OSPAR COMMISSION

Hazardous Substances Thematic Assessment

OSPAR

QUALITY STATUS REPORT 2023

2022

OSPAR's Quality Status Report 2023

Hazardous Substances Thematic Assessment

OSPAR Convention

The Convention for the Protection of the Marine Environment of the North-East Atlantic (the "OSPAR Convention") was opened for signature at the Ministerial Meeting of the former Oslo and Paris Commissions in Paris on 22 September 1992. The Convention entered into force on 25 March 1998. The Contracting Parties are Belgium, Denmark, the European Union, Finland, France, Germany, Iceland, Ireland, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

Convention OSPAR

La Convention pour la protection du milieu marin de l´Atlantique du Nord-Est, dite Convention OSPAR, a été ouverte à la signature à la réunion ministérielle des anciennes Commissions d´Oslo et de Paris, à Paris le 22 septembre 1992. La Convention est entrée en vigueur le 25 mars 1998. Les Parties contractantes sont l´Allemagne, la Belgique, le Danemark, l´Espagne, la Finlande, la France, l´Irlande, l´Islande, le Luxembourg, la Norvège, les Pays-Bas, le Portugal, le Royaume- Uni de Grande Bretagne et d´Irlande du Nord, la Suède, la Suisse et l´Union européenne

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Supported by: Working Group on Monitoring and on Trends and Effects of Substances in the Marine Environment (MIME), Hazardous Substances Thematic Assessment Technical Group to develop the Thematic Assessments for the QSR 2023 (TG-HasTA), OSPAR Hazardous Substances and Eutrophication Committee (HASEC), Intersessional Correspondence Group on Ecosystem Assessment Outlook - Cumulative Effects (ICG-Eco-C), Intersessional Correspondence Group on Economic and Social Analysis (ICG-ESA), Climate Change Expert Group (CCEG) and the OSPAR Commission Secretariat

Citation

OSPAR, 2023. *Hazardous Substances Thematic Assessment*. In: OSPAR, 2023: Quality Status Report 2023. OSPAR Commission, London. Available at: https://oap.ospar.org/en/ospar-assessments/quality-status-reports/qsr-2023/thematic-assessments/hazardous-substances

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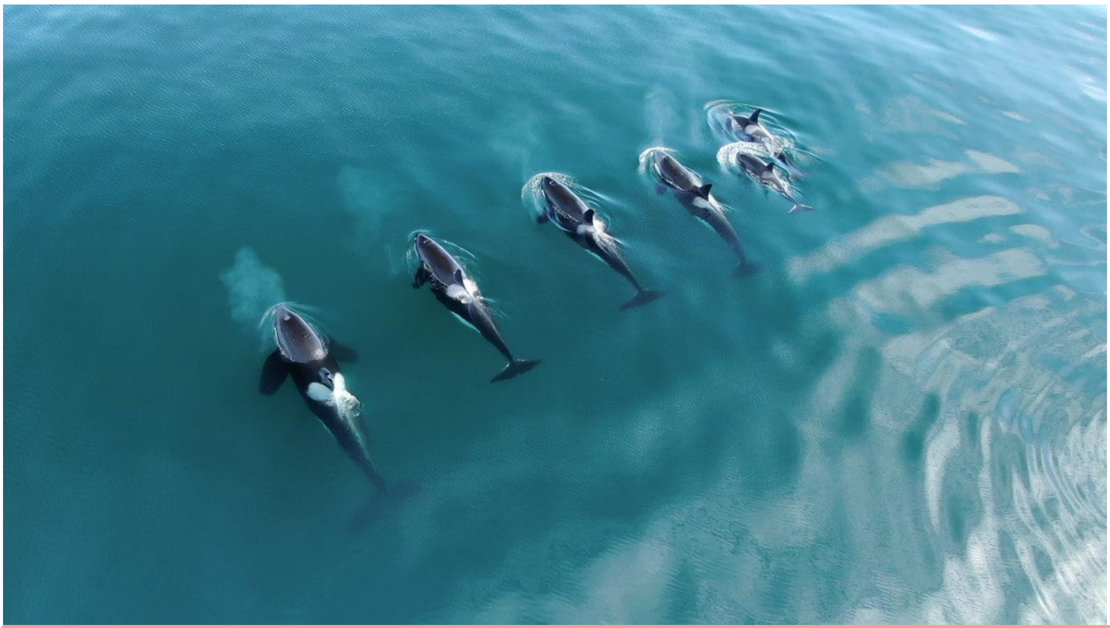
Executive Summary

Since 1998, including under the NEAES 2010-2020 Strategy, OSPAR's objective for Hazardous Substances has been "*to prevent pollution of the OSPAR Maritime Area by continuously reducing discharges, emissions and losses of hazardous substances, with the ultimate aim to achieve concentrations in the marine environment near background values for naturally occurring substances and close to zero for man-made synthetic substances*". OSPAR also aimed to move towards the cessation of discharges, emissions and losses of hazardous substances by the year 2020.

Concentrations of many of the most serious hazardous substances, such as PCBs, PAHs and organochlorine insecticides, have decreased substantially compared with the 1980s-1990s. Nevertheless, we find that most OSPAR sub-regions (ten out of twelve) have a poor status for hazardous substances in marine animals (fish, mussels and oysters). This is mainly caused by excessive concentrations of mercury and PCB118 (a dioxin-like polychlorinated biphenyl). Moreover, current trends indicate that only one of the sub-regions may improve substantially during the next 10-20 years. For hazardous substances in sediment, the situation is somewhat better, as approximately half of OSPAR's sub-regions have a good status. Again, mercury is the main culprit. One Region may be expected to go from poor to good environmental status during the next 10-20 years, but no Regions are expected to go from good to poor. The ban on TBT in antifouling paints from 2008, however, seems to have worked, resulting in a general reduction in imposex levels in gastropods to values below the EAC in open waters; TBT levels in coastal areas are, thus, declining, and in some places below the EAC. It should be noted that gastropods are not the most sensitive species, as some fish larvae are hampered in their development at even lower TBT concentrations, so we are on the right track but good status for all waters is still a distant target.

Most OSPAR sub-regions have a poor status for hazardous substances in marine animals (fish, mussels and oysters). © Shutterstock

Thus, while society has made considerable progress in reducing many hazardous substances, from high levels in the early 1980s to more moderate levels over the past decade, further progress towards OSPAR's objective of cessation of discharges and emissions is considerably slower. This is because of the high chemical stability of hazardous chemicals and their re-release from marine sediment, which acts as storage for past contamination. This re-release is caused by both natural (e.g., hydrodynamic and biogenic) and anthropogenic processes (e.g., bottom trawling, anchoring, dredging, and dumping operations). Also, there is continued discharge from sources both within and outside the OSPAR area. For animals at high trophic levels such as predatory whales, even PCBs, which were mostly banned decades ago, are a real threat to survival. In recent years, there has also been more focus on emerging contaminants such as PFAS (a large group of fluorinated substances), pharmaceuticals, and chemicals in personal care products (e.g., cosmetics, hygiene products and sunscreens). The diversity of these substances exposes marine organisms to a "cocktail" of chemicals. Owing to the complexity of this issue, there is still quite limited knowledge on the cumulative impact of this mixture of chemicals.



