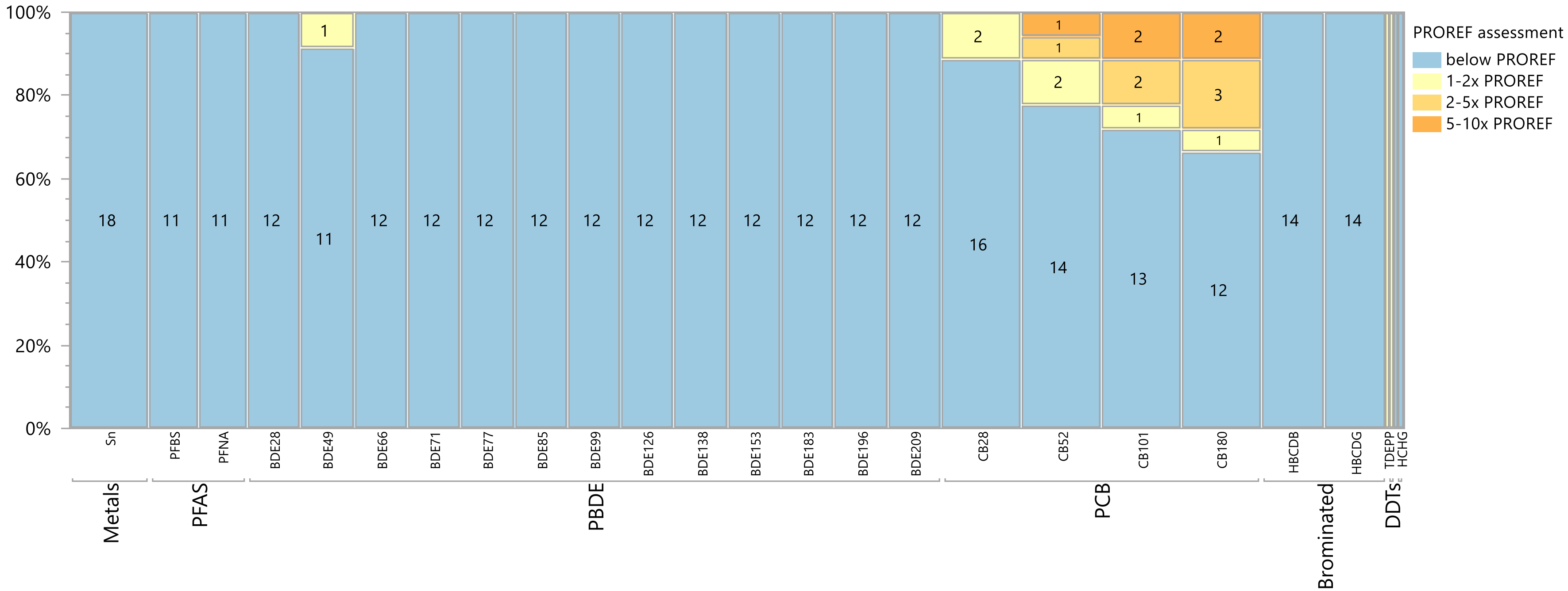

Figure S3. Exceedances of PROREF for contaminants not selected in 2023 in cod by parameter and group of contaminants. The cells are labelled by the number of stations sampled. The exceedances are considered by the median for each station. The colours represent below or above exceedance of PROFEF (darker yellow to red), or that the PROREF was below LOQ, and therefore could not be classified (grey).

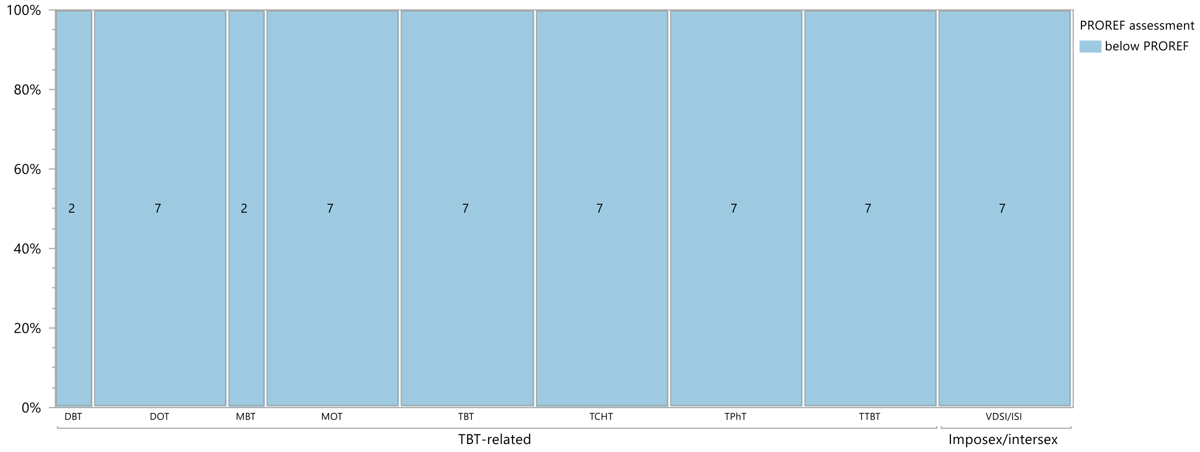

Figure S4. Exceedances of PROREF for contaminants not selected in 2023 in snails by parameter and group of parameters. The cells are labelled by the number of stations sampled. The exceedances are considered by the median for each station. The colours represent below or above exceedance of PROFEF (darker yellow to red), or that the PROREF was below LOQ, and therefore could not be classified (grey).

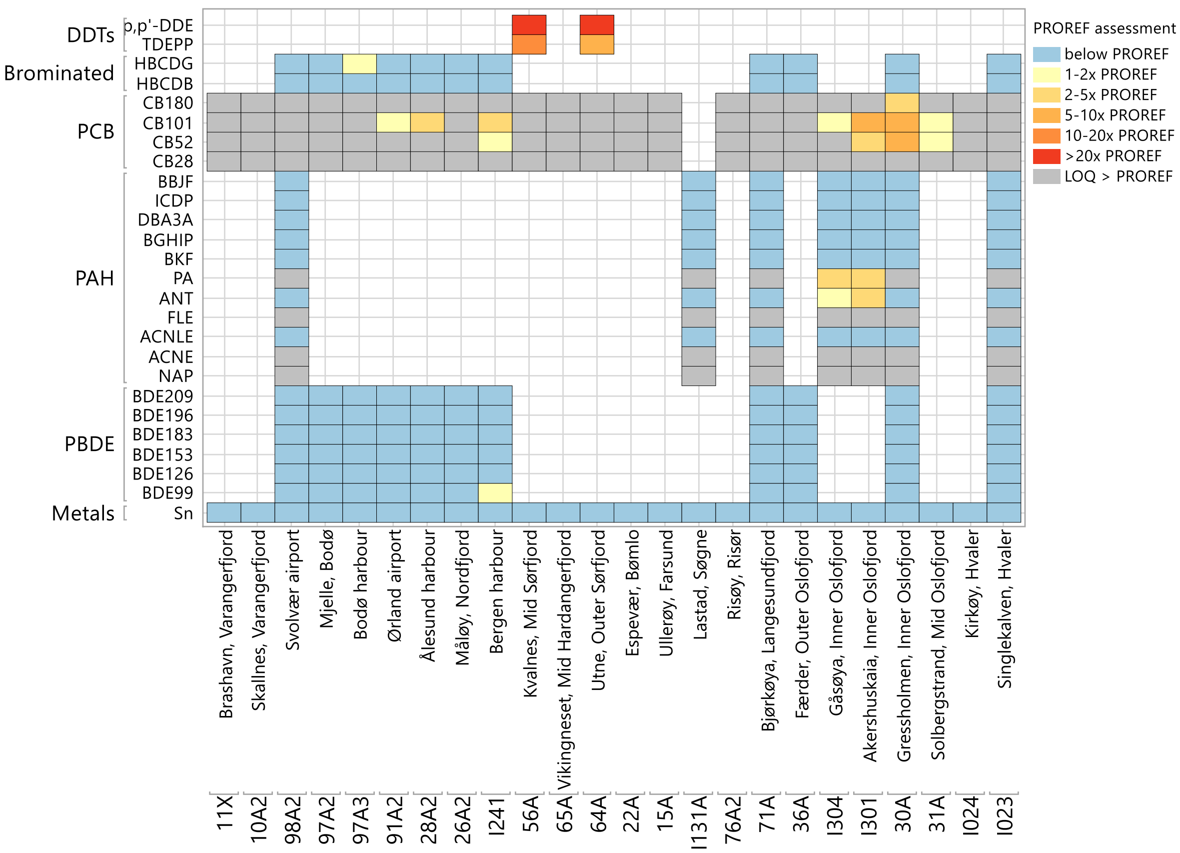

Figure S5. Heatmap of exceedances of PROREF in mussel for contaminants not selected in 2023. The colours represent below or above exceedance of PROREF. Empty "cells" mean that the contaminant was not analysed for at the indicated station. Grey lines show the midpoint of each station and contaminant.

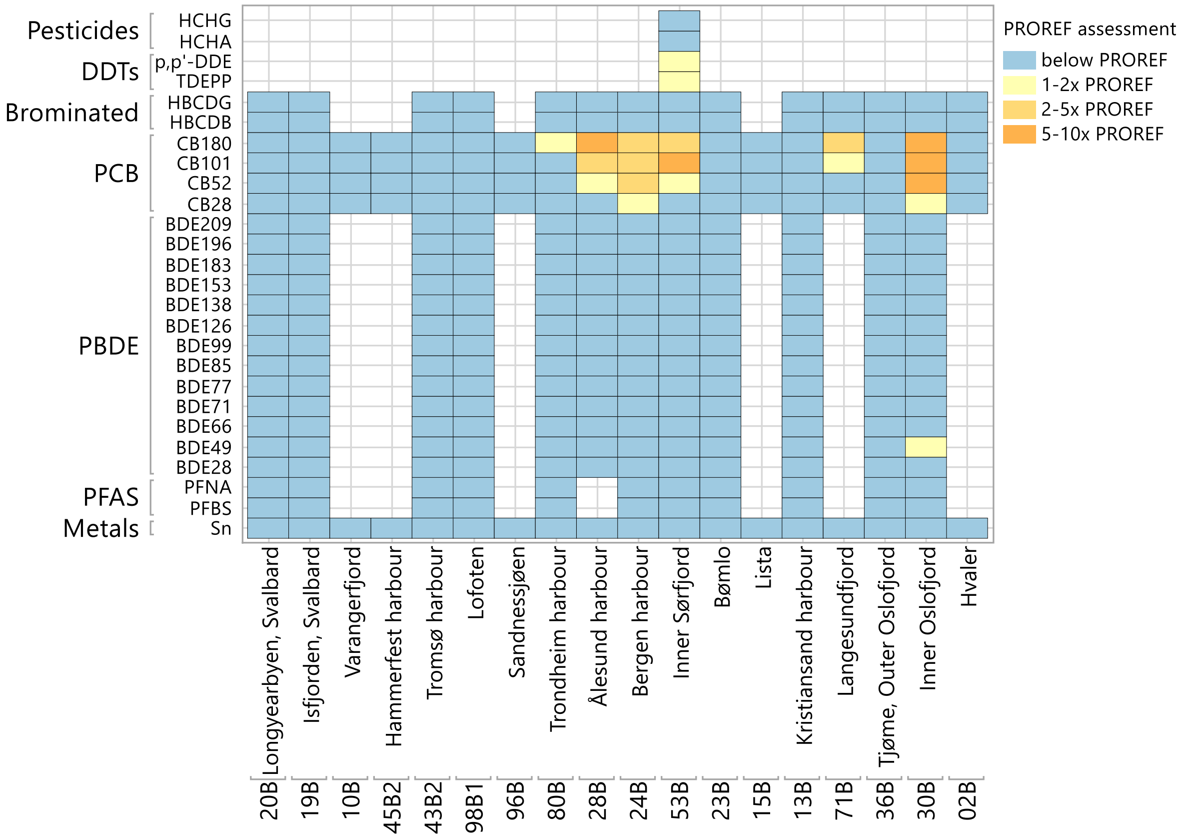

Figure S6. Heatmap of exceedances of PROREF in cod for contaminants not selected in 2023. The colours represent below or above exceedance of PROREF. Empty "cells" mean that the contaminant was not analysed for at the indicated station. Grey lines show the midpoint of each station and contaminant.