For animals at high trophic levels such as predatory whales, even PCBs, which were mostly banned decades ago, are a real threat to survival. © Shutterstock

This thematic assessment focuses on the time trends for hazardous substances in the OSPAR CEMP monitoring programme, and the effects of current levels of contaminants. Emerging contaminants have been addressed by the COnNECT screening initiative, which represents an important tool in their identification and quantification and should be implemented in all OSPAR Regions as reported elsewhere.

Q1. Identify the problems? Are they the same in all OSPAR regions?

Hazardous substances affect living organisms

Many man-made chemicals enter the North-East Atlantic through land-based and sea-based human activities. Some of them are hazardous for the marine environment. In addition, industrial use of naturally occurring substances such as heavy metals (e.g., mercury and lead) have considerably increased the levels of those metals in the marine environment. Hazardous substances have different effects depending on their type, affecting the health, reproduction or survival of individuals, even up to species-level extinction, and can seriously affect human health through seafood consumption.

Impact across OSPAR Regions

In most parts of the Regions metals, particularly mercury, and the dioxin-like chlorinated pollutant CB 118 are found at above the levels which are expected to have an impact on the marine environment. Local pollution can affect individual Regions, but most substances reach all the Regions through large-scale air- or waterborne transport, both from the countries around the North Sea and through long-range transport from other Regions.

The problem substances and their sources

OSPAR works to identify which substances are hazardous (historical and emerging contaminants) for the marine environment, to prevent, reduce and ultimately eliminate pollution by these substances, and to monitor the effectiveness of the measures for achieving this.

Heavy metals

Heavy metals are naturally occurring substances, but their use in society has led to a significant increase in their concentrations. The heavy metals showing the highest toxicity to humans and animals are mercury, cadmium and lead. They enter the marine environment through several natural processes and human activities, via long-range aerial transport, riverine input, or run-off. Mercury is the most dangerous, as it is transformed into the highly bio-accumulative and poisonous form of methylmercury by anaerobic microbes. As a result, few parts of the Regions present mercury concentrations in organisms that are below the good environmental status threshold. The levels are highest in the North Sea, the English Channel and the Northern Bay of Biscay. Lead and cadmium are also above background levels, but the status of these metals is still considered good.

Leaded fuels, introduced in 1921, were discovered to have huge impact on human health and to increase lead pollution in the atmosphere by a factor of 100. This resulted in the adoption of clean air acts in several countries during the 1990s. In 2021, Algeria was the last country in the world to stop using leaded fuel, ending 100 years of tetraethyllead in fuels. Lead is still an important component in national water distribution, and the input through professional and, especially, recreational fishing is considerable.

Persistent organic pollutants

Many of these pollutants are exclusively man-made; they are not found in nature or produced by natural processes, they are sometimes (extremely) persistent and degrade very slowly by natural processes in the marine environment. Most of these substances have chemical properties that cause them to be excreted very slowly, so that they bioaccumulate in long-lived organisms such as fish. They may have properties that cause biomagnification, meaning that their concentrations become higher in predators than in their prey, so that those concentrations then increase as the substance moves up the food web. Nevertheless, recent findings point to a dilution at low trophic levels because of a high primary production rate occurring too fast to establish equilibrium with lipophilic contaminants (although this does not imply any degradation). Production of many of these pollutants has been banned, at least in Europe, for decades, but they still linger in the environment due to their pervasive use and stability. One example is polychlorinated biphenyls (PCBs), of which 1,2 billion tonnes were produced globally before they were banned in the mid-1980s. This is a typical example of legacy contamination – because the substances are so persistent, they remain present both in the ecosystem and in landfills, harbour sediments and marine dumping sites. Polybrominated diphenyl ethers (PBDEs) have also had widespread usage, for example as flame retardants in textiles, plastics and electronic products, but were banned from 2004 onwards in the European Union. Other compounds are by-products of both industrial and household combustion processes: PAHs (polycyclic aromatic hydrocarbons) are formed in iron mills and other metallurgic industries as well as in oil refineries, but also, and equally importantly, in transport (road, shipping and even air traffic). High concentrations of PAHs may be found near industrial sites, but their airborne release often renders the input diffuse.

Of course, industrial regions like the Southern North Sea exhibit higher contaminant concentrations. Owing to bioaccumulation and biomagnification, species at the top of the food web, like marine mammals, have body burdens likely to produce health consequences.

PBDEs we widely used as flame retardants in textiles, plastics and electronic products, but were banned from 2004 in the EU. © Shutterstock

Organotin compounds

Organotins are biocides, used as plant protection or to prevent biofouling on ships and boats. The best-known substance is tributyltin (TBT), which causes malformations in oyster shells and the development of male characteristics in female marine snails, rendering the most sensitive species sterile. As a result, the dog whelk has become locally extinct in several parts of the OSPAR Maritime Area. The problem is greatest along major shipping lanes and ports. These substances are also toxic to fish larvae and influence a wide variety of marine organisms at very low concentrations.

Q2. What has been done?

OSPAR Maritime Area

Among the earliest international environmental agreements were the Oslo Convention for the Prevention of Marine Pollution by Dumping from Ships and Aircraft, adopted in 1972, and the Paris Convention for the Prevention of Marine Pollution from Land-based Sources, adopted in 1974, which cover what today is the

OSPAR Maritime Area. Under the Paris Convention, the signatory countries agreed to eliminate pollution by organohalogen compounds, mercury and cadmium. These agreements formed the basis for what in 1992 became OSPAR.

In total, 65 OSPAR Decisions and Recommendations have been adopted targeting point and diffuse sources of pollution from hazardous substances. Most of these are either fully implemented or have been set aside after being overtaken by measures adopted at national level or within other forums, and are therefore no longer followed by OSPAR. Only one Recommendation, (https://www.ospar.org/documents?d=32606) concerned with controlling the dispersal of mercury from crematoriums, is still in force, and the status of four others concerning oil facilities, aquaculture, metals in sewage sludge and pesticides was found to be unknown in the latest progress report on the implementation of OSPAR measures (link= https://www.ospar.org/documents?d=32606).

Internationally

Historically, many substances have first been restricted or banned at national level, while multi- and bilateral cooperation restrictions and bans at international level have taken years or even decades to be put in place. For instance, France restricted the use of tributyltin (TBT) in 1982 and the Paris Convention adopted a first regional Recommendation addressing the use of TBT in 1987, while the International Convention on the Control of Harmful Anti-fouling Systems on Ships (adopted by most coastal countries https://www.imo.org/en/about/conventions/pages/international-convention-on-the-control-of-harmful-anti-fouling-systems-on-ships-(afs).aspx) banning the presence of TBT on ships' hulls did not come into force until 26 years later in 2008. In 2000, the EU took the major step of adopting the Water Framework Directive (WFD), under which a list of priority substances was produced in 2001, and of setting Environmental Quality Standards (EQS) for water and biota concentrations under Directive 2008/105/EC. While the WFD is limited to freshwater and near-coastal environments, the Marine Strategy Framework Directive (MSFD, 2008) extends the WFD's concentration thresholds for hazardous substances to the marine environment.

The Paris Convention adopted a first regional Recommendation addressing the use of TBT in 1987. © Shutterstock

Major global-level agreements include the Stockholm Convention, http://www.pops.int which forbids or restricts the use of a number of organic persistent chemicals (entered into force 2004), and the Minamata Convention, https://www.mercuryconvention.org/en which provides controls over numerous products containing mercury (signed in 2013).