Time trends (combinations of contaminant × station) have also been estimated for contaminants not selected for presentation in 2023. The contaminants are listed in **Table S2**. The figures with time trends are shown in **Figure S7** to **Figure S15**. The time trends presented for selected contaminants (**chapter 3.3**) have been manually quality assured, but the time trends presented in this chapter has 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.

Table S2. List of parameters for which a time trend is shown in supplementary data.

Contaminant group	Contaminant	Blue mussel	Cod	Snails
Metals	Sn	24	18	0
PFAS	PFBS	6	11	0
	PFHxS	6	11	0
	PFNA	6	11	0
	PFUnDA	6	11	0
PBDE	UB sumBDE6	10	12	0
	BDE28	11	12	0
	BDE66	11	12	0
	BDE85	11	12	0
	BDE99	11	12	0
	BDE126	11	12	0
	BDE153	11	12	0
	BDE183	11	12	0
	BDE209	11	12	0
PAH	NAP	7	0	0
	ACNE	7	0	0
	ACNLE	7	0	0
	FLE	7	0	0
	ANT	7	0	0
	PA	7	0	0
	BGHIP	7	0	0
	DBA3A	7	0	0
	ICDP	7	0	0
PCB	CB28	23	18	0
	CB52	23	18	0
	CB101	23	18	0
	CB105	23	18	0
	CB126	23	18	0
	CB156	23	18	0
	CB180	23	18	0
	CB180	23	18	0
	UB sumPCB7	23	18	0
Siloxanes	D4	0	8	0
	D6	0	8	0
CP	UB MCCP	11	14	0
	UB SCCP	11	14	0
Brominated	HBCDB	11	14	0
	HBCDG	11	14	0
DDTs	TDEPP	2	0	0
	o,p'-DDT	2	0	0
	p,p'-DDE	2	1	0
Pesticides	HCHA	2	0	0
	HCHB	2	0	0
	HCHG	2	1	0
	UB HCH	2	0	0
TBT-related	DBT	0	0	9
	MBT	0	0	9
	TBT	0	0	9
	TPhT	0	0	9
BEM	ALAD	0	1	0
	EROD	0	1	0
Imposex/intersex	VDSI/ISI	0	0	9

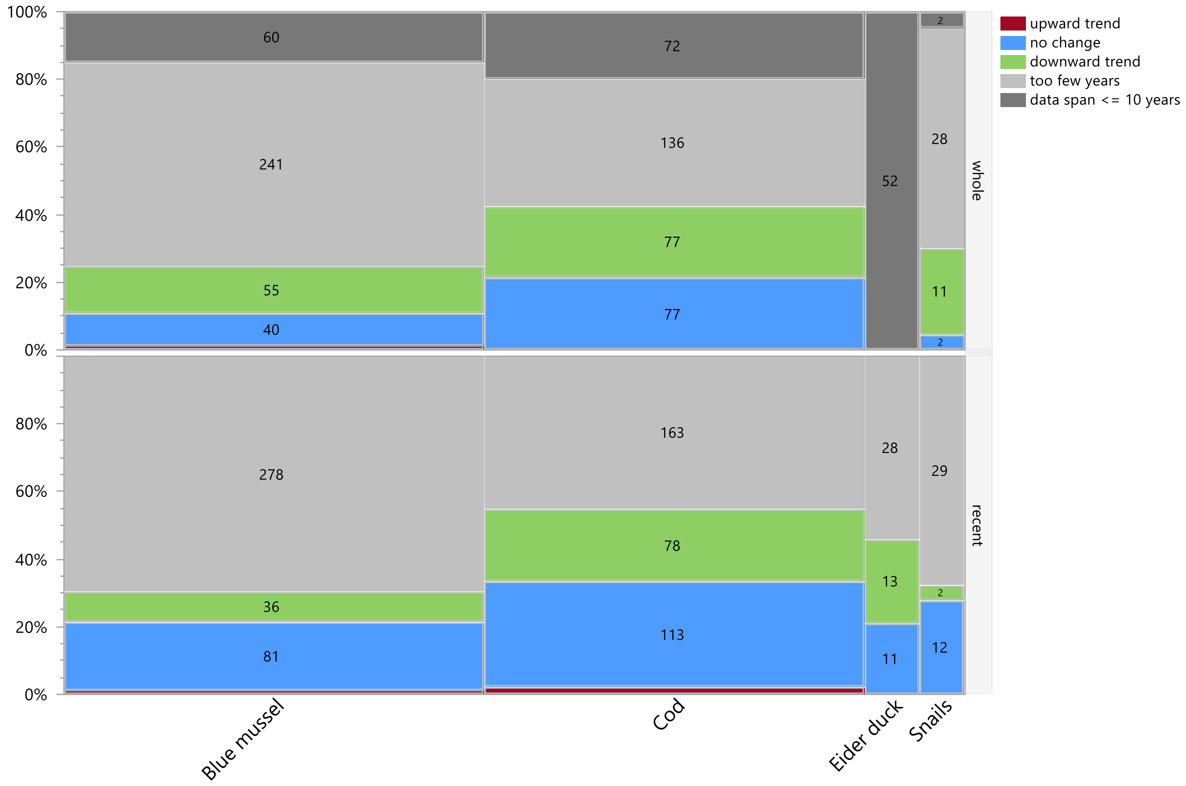

Figure S7. Mosaic plot of time trends for blue mussel, cod, eider duck and snails for contaminants not selected in 2023. Upper panel shows whole period trends, while lower panel shows recent trends. The number of stations/species/tissues are indicated in the respective cells.

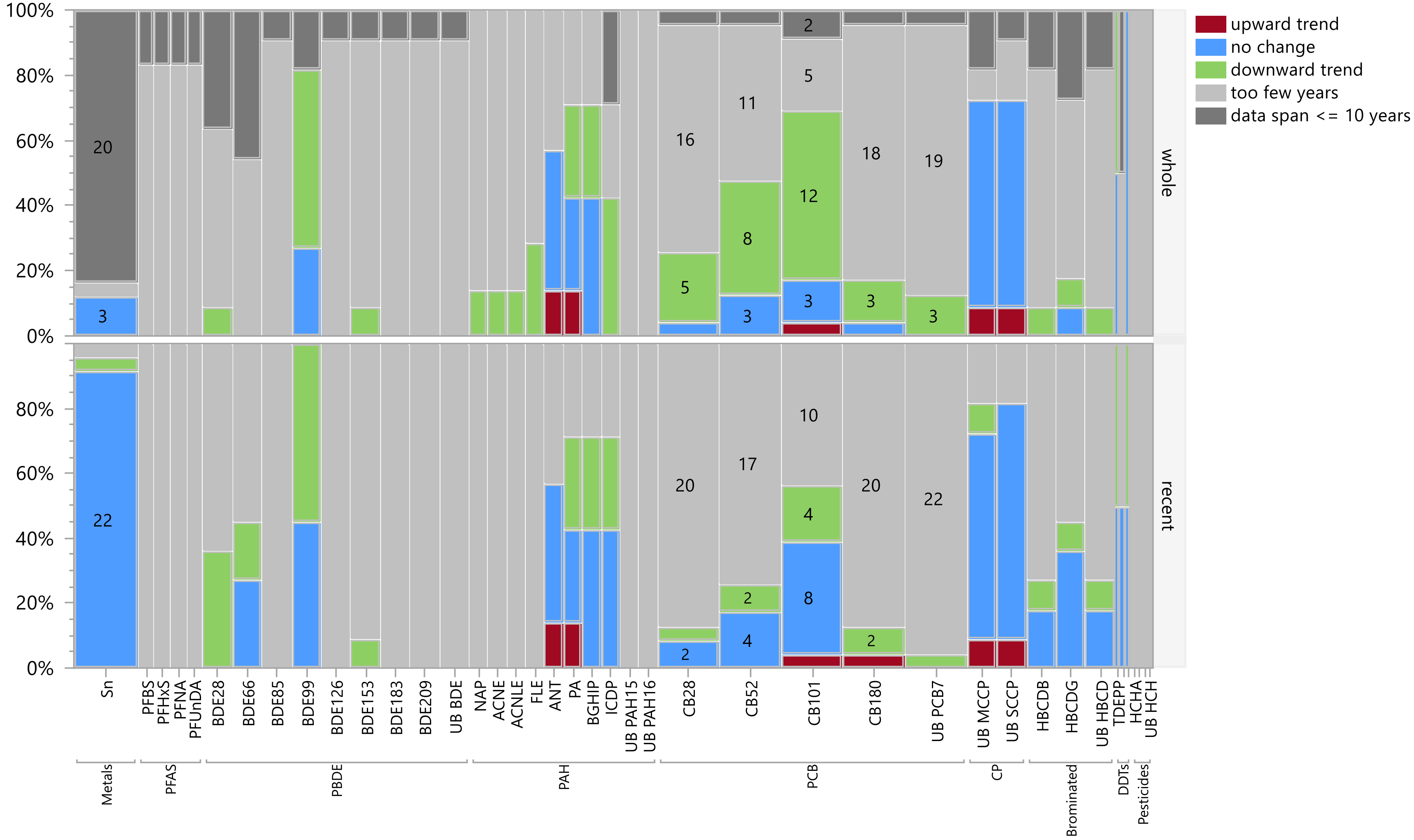

Figure S8. Time trends for blue mussel for contaminants not selected in 2023. Upper panel shows whole trends, while lower panel shows recent trends. The number of stations is indicated in the respective cells. For contaminant names not visible in this figure, please see **Figure S12**.