Within the EU, a proposal to ban 200 PFAS substances was put forward in 2017 by Sweden and Germany, and work is underway to ban the use of PFAS in firefighting foams and a range of other applications (https://ec.europa.eu/environment/chemicals/pfas/index_en.html).

Q3. Did it work?

Levels of legacy substances have decreased substantially since the onset of OSPAR and EU measures but these decreasing trends have slowed and become less distinct in recent years

The national and regional regulations and initiatives introduced from the 1980s-90s onwards have led to a strong decrease in the concentrations of most legacy hazardous organic and inorganic substances in both sediment and biota, such as insecticides and PCBs. In some "hotspot" locations, concentrations in fish have decreased by a factor of 1 000 since the 1970s. In the last 1-2 decades, the downward trends have been smaller compared with former decades, when decreases were driven by the elimination of large industrial point sources of contamination. Most metals follow the same pattern, but in the more populated OSPAR Regions (Region II and eastern parts of Regions III and IV) increasing trends are being observed in some locations for selected substances like mercury. There is an overall increasing trend for pollution in the

Southern North Sea in Region II, whereas no significant improvements have been seen in the Northern North Sea, the English Channel, or the Northern Bay of Biscay, which have poor environmental status.

The OSPAR objective to continuously reduce discharges, emissions and losses has been partially achieved. OSPAR has moved towards the 2020 cessation target. The objective has been partially fulfilled for many legacy contaminants such as PCBs and PBDEs, with many time series showing downward trends and few showing upward trends. However, for heavy metals, there are more upward than downward trends for concentrations in fish and shellfish. For mercury, three times more upward than downward trends are evident in Region II, and this is also the case in all other Regions. Analysis of mercury inputs, however (see: Inputs of Mercury, Cadmium and Lead via Water and Air to the OSPAR Maritime Area), shows that those from air and rivers are decreasing, which is also reflected in the decreasing mercury concentrations found in sediment. The generally upward time trends for fish and shellfish could be due to internal release from sediment to water and marine organisms or to a change in the uptake of metals by fish and shellfish owing to higher temperatures. However, it could also be related to a change in the general biological condition at stations. Continuation of the current dependence on coal in Russia, China, and India for power generation, together with increasing risks of forest fires, could imply a risk of increasing atmospheric deposition of mercury in the future, despite the efforts made under the Minamata Convention.

It should be borne in mind that most long-term time series of contamination which are used for assessment, relate to sediment and to relatively short-lived species in the low to middle part of the food web. Long-lived species at the top of the food web, such as marine mammals, still exhibit extremely elevated levels of persistent organic pollutants (POPs) which were banned decades ago, such as organochlorinated pesticides (e.g., DDTs and dieldrin), polybrominated diphenyl ethers (PBDEs) and PCBs. Furthermore, the decrease of PCBs in these species seems to have stalled.

Q4. How does this field affect the overall quality status?

Environmental concentrations are still not near background values for most metals and hazardous substances

Under OSPAR's NEAES 2010-2020 Strategy, the objective for Hazardous Substances was "*to prevent pollution of the OSPAR Maritime Area by continuously reducing discharges, emissions and losses of hazardous substances, with the ultimate aim to achieve concentrations in the marine environment near background values for naturally occurring substances and close to zero for man-made synthetic*".

Mercury concentrations are not moving closer to background values for naturally occurring substances, and good environmental status has not been achieved owing to continued (but decreased) atmospheric transport from sources outside the OSPAR Contracting Parties, and possibly to the remobilisation of historically contaminated materials. Therefore, global initiatives to limit atmospheric pollution, as well as land-based remediation measures, are needed in order to achieve the environmental objectives. For many synthetic legacy substances such as PCBs and PBDEs the concentrations are slowly approaching the goal of "close to zero" concentrations, at least for animals low in the food web. However, for animals higher in the food web, it is uncertain whether there is any progress at all at this stage.

Q5. What do we do next?

Preventing pollution is a world-wide task and more knowledge on occurrence and effects is needed
Building on its strategic objectives for 2010-2020, OSPAR has set new strategic objectives for 2020-2030, including the following new operational objectives for this period, as listed in the North-East Atlantic Environment Strategy (NEAES) 2030:

Operational objective S2.01: Identify contaminants of emerging concern and prioritise them for action. One of the main tools used to follow this up has been the [COnNECT (*CONtaminants of Emerging Concern and Threat*) project] run by a consortium of Contracting Parties together with the NORMAN network. Here, samples from across the OSPAR area are analysed using methods that can potentially identify risk assessments for thousands of substances, thus highlighting substances that are widespread and that also occur in concentrations that may affect organisms negatively. In addition, OSPAR has recently developed more robust and holistic models to support future prioritisation listings.

Operational objective S2.02: Further develop and identify marine-relevant assessment criteria. Work needs to be continued to allow assessment of a wider range of substances while enabling Contracting Parties to focus their efforts. In order to be taken seriously by society, the assessment criteria must be credible, and therefore it is important that they are well underpinned by ecotoxicological studies. Such studies should be performed where there is a need for more data. In some cases, such as for PBDEs, the scarcity of proper ecotoxicological data has been pointed out for years. It is highly important that ecotoxicological information on marine organisms be added to admission files of substances in ECHA. The assessment criteria must also be operational for the species commonly used in contaminant monitoring.

Operational objective S2.O3: By 2027, ensure that measures to eliminate discharges, emissions, and losses of hazardous substances are in place to achieve or maintain good environmental status. Consideration must first be given to whether there are unknown sources for the substances with increasing trends and unsatisfactory good environmental status within the Contracting Parties. This is, however, hard to achieve without a comprehensive analysis of the inputs of hazardous substances, which is currently available for only three substances, namely mercury, cadmium and lead. Other analyses of inputs to the environment exist in the scientific literature but do not cover each OSPAR Region comprehensively.

Second, more effective legislation or guidelines for minimising pollution must be introduced. While the production and use of many man-made substances have been banned in Europe, many substances have been replaced by unregulated substances that have similar properties, including toxicity. Such substitution can happen much faster than authorities are able to discover and regulate. One solution is to regulate entire classes of substances, as exemplified by the European Chemicals Agency's proposal to ban all per- and polyfluoroalkyl substances (PFASs) in fire-fighting foams.

Finally, work is required in order to establish worldwide conventions for reducing long-range transport. Many substances spread through the atmosphere, for example mercury (which has a very low boiling point) and PBDEs (which attach to airborne particulates such as dust, soot, smoke, and liquid droplets). In northern latitudes (parts of OSPAR Region I), long-range transport is the dominant input factor, and pollution affects enzyme and immune systems, hormones, reproduction, and the survival of sea birds.

OSPAR Strategic objectives 10, 11 and 12 on climate change. There is substantial evidence that increases in temperature and extreme events may enhance the release, transportation, and mobilisation of both hydrophobic and hydrophilic pollutants in the marine environment. Also, the toxicity of pollutants may increase with increasing temperatures. Climate change also contributes to oxygen depletion (hypoxia and anoxia) in the marine environment, which can increase the uptake of methylmercury in food webs and in several cases has also been found to increase the toxicity of contaminants. Thus, there is a risk that the efforts to combat the spread of hazardous substances will be cancelled out by climate change effects.

D - Drivers

Societal drivers that lead to the spread of hazardous substances

The main drivers in human activities leading to contamination from hazardous substances are power production, long-range transport and legacy contamination in sediments.