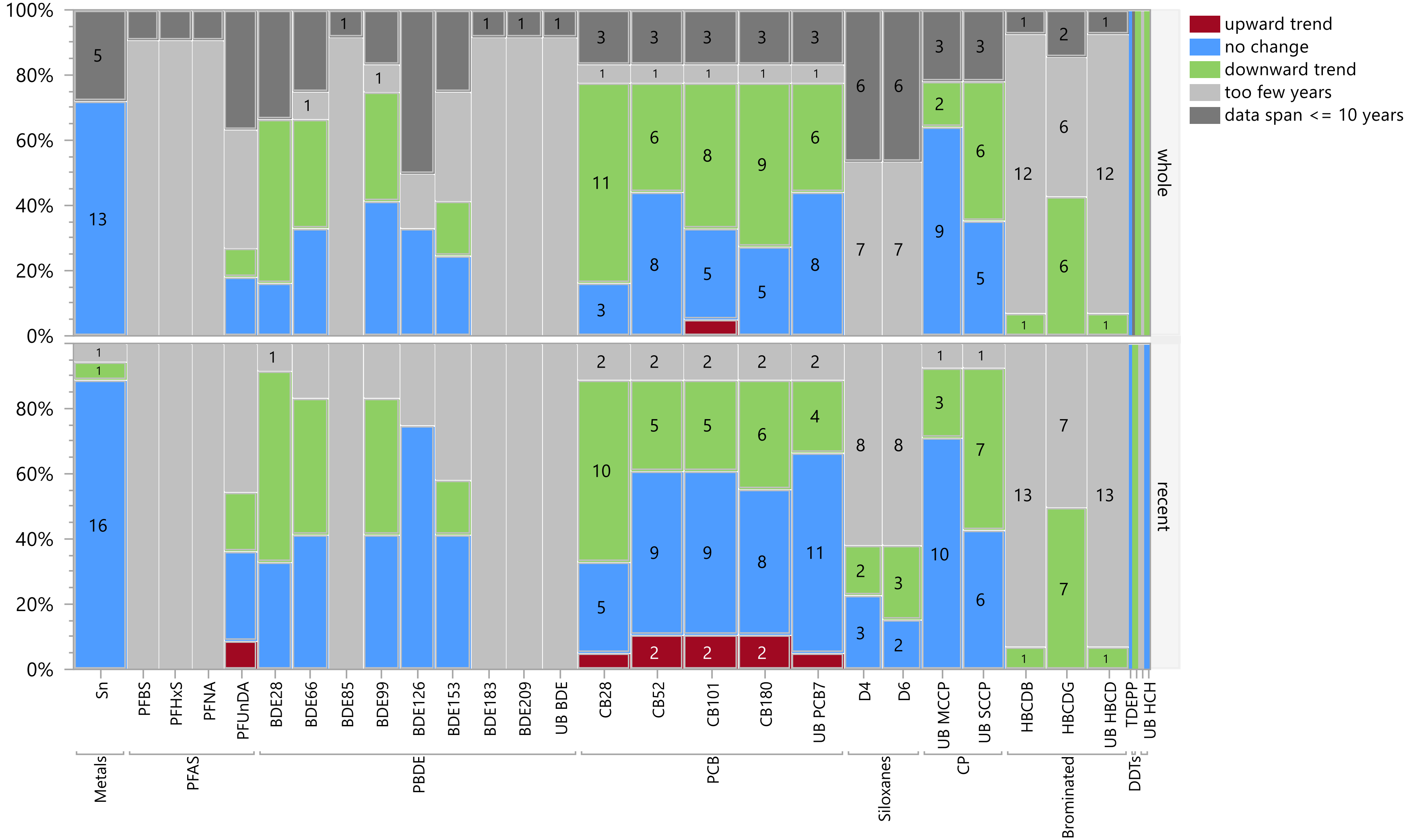

Figure S9. Time trends for cod for contaminants not selected in 2023. Upper panel shows whole trends, while lower panel shows recent trends. The number of stations is indicated in the respective cells. For contaminant names not visible in this figure, please see **Figure S13** and **Figure S14**.

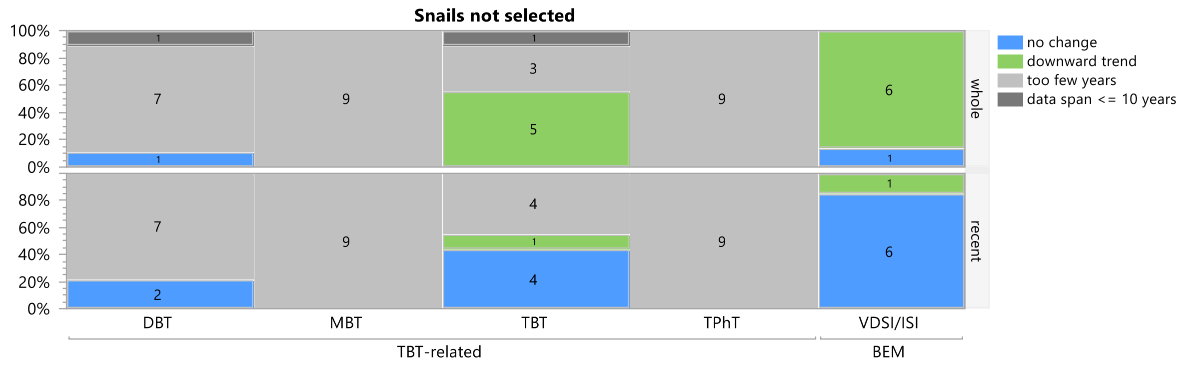

Figure S10. Time trends in snails for contaminants not selected in 2023. Upper panel shows whole trends, while lower panel shows recent trends. The number of stations is indicated in the respective cells.

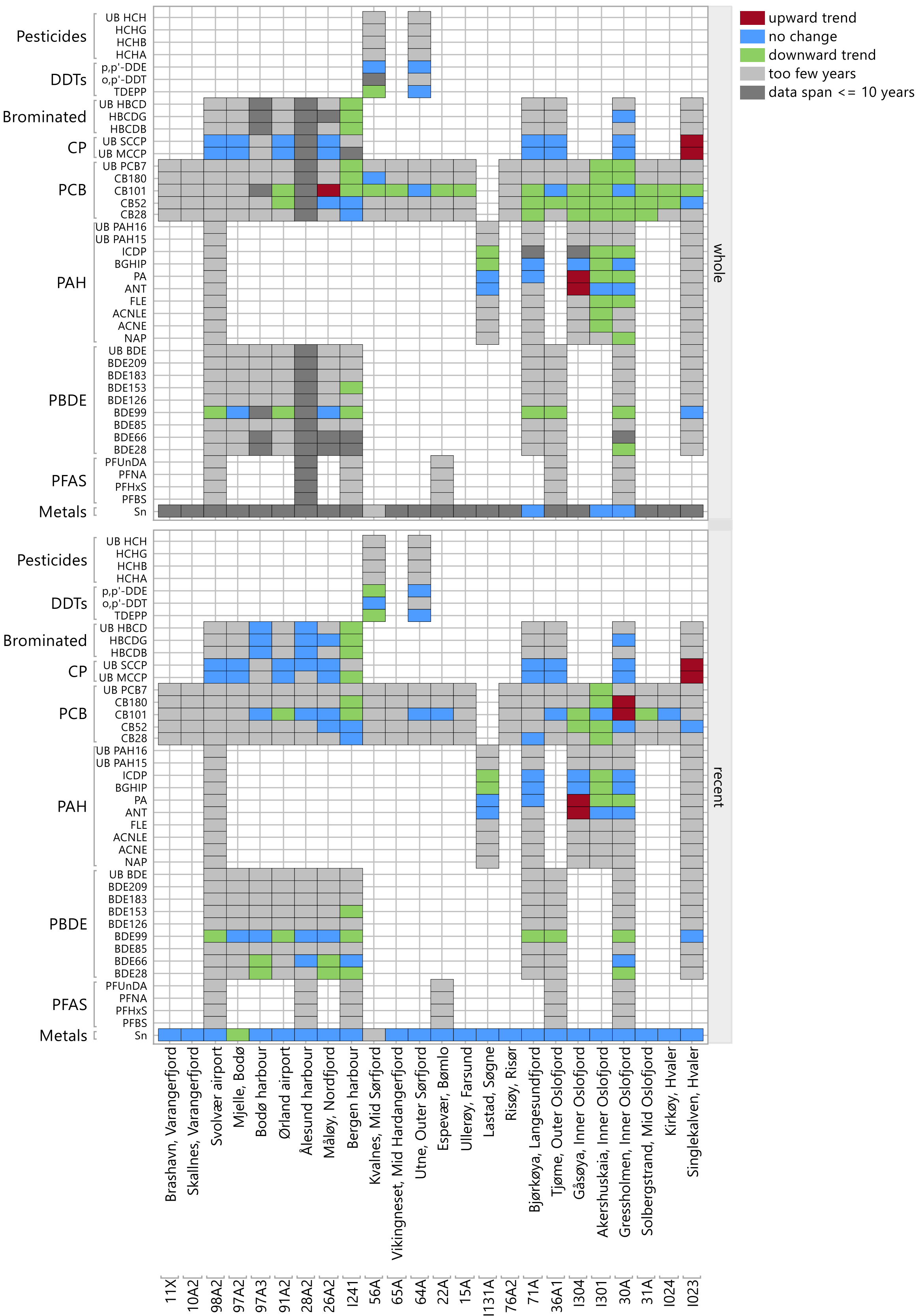

Figure S11. Heatmap for time trends blue mussel for contaminants not selected in 2023. The colours represent time trends observed at stations. Empty "cells" mean that the contaminant was not analysed for at the indicated station. Grey lines show the midpoint of each station and contaminant.

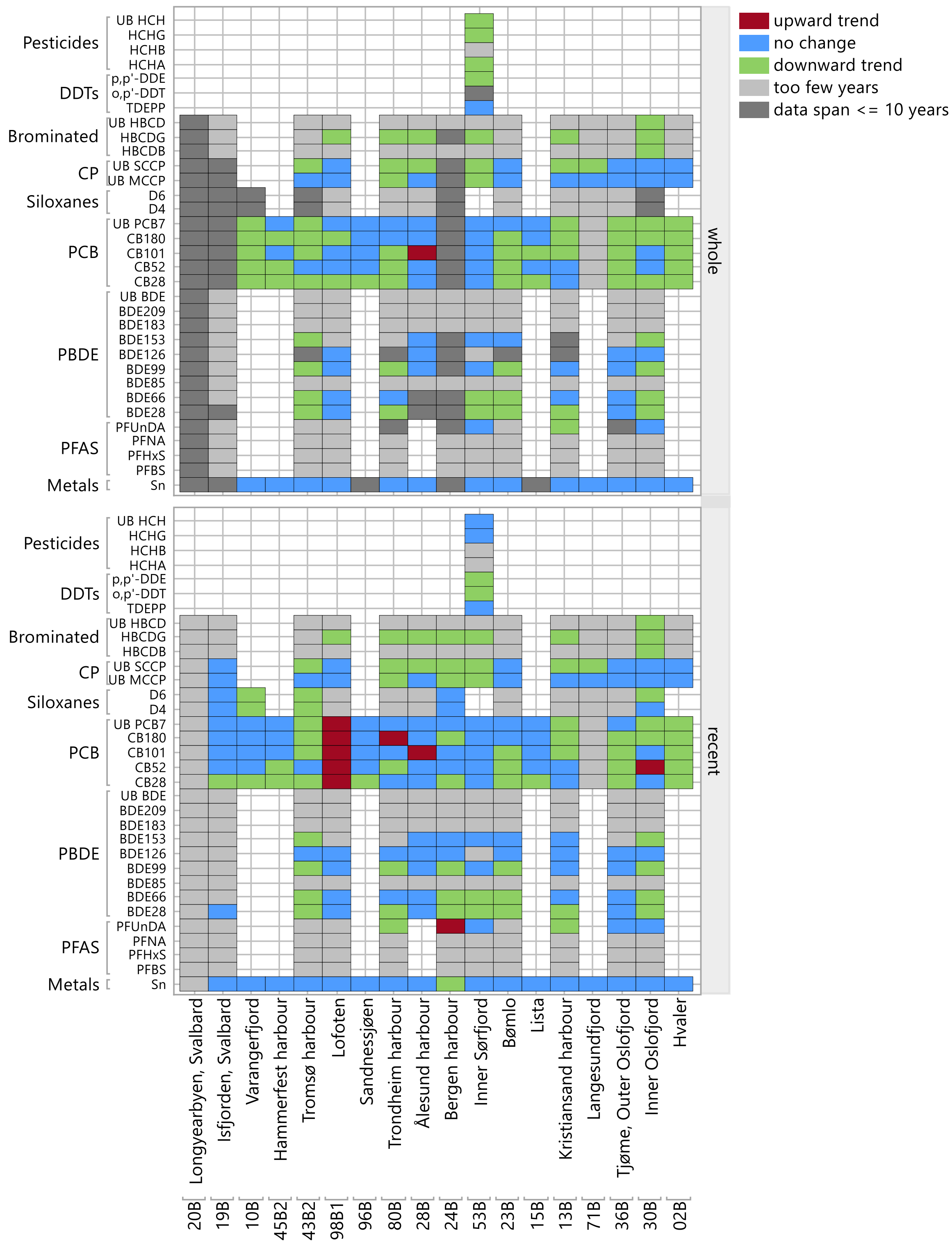

Figure S12. Heatmap for time trends in cod for contaminants not selected in 2023. The colours represent time trends observed at stations. Empty "cells" mean that the contaminant was not analysed for at the indicated station. Grey lines show the midpoint of each station and contaminant.