The main driver for the input of most legacy hazardous substances except radionuclides is power production using non-renewable resources, not only in Western Europe but also from the long-range transportation of emissions from China, India and Russia, particularly from coal burning. The focus is now shifting to chemicals for domestic use and waste products from other sectors and industrial production, such as pharmaceuticals and personal care products. Local drivers such as industries and wastewater from major cities, and consumer products, can influence locally, but there are also hotspots of historic pollution, buried in sediments and released during storm events, dredging operations and shipping, which can have a major influence on shipping lanes and harbours. Land use and agriculture can have a more general impact, either via run-off or directly from aquaculture.

All social and economic drivers have the potential to influence levels of hazardous substances in the marine environment. Chemicals are integral to all aspects of society, including the production and processing of food, health and welfare, energy, materials, industrial processes and trade and movement of goods.

Agriculture, aquaculture, energy production and many materials and processes are dependent on chemicals. The production of goods and the associated chemical use contributes to stable economies. Growing global populations increase the demand for food, which is met by agriculture, aquaculture and fishing. Aquaculture and agricultural run-off can introduce contaminants into the marine environment (further information in the human activities thematic assessment).

Growing populations also increase the demand for housing and utilities, in turn increasing the demand for materials and their processing. The manufacturing and processing of goods can introduce pollutants into the marine environment. The shipment of goods by sea and navigational dredging in support of shipping can each contribute to the input or release of hazardous substances into the marine environment. Combustion activities to produce energy and the manufacture, installation and operation of infrastructure, including oil and gas production facilities, for example in the North Sea, can also release hazardous substances into the marine environment. The movement of ships at sea can contribute to the input of hazardous substances (e.g., PAH and heavy metal emissions from scrubbers); oil spills and the testing and historic deposits of munitions can input a range of hazardous substances.

Society benefits from chemicals but can be adversely affected by hazardous substances. The measures to protect society include processes to control their safe manufacture, transportation, use and disposal. Policy responses for managing hazardous substances need to consider all these driving forces so as to reduce inputs, reduce the risks associated with chemical pollutants and facilitate societal change.

A – Activities

Many different activities onshore and in the marine ambit can introduce hazardous substances to the marine environment, particularly harbours and industry onshore, aquaculture, shipping, offshore oil and gas exploration at sea.

The activities that can potentially introduce hazardous substances into the marine environment are closely linked to urban population size, particular examples being power production, industrial activity wastewater treatment, transport and shipping. Other such activities not linked to urban areas are the use of biocides in agriculture, encompassing pesticides, herbicides, fungicides, etc, and dredging. Tourism can be linked to both urban and rural activities, trending probably towards larger cities for the majority of tourists.

The key human activities affecting levels of hazardous substances are:

Dredging for navigational purposes (physical restructuring of rivers, coastline or seabed): Many harbours, rivers, river mouths, estuaries and other near-coastal freshwater and marine areas accumulate contaminated sediment. The contamination may go back several decades, resulting from discharges into water by coastal or riverine industries, dumping of industrial and household waste, accidents involving the sinking of ships and loss of cargo at sea, leakage from landfills, dumped munitions, or simply the accumulation of contamination from boats (e.g., tributyltin, copper). Sediment contamination may be severe and will include persistent chemicals phased out decades ago, such as PCBs. The disturbance of sediments for maintenance or capital dredging activities has the potential to remobilize these contaminants. Remobilization can occur at all stages of the dredging process. The dredging itself can lead to the dispersal of contaminated sediment, depending on the technique used (e.g., conventional dredging with an excavator or suction dredging). Where dredged material is relocated to sea disposal sites, there will be some spread of material during the dumping process, typically 5-10%.

Dredging and the dumping of waste and other matters have been well regulated since the Oslo Convention came into force in 1974. OSPAR Guidelines specify best environmental practice (BEP) for managing dredged material, with the most recent version adopted in 2014 (OSPAR Agreement 2014-06). Sediment that is heavily contaminated is considered hazardous waste and must be deposited on land. Dredging is most extensive in countries where large, sediment-loaded rivers meet the ocean, such as the Netherlands, Belgium and France. Approximately 1 500 million tonnes of sediment are dredged in the OSPAR area annually, with the amount increasing slightly over the period 2008-2014 (OSPAR 2022).

Two vessels engaged in dredging. © Shutterstock

Non-renewable energy generation: Coal combustion in power plants is the most important source of atmospheric mercury, making up 65% of all anthropogenic mercury emissions to the atmosphere. For the entire OSPAR area combined, atmospheric mercury dominates the input of mercury into the ocean. This and other sectors like refineries and iron mills also discharge other heavy metals such as nickel, vanadium, arsenic, lead, selenium, chromium, and cadmium.

Extraction of non-living resources: The exploration and production of oil and gas utilises a range of chemical products (see OIC Thematic Assessment and Human Activity Thematic Assessment). During the drilling phase, drill cuttings which may be polluted by drilling fluids and hydrocarbons build up on the sea floor. The North Sea contains several million tons of such cutting piles, which can be the source of hydrocarbons and heavy metals. OSPAR has put measures in place to reduce the impacts of pollution by oil and/or other substances from cuttings piles (OSPAR Recommendation 2006/5) and to manage the use of organic-phase drilling fluids (OPF) and the discharge of OPF-contaminated cuttings (OSPAR Decision 2000/3).

During the production phase, the water in the oil/gas reservoir will contain traces of petroleum products and be released into the ocean after separation from the bulk petroleum. This is called produced water. After treatment to lower the content of unwanted components, the produced water can either be reinjected into a geological formation or discharged to the sea. Reinjection is considered the Best Environmental Practice, but is not always technically feasible, in which case the water must be discharged to the sea. This constitutes, by volume, the largest discharge from petroleum production (appx. 300 million m^3 annually in the OSPAR area; Beyer et al., 2020). These discharges contain dispersed crude oil, polycyclic aromatic hydrocarbons

(PAHs), alkylphenols (APs) and metals. The PAH compounds are a key risk element. Typically, total PAH water concentrations are 25–350 ng/L within 1 km downstream of a typical oil platform, and background PAH levels have reached 5-10 km downstream (Beyer et al., 2020). Fish samples generally contain low levels of PAH even in the North Sea, although metabolites indicating PAH exposure have been found in fish in the production intensive Tampen area on the northern border between Region I and II (Beyer et al., 2020). Future oil production in the Arctic could lead to similar constant oil pollution and the ensuing increased shipping in Arctic waters would increase the risk of shipping accidents.

Oil flaring can also introduce combustion products into the environment. The North Sea oil industry has low flaring intensity per barrel of oil (about 1/3 of the global average). For instance, Norway banned non-emergency flaring in 1971.

The extraction of sand and gravel could not only destroy habitats but also remobilise contaminants otherwise bound to undisturbed sediments. Mining with sea disposal of mining waste may also contribute to contamination, in particular mining for metals, as the fine-grained residue from the mining process will contain more metals. This practice occurs in Norway, but not with metal-rich ores (one copper mine with sea disposal is planned, but not yet active). Deep-sea mining for metals may also increase the dispersal of metals to the environment. The area between Svalbard and Jan Mayen has turned out to be rich in copper and zinc, and Norway began a process towards the possible opening of the seafloor areas for mineral extraction in 2019.