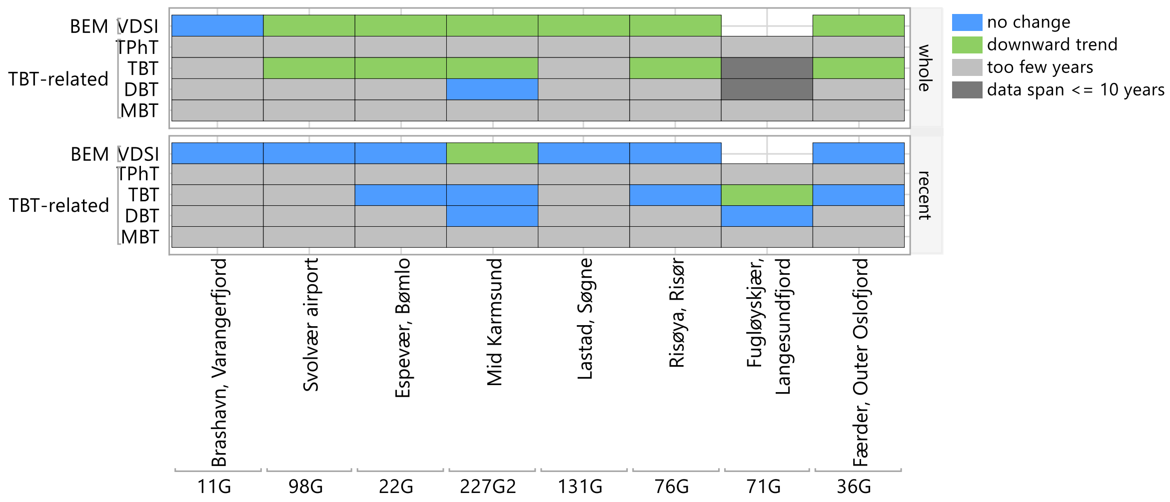

Figure S13. Heatmap for time trends in snails for contaminants not selected in 2023. The colours represent time trends observed at stations.

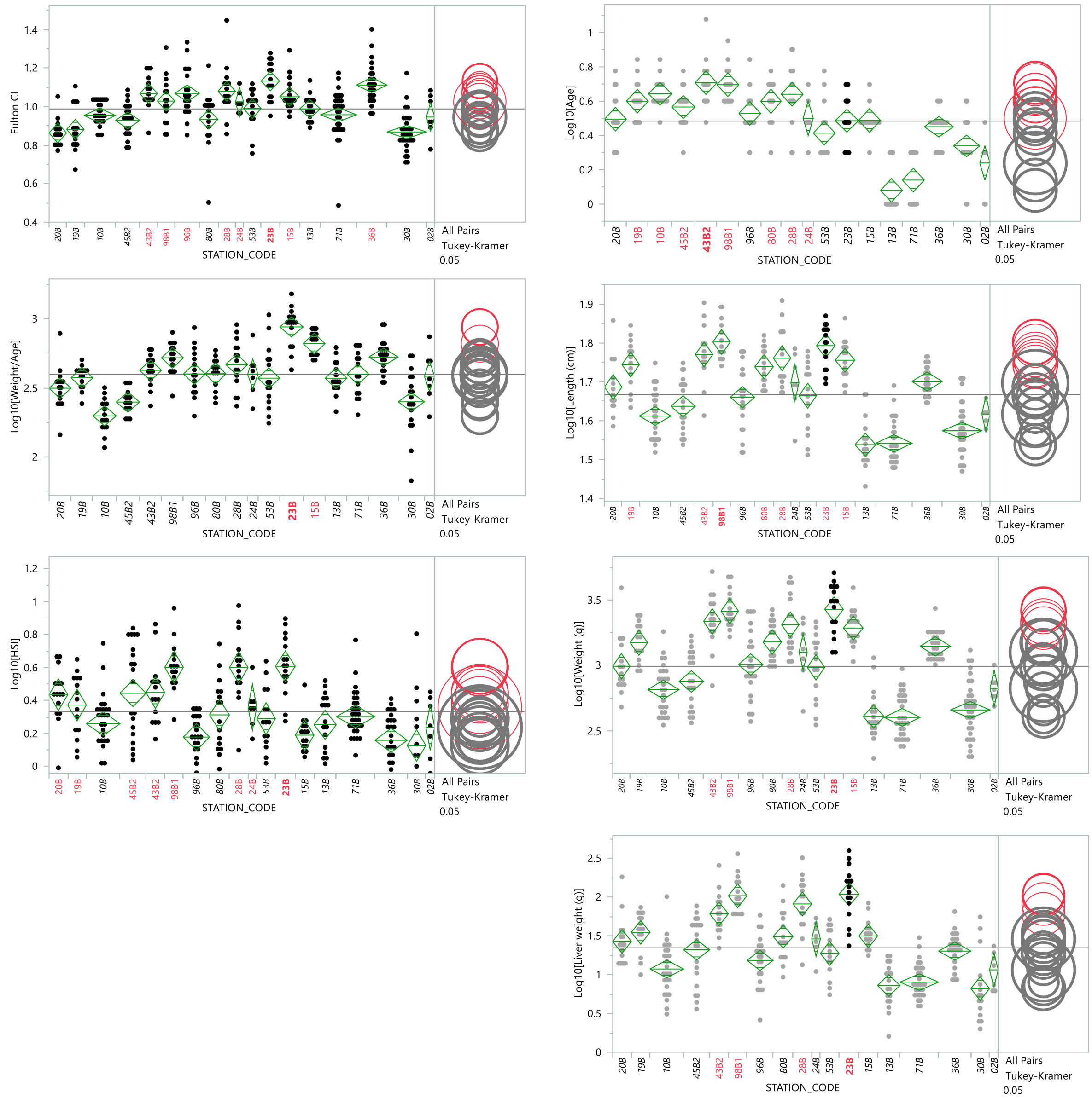

Figure S14. Tukey statistics for cod parameters. Stations are ordered along the coast from north to south. Health related parameters are shown to the left. The mean diamonds are shown in green where the upper and lower vertical tip indicate the 95 % confidence level, and the midpoint indicate the mean. The width of the stations horizontally is proportional to the sample size for the station. The green lines near the top and bottom of the diamonds are overlap markers. To the right are comparison circles. Circles for means that are significantly different from each other either do not intersect or intersect slightly. The highest mean of each parameter is highlighted in red (station name is in red and bold), and other circles in red are not significantly different from that station, while circles in grey are significantly different. See more details in **Table S3**.