Extraction of living resource: Fish and shellfish harvesting by trawling have the potential to remobilise contaminants bound to sediments. Trawl doors weigh several tons and create furrows when dragged along the sea bottom; the North Sea especially is criss-crossed by such trawler tracks. Fishing-boat engines, as well as fish and shellfish processing, also have the potential to introduce hazardous substances.

Aquaculture – marine, including infrastructure: Aquaculture is an industry of major importance in some areas (e.g., salmon production in Norway, the Faroes and the United Kingdom, and shellfish production in Spain and France). Aquaculture cages are a substantial source of copper input, through leakage from the copper-based paint used for antifouling. Chemicals can be used as antifoulants or to clean facilities, and pharmaceuticals for the treatment or prevention of disease and parasites, especially the removal of salmon lice. In Norway, which has the largest aquaculture industry in OSPAR, several pharmaceuticals and treatment forms have been used over the years. Bathing treatments using organophosphate insecticides such as dichlorvos (until the early 1990s) and later azamethiphos were used extensively until the mid-2010s (Overton et al., 2019). During the 2000s, treatment using food pellets containing flubenzurons (diflubenzuron and teflubenzuron) and bathing treatments using pyrethroids (cypermethrin and deltamethrin), azamethiphos (an organophosphorous substance) and hydrogen peroxide gained popularity. Similar changes also occurred in Scotland during the period 2005-2011 (Murray, 2016). While hydrogen peroxide degrades relatively quickly, flubenzurons and pyrethroids degrade quite slowly and are poisonous to all crustaceans including non-target animals such as shrimp and lobster. Since 2015, the trend has been to make less use of pharmaceutical treatments and increased use of non-medicinal methods (mechanical or thermal delousing) (FHI 2022). In part, this is because of the evolution of resistance in salmon lice (especially to pyrethroids and azamethiphos). In shellfish production, usage of antibiotics such as tetracycline affects the aquatic environment and poses a threat to human beings as well.

Transport (infrastructure, shipping, air and land) Transport can introduce hazardous substances either directly (e.g., fuel combustion, antifoulants) or indirectly (e.g. leaks, poorly maintained vessels and equipment). The most obvious source is acute oil pollution episodes from either intentional oil discharges or ship accidents. In recent years, exhaust scrubbers have emerged as a new source of marine pollution. On 1 January 2020, the so-called IMO 2020 regulation came into force, reducing the upper limit of sulphur content in fuel oil from 3,50% to 0,50% globally. Some areas, including the North Sea, have an even stricter limit of 0,10%. However, it is acceptable to use fuel oil with a higher sulphur content but limit the air pollutants by installing exhaust gas cleaning systems (“scrubbers”). This has led to a huge increase in the use of exhaust scrubbers since 2018, mostly of the open-loop type which discharge the water used for scrubbing into the sea. A medium-sized ship (12 MW engine power) discharges approximately 500-1 000 m^3 of "used" water per hour. This water is contaminated by PAHs (e.g., naphthalene and phenanthrene) and metals (e.g., nickel and vanadium). The discharged water also has a very low pH (*ca*. 3), which may increase the toxicity effect of the contaminants. The open scrubbers prevent the atmospheric release of contaminants but instead directly discharge into the sea along shipping routes. Finally, ship paint containing copper (as an antifoulant) is a major source of copper input to marine areas with heavy maritime traffic, as well as to harbours.

Ships and leisure boats also use antifoulant paint to reduce biofouling (growth of marine organisms on the hull). While the use of tributyltin as an antifoulant is now banned, current antifoulants typically contain copper, and account for a substantial part of the input of that metal into the marine environment. Corrosion anodes are typically made of zinc with trace impurities of cadmium and lead.

Image A.2: The”Prøvestenen” oil depot south of Copenhagen Harbour. In 2008, a 200 m^3 oil spill from a broken transfer line, covering an area of 400x500m, threatened the beaches in both Copenhagen and Malmö, but was contained by Danish and Swedish anti-oil pollution vessels.

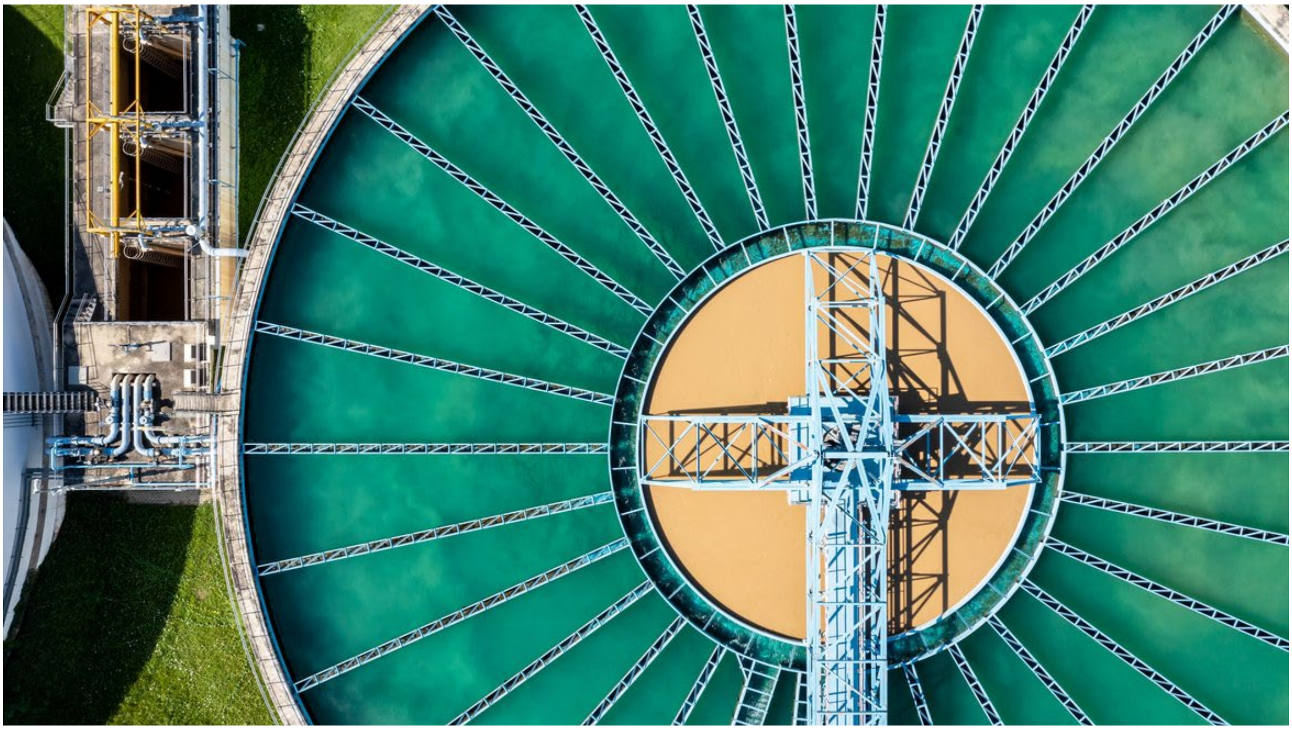
Local ferries and a coaster in the Great Belt, Denmark

Urban and **Industrial uses** - Society's need for trade and movement of goods, stable economies, industrial processes, materials, and health and well-being are drivers of industrial uses. Industrial atmospheric emissions and direct discharges into the sea can lead to the input of substances into the environment, and long-range transport can be a major contributor to the North Sea area. In the OSPAR area, as well as globally, discharges of substances like PAHs and PCBs from industry into the air and sea have been strongly reduced during recent decades.

However, other challenging substances remain in use. Perfluorinated alkyl substances (PFAS) are a group of substances manufactured or used in many industrial processes including metal plating, textile industries and the manufacturing of fluoropolymers. Long-chained PFAS such as PFOS and PFOA are known to be highly persistent, to accumulate in the ecosystem, and for their toxicity. While PFOS and PFOA historically were the most widely produced PFAS substances, they were phased out by European industry after 2005 and later placed under restrictions (PFOS by the Stockholm Convention in 2009; PFOA by the EU REACH regulation (Registration, Evaluation, Authorisation and Restriction of Chemicals) in 2019). However, there are over 4 000 PFAS substances on the market, and little is known about their toxicological effects and environmental fate. Some of these substances can also be transformed into PFOS or other PFAS known to be hazardous. Accordingly, the EU has recently proposed the banning of a wide range of PFAS substances.

Waste and disposal [Urban and industrial uses]: Society's need for health and well-being and for industrial goods and materials processing are drivers of waste treatment and disposal. Direct discharges can lead to the input of substances into the environment. In advanced wastewater treatment plants, co-precipitation of some contaminants will occur when phosphor is flocculated, and bacteria can degrade some organic contaminants, but more water-soluble and less degradable contaminants will not be retained. Wastewater treatment plants have been shown to be a major source of PFAS in some areas. Furthermore, plants where contaminated waste is treated appear to be important sources of PFAS.

Sewage is a major pathway for substances used in pharmaceutical and personal care products. More than 100 pharmaceuticals and pharmaceutical metabolites have been detected in coastal waters. The most frequent substances found are antibiotics, followed by non-steroidal anti-inflammatories and analgesics (Gaw et al., 2014). Pharmaceutical metabolites (i.e., the results of the body's metabolism of these substances) and transformation products can be present in higher concentrations than in the original substance and can also be more toxic (Gaw et al., 2014). Substances originating from personal care products (including soaps, sunscreens, insect/tick repellents and toothpaste) are also found in the environment, in some cases in concentrations large enough to have harmful effects on marine life (Hopkins and Blaney 2016, EU 2016). Wastewater treatment may remove 10-100% of pharmaceuticals and personal care product substances, depending on the properties of the substance and the treatment technology used (Gaw et al., 2014, Hopkins and Blaney 2016).



Aerial view of purification tanks of wastewater treatment plant. ©Shutterstock

Tourism and leisure: Tourism is linked to several of the other activities, and in particular is responsible for a large part of the transport component. Recreational boating is linked to a substantial part of the usage of antifoulant paints, which typically contains copper that leaks into the environment. Poorly maintained vessels have the potential to introduce other hazardous substances such as TBTs and petroleum products.

Agriculture [Cultivation of living resources]: Society's need for food drives the need for agriculture. Agricultural run-off can lead to the input of substances to the environment, such as pesticides and micronutrients used in fields, and growth promoters. The agricultural sector has a long history of using persistent herbicides and pesticides, some of which eventually end up in the marine environment. Many of these substances, such as DDT and organophosphates, have been banned in the OSPAR area since the 1970s-1980s but can still be detected in marine life in many locations. In some places, DDT has been found to increase in shellfish, and this has been linked to DDT mobilisation in the soil owing to increased precipitation (which again is possibly linked to climate change). Older, more toxic insecticides such as organophosphates were replaced by neonicotinoids in the early 1990s (Hladik et al., 2018), but these substances also ended up in the marine environment in concentrations large enough to be a threat in some coastal areas. As a result, the three main neonicotinoids (clothianidin, imidacloprid, and thiamethoxam) were banned in the EU in 2018, but have sometimes been legalised for certain uses (sugar-beet crops).

P – Pressures

The pressures from some contaminants are increasing in several places, as seen in the upward time trends. Elsewhere, the decreases from previous quality assessments have slowed or stopped.

Input of other substances (e.g., synthetic substances, non-synthetic substances, radionuclides) - diffuse sources, point sources, atmospheric deposition, acute events: Human activities can introduce a range of hazardous substances (**Figure P.1**). Radionuclides are assessed in the Radioactive Substances thematic assessment. The pressures associated with synthetic substances and non-synthetic substances relate to increasing levels of contaminants in sediment (PBDE, PAH, PCB, metals, organotins, etc.) and in biota (PBDE, PAH, PCB, metals, organotins, PFAS, etc.). An overview of uses and sources leading to the pressure for each hazardous substance covered is shown in **Table P.1**.

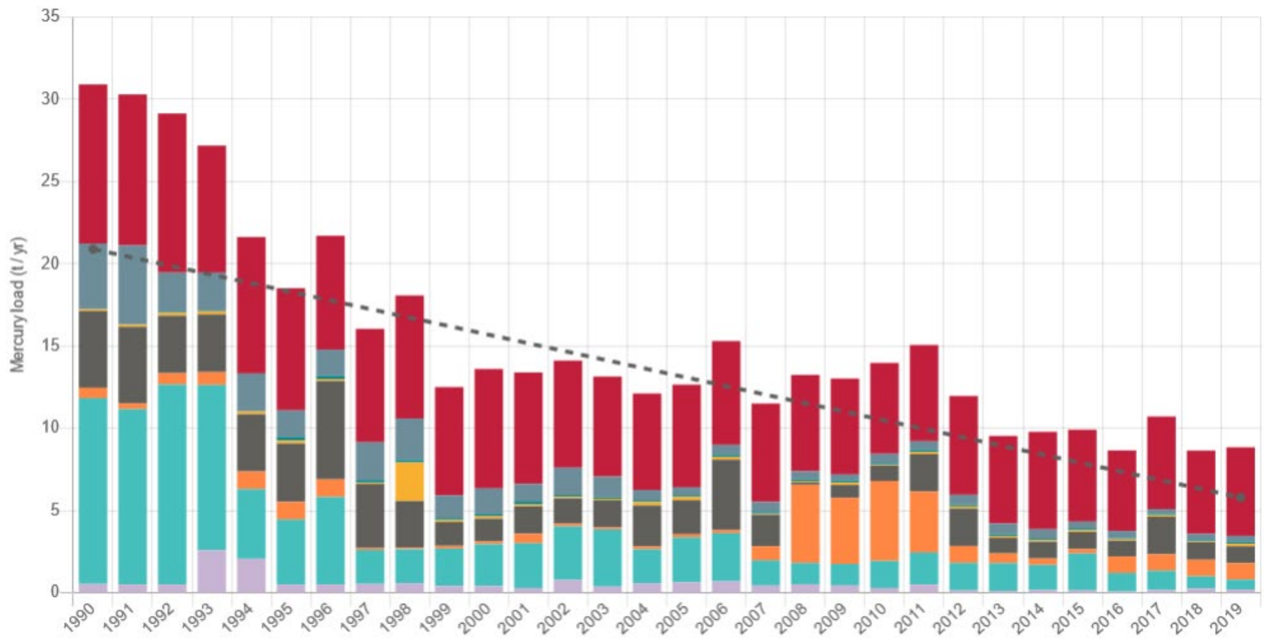


Figure P.1: Example of mercury input to the North Sea

The OSPAR 'other assessment' of atmospheric and riverine inputs describes the pathways by which these hazardous substances enter the marine environment. The Offshore Industry Committee thematic assessment and Human Activities thematic assessment provide further details on the mechanisms by which human activities contribute to hazardous substance pressures. These hazardous substances can lead to changes in biodiversity state through effects on mortality, reduced breeding success and species fitness (see Benthic Habitats Thematic Assessment, Fish Thematic Assessment, Marine Birds Thematic Assessment and Marine Mammals Thematic Assessment).