Table S3. Tukey statistics for the cod data. Health related parameters to the left. Means are given with three significant figures. The letters signify the Tukey statistics, where stations not connected by the same letter are significantly different. See figures of the statistics in **Figure S14**.

Parameter	Level	Letter	Mean	Rank		Parameter	Level	Letter	Mean	Rank
Fulton CI	23B	A	1.13	18		**Log10[Age]**	43B2	A	0.709	18
	36B	A	1.11	17			98B1	AB	0.698	17
	28B	AB	1.08	16			10B	ABC	0.645	16
	96B	AB	1.07	15			28B	ABC	0.642	15
	43B2	ABC	1.07	14			19B	ABCD	0.601	14
	15B	ABCD	1.05	13			80B	ABCD	0.601	13
	98B1	ABCDE	1.03	12			45B2	ABCDE	0.567	12
	24B	ABCDEF	1.02	11			96B	BCDE	0.53	11
	53B	BCDEF	0.99	10			24B	ABCDEF	0.502	10
	13B	BCDEF	0.988	9			20B	CDEF	0.496	9
	71B	CDEF	0.958	8			15B	CDEF	0.489	8
	10B	CDEFG	0.954	7			23B	CDEF	0.487	7
	02B	BCDEFG	0.946	6			36B	DEF	0.452	6
	80B	DEFG	0.934	5			53B	EFG	0.415	5
	45B2	EFG	0.928	4			30B	FG	0.34	4
	19B	FG	0.882	3			02B	GH	0.24	3
	30B	G	0.868	2			71B	H	0.14	2
	20B	FG	0.863	1			13B	H	0.0803	1
Log10[Weight/Age]	23B	A	2.94	18		**Log10[Length (cm)]**	98B1	A	1.8	18
	15B	AB	2.82	17			23B	AB	1.79	17
	36B	BC	2.72	16			43B2	ABC	1.77	16
	98B1	BC	2.72	15			28B	ABCD	1.76	15
	28B	BCD	2.67	14			15B	ABCD	1.76	14
	43B2	CD	2.63	13			19B	ABCDE	1.74	13
	80B	CD	2.6	12			80B	ABCDE	1.74	12
	96B	CD	2.6	11			36B	CDEF	1.7	11
	24B	BCDE	2.6	10			24B	BCDEFG	1.7	10
	71B	CD	2.6	9			20B	DEF	1.69	9
	02B	BCDE	2.58	8			53B	EFG	1.66	8
	19B	CDE	2.57	7			96B	FG	1.66	7
	53B	CDE	2.57	6			45B2	FG	1.64	6
	13B	CDE	2.57	5			02B	FGHI	1.62	5
	20B	DE	2.5	4			10B	GH	1.61	4
	30B	EF	2.4	3			30B	HI	1.57	3
	45B2	EF	2.4	2			71B	I	1.54	2
	10B	F	2.3	1			13B	I	1.54	1
Log10[HSI]	23B	A	0.608	18		**Log10[Liver weight (g)]**	23B	A	2.04	18
	98B1	A	0.602	17			98B1	A	2.02	17
	28B	A	0.6	16			28B	AB	1.91	16
	43B2	AB	0.448	15			43B2	ABC	1.78	15
	45B2	AB	0.444	14			19B	BCD	1.55	14
	20B	AB	0.435	13			15B	CDE	1.5	13
	19B	ABC	0.372	12			80B	CDE	1.49	12
	24B	ABCD	0.359	11			24B	BCDEF	1.46	11
	80B	BCD	0.312	10			20B	CDE	1.43	10
	71B	BCD	0.302	9			45B2	DEF	1.32	9
	53B	BCD	0.29	8			36B	DEF	1.3	8
	10B	BCD	0.259	7			53B	DEF	1.27	7
	13B	BCD	0.252	6			96B	EFG	1.18	6
	02B	BCD	0.238	5			10B	FGH	1.07	5
	15B	CD	0.189	4			02B	DEFGH	1.06	4
	96B	CD	0.178	3			71B	GH	0.904	3
	36B	CD	0.158	2			13B	GH	0.861	2
	30B	D	0.126	1			30B	H	0.82	1
						Log10[Weight (g)]	23B	A	3.43	18
							98B1	AB	3.42	17
							43B2	ABC	3.34	16
							28B	ABC	3.31	15
							15B	ABC	3.29	14
							80B	BCD	3.18	13
							19B	BCD	3.17	12
							36B	CD	3.15	11
							24B	CDE	3.1	10
							96B	DEF	3.01	9
							20B	DEF	2.99	8
							53B	DEF	2.99	7
							45B2	EF	2.88	6
							02B	EFGH	2.82	5
							10B	FG	2.81	4
							30B	GH	2.66	3
							13B	H	2.61	2
							71B	H	2.6	1

Table S4. 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	
	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), Langesundsfjorden
	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 nord-vest
	I023	Singlekalven, Hvaler	59.0951	11.1368	Hvaler-Singlefjorden, Singlekalven syd
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 Trondheimsfjorden
	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, Breviksområdet
	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
	131G	Lastad, Søgne	58.0284	7.699	Lastad (Selskjær), Trysfjorden
	15G	Ullerøy, Farsund	58.0493	6.9012	Gåsøy, Lista
	227G	Mid Karmsund	59.3396	5.3122	Flatskjer, Karmsundet (227G1)
	22G	Espevær, Bømlo	59.5837	5.1445	Espevær, Bømlo
	36G	Færder, Outer Oslofjord	59.0278	10.5256	Færder, Ytre Oslofjord
	76G	Risøya, Risør	58.728	9.2755	Risøya, Risør
	98G	Svolvær airport	68.247	14.6664	Husvågen, Svolvær
Common periwinkle	71G	Fugløyskjær, Langesundfjord	58.985	9.8046	Fugløya, Langesundbukta
(*Littorina littorea*)	131G	Lastad, Søgne	58.0284	7.699	Lastad (Selskjær), Trysfjorden
Common eider (*Somateria mollissima*)	19N	Kongsfjorden, Svalbard	79.004	12.11	Breøyane