Generally, there has been no development or improvement over the last 10 years in most OSPAR Regions, indicating that the pressures are stable for hazardous substances in sediment and biota. For some individual hazardous substances, the trends are still edging downwards, but at a very low rate per year, sometimes because of concentration levels close to the detection limits, but for other substances increasing trends are found, contrary to the overall status of Regions.

Table P.1: Uses and sources of hazardous substances

PBDE	Historically used as flame retardant, mainly in electronics, clothing and furniture. PBDEs are man-made substances manufactured as groups of PBDEs with different properties.
PAH	Combustion products from fossil fuels. Also associated with shipping fuel leaks/spills as well as produced water discharged from oil and gas platforms and applications of coal tar and creosote. Naturally occurring in tar-pits and geological formations.
PCB	Wide variety of uses, historically mainly as insulator oil in transformers, but also including electrical switch gears and plasticisers.
Tributyltin and other organotins	Historic main use as antifoulant on boat/ship hulls – cause imposex; other uses include antifungals in farming and clothing. Man-made substances not naturally occurring.
Arsenic	Alloy to strengthen copper and lead, e.g., in car batteries and in electronics as doping material in integrated circuit and transistors. Used in pesticides, insecticides, and pharmaceuticals.
Cadmium	Historically used in rechargeable batteries, anticorrosion, currently mainly as minor constituents of other metal ores like zinc and iron.
Chromium	Corrosion-resistant finish on iron, different alloys for high strength steel.
Copper	Used as antifoulant on boat / ship hulls and sea farm pens – still in use. Gutter and roof material, water pipes, different alloys including bronze, mined since the Bronze Age, and brass.
Mercury	Historically used in dental products, thermometers, batteries, paper industries as floating anode. Currently mainly used in artisanal mining and released from coal burning.
Nickel	Part of alloy often used for jewellery, zippers and other clothes and footwear related metal parts. Also in non-corroding steel, magnets, coins and electronics.
Lead	Historically one of the first metals used for water tubing. From 1922 to 2022 main uses include methyllead-fuel additive, roofing, electrical wiring, fishing gear, ammunition, plastic additive.
Zinc	Building material for e.g., gutters, roofing, sacrificial anodes on ships and marine structures, household products, personal care products and alloys such as brass.
PFAS	A large group of substances used as flame retardants in firefighter foams, non-stick coating on cookware, waterproofing for shoes, and for various other purposes including on clothing

Given the restrictions on the use of a wide range of chemicals, the expectation was that most areas would be found to have a decreasing impact (good status) (**Table P.2**). However, only for the Irish Sea and Iberian Coast sub-regions in Regions III and IV is a decreasing impact on sediments indicated, and for the Irish Sea also biota, whereas for Region II, the Southern North Sea biota impact is increasing; for sediments, decreasing levels have been observed for both the Southern North Sea and the English Channel. This could indicate an increase in the bioavailability of contaminants and reduced sedimentation or the re-release from sediment of buried contaminants.

Table P.2: Status of Regions based on OHAT model and confidence for the number of stations/time trends for each Region; this is a fair estimate of the confidence for each assessment

OSPAR Region	Arctic Waters (Region I)	Greater North Sea (Region II)	Celtic Seas (Region III)	Bay of Biscay and Iberian Coast (Region IV)	Wider Atlantic (Region V)
Status	Stable	Poor/Stable	Stable	Stable medium	Not enough data
Confidence	Medium	High	High	Medium	
Basis	High agreement, medium evidence)	Southern part more densely populated Poor, northern part with fewer inhabitants stable Medium agreement, robust evidence	Medium agreement, robust evidence	Medium agreement, medium evidence	

The pressures from **Physical disturbance to seabed** and **Changes to hydrological conditions** both have the potential to (re)mobilise hazardous substances adsorbed to sediments, making them available to affect biota. These hazardous substances are associated with historic pollution events.

S – State

The state of the environment is poor in areas with high population and industrialisation levels, particularly because of mercury and PBDE, when current concentration levels are compared with assessment criteria for areas where no harm to the environment is expected.

The comparison of hazardous substances with assessment criteria indicates a low impact by hazardous substances in the sparsely populated areas of Regions I and III (**Table S.1**), whereas the more densely populated and industrial areas of Regions II and IV are at levels where impact from hazardous substances cannot be excluded.

Table S.1: Status of Regions based on OHAT model and confidence for the number of stations/time trends for each Region; this is a fair estimate of the confidence for each assessment

OSPAR Region	Arctic Waters (Region I)	Greater North Sea (Region II)	Celtic Seas (Region III)	Bay of Biscay and Iberian Coast (Region IV)	Wider Atlantic (Region V)
Status	Good	Poor	Good	Poor	Not enough data
Confidence	Low	High	Medium	Medium	
Basis	Medium agreement, limited evidence)	Medium agreement, robust evidence	Medium agreement, medium evidence	Medium agreement, limited evidence	

Integrated assessment using CHASE (State)

A mathematical method, CHASE, was used to make an integrated assessment of sediment and biota based on several indicators. Following this analysis, the status was classified as either good (contaminant concentrations well below EQS thresholds) or poor (one contaminant has concentrations above EQS, or several contaminants are very close to EQS). Time trends were also assessed. (For more details on method and results, refer to the CHASE Assessment)

For sediment, about half of the Regions have a good status using this method (**Table S.2**). Among the Regions with poor status, the Irish Sea may possibly progress from poor to good environmental status during the next 10-20 years, while in the others, either no significant improvement can be detected or improvement is too slow to lead to a change in status in the foreseeable future. No Regions with currently good status are in danger of taking on poor status. The main substances that lead to overall poor contamination status are mercury, lead and, in one case, CB118.

For biota, only two out of twelve Regions have good status (**Table S.2**). Again, the Irish Sea may possibly progress from poor to good environmental status during the next 10 years; for most other Regions, there is no evidence of improving status. The main culprits causing poor status in most parts of the Regions are mercury and CB118. Also, mercury is the main reason for the lack of improvement, as mercury concentrations, with few exceptions, are either increasing (Southern North Sea, English Channel) or stable.

Table S.2: Summary of CHASE integrated analyses of status in 2020, as well as predicted status in 2030 if current trends continue. A hyphen indicates that there were not enough data for the analysis. The sub-regions Barents Sea, Norwegian Sea, Norwegian Trench and Gulf of Cadiz did not present enough data for any integrated analysis. For more details, see "Other assessment – CHASE"

	Sediment		**Biota**	
	Status 2020	**Pred.2030**	**Status 2020**	**Pred.2030**
Region I - Arctic Waters				
Greenland-Scotland ridge	-	-	Good	Good
Region II - Greater North Sea				
Northern North Sea	Good	Good	Poor	Poor
Skagerrak and Kattegat	-	-	Poor	Poor
Southern North Sea	Poor	Closer to good	Poor	Farther from good
English Channel	Poor	Poor	Poor	Farther from good
Region III - Celtic Seas				
Irish and Scottish West Coast	Good *	Good	Close to Good	Close to Good
Irish Sea	Poor	Possibly good	Poor	Closer to good
Celtic Sea	-	-	Poor	Close to Good
Region IV – Bay of Biscay and Iberian Coast				
Northern Bay of Biscay	-	-	Poor	Farther from good
Iberian Coast	Good	-	Poor	Closer to good

* The point estimate indicates “good” status, but "poor" is not outside the 95% confidence limits

Individual indicator assessments (State):

- PCBs

Polychlorinated biphenyls (PCBs) were banned in many countries in the mid-1980s. Although local problems remain, PCB concentrations in sediment and biota have decreased in most OSPAR assessment areas. Except for the most toxic congener (CB118), concentrations are below the level at which they could present an unacceptable risk to the environment.

The high bioaccumulation rate leads to very high concentrations in marine mammals and birds. The PCB concentration ranges found in the tissues of marine mammals generally show decreasing trends between the 1970s and 2010s. However, small toothed whales and pinnipeds still present PCB levels surpassing the proposed toxicity thresholds.

- PAHs

Although mean concentrations of polycyclic aromatic hydrocarbons (PAHs) in shellfish and sediment, and of PAH bile metabolites in fish are above background concentrations in most assessed areas, they are below levels likely to harm marine species. Concentrations are decreasing or stable in all but one (Irish and Scottish West Coast sediment) of the areas assessed.

- PBDEs

Biota sites have good geographical coverage, sediment sites are more limited. PBDEs in sediment and biota have been stable (54% of assessed areas) or declining (46%) for the past 20 years. Concentrations are below thresholds (FEQGs) for all assessment areas and congeners, except BDE209 in Irish Sea sediment, and should not cause adverse effects to marine wildlife.

- Metals

In most areas, concentrations of lead and mercury in fish and shellfish are above background levels and mercury is above the environmental threshold. Despite bans, concentrations in biota are mostly increasing, particularly in Region II. Concentrations in sediments are often above the environmental thresholds but decreasing in most sub-regions.

- Organotins

Following the bans on the use of tributyltin in antifouling paints there has been a marked improvement in the reproductive condition of marine snails since QSR 2010 over the assessment period 2008–2020. Mean concentrations in sediment have measurably reduced, at the rate of approximately -10% per year, in the Southern North Sea, but no monitoring station is yet significantly below the EQS value proposed by Sweden of 0,8 µg kg^{-1} at 2,5% OC (see: Background document on Tributlytin (TBT) in sediment, Swedish Quality Standard) assessment criteria, which in many cases are below the detection limits of the methods used for analysis. Normalisation is not employed all over the OSPAR Region. The need for follow-up of the situation is still apparent.

I – Impact (on Ecosystem Services)

The impact on ecosystem services from current levels of hazardous substances in the OSPAR Maritime Area

There is evidence that current levels of hazardous substances impact the reproduction of sea mammals to a smaller or larger degree, and several European sea mammal populations may become extinct. This affects several ecosystem services. At the more local scale, several fish populations are too contaminated for human consumption.

Environmental impacts:

- The pressures from human activities collectively contribute to the presence of hazardous substances in sediments and biota and lead to measurable biological effects, either when measured directly as a biological response or through contaminant concentration levels in biological tissues and comparison with an Environmental Quality Standard (EQS) value where no effects on Benthic Habitats or Fish, are expected:
  - **Hormonal and behavioural changes** due to hormonal/ chemical imbalance: In marine mammals, PCBs show toxic effects such as immunosuppression, endocrine disruption, reproductive impairment and reduced lifespan.
  - **Reduced species fitness** is a general trait of poisoning, as the body of the marine organism tries to counter the toxic effect of the contaminant, thereby reducing the energy available for ordinary functions like feeding, growth and reproduction. Examples are PAH in fish, which have a metabolic system that transforms the PAHs to a less toxic form that can be more readily excreted (PAH, PCB and dioxins are known to be detoxified by fish via the EROD system (7-ethoxyresorufin O-deethylase activity). Other biological and physical factors like species, sex, reproductive status, season and environmental temperature can also affect the EROD system. In shellfish, the glutathione sulfhydryl transferase (GST) enzyme is activated by PCBs to reduce toxicity by removing chlorine. In fish blood, detoxification of lead increases the production of ALA-D (δ-aminolevulinic acid dehydratase).
  - **Reduced breeding success**: The effects of organotins on female marine snails, measured as imposex, impede breeding success as the ovaries become increasingly blocked; for the most sensitive species the end-point is sterility. In live breeding Eelpouts, fry in the womb have been seen to have a higher fraction of malformation with higher doses of a wide range of contaminants.
  - **Mortality** is observed for many contaminants at high concentrations. Acute toxicity in water is expressed as LD50, where 50% of the most sensitive species dies from exposure to the contaminant. Biota EQS values are set on the basis of sub-lethal effects (EC10 or NOEC), with an additional assessment factor to take into account that a limited set of species has been tested. Acute toxicity usually occurs at much higher concentration levels than the EQS thresholds and is thought to be relatively uncommon.

The environmental impacts from hazardous substances also exert pressure on ecosystem services (ES), with important implications for human welfare, by impacting negatively on economic sectors such as recreation, tourism, fisheries and aquaculture and inflicting economic losses on individuals, enterprises and communities.

Impact on ecosystem services through decline or extinction of marine populations

The most obvious instance of hazardous substances causing the extinction of marine organisms is the effect of TBT on marine snails. This has led to the extinction of dog whelk in large parts of the Southern North Sea. Although TBT pollution has decreased greatly, this species has still not recovered in many areas, and this affects the entire ecosystem (e.g., bird populations). Another example is the effect of PCBs on marine mammals. Again, pollution by this class of contaminants has decreased greatly in sediments and in the lower trophic levels of the food web, but is stable or increasing in many marine mammal populations. As a result, the killer whale populations of the Canary Islands, Greenland, the Strait of Gibraltar, and the United Kingdom are at high risk of collapse over the coming 100 years (Desforges *et al*., 2018). In both cases, a significant component of the ecosystem is lost, affecting the regulation and maintenance of marine food webs negatively. For most marine populations, for example most fish stocks, there is no hard evidence that hazardous substances contribute to population decline. However, in most of the OSPAR area, levels of mercury are known to be high enough to have deleterious effects on organisms. Also, little is known about the mixture effects (simultaneous exposure to a multitude of hazardous substances) and population fitness effects arising from sub-lethal doses of contaminants, i.e., the behavioural effects of pharmaceuticals (Orive et al., 2022).

Impact on harvesting for commercial or leisure purposes

In many localised areas (fjords, bays, and estuaries) the concentrations of toxins (especially mercury and PCBs) in fish and seafood are too high for human consumption, and it is illegal to sell locally caught fish. This impacts local businesses. In other cases, selling local fish is allowed but the food authorities advise part of the population (e.g., pregnant women) not to eat local seafood. This may also affect commercial fishing, as well as have a negative impact on cultural services: the existence of official advice against eating local fish may lead to a feeling of loss of natural heritage because the ecosystem no longer appears pristine and clean.

Other possible, but uncertain, impacts on ecosystem services:

- **Water quality regulation:** Lethal and/or sub-lethal effects related to hazardous substances can impair to varying degrees the ability of marine ecosystem components to provide water quality regulation, for example through the death of components such as reefs, and the death of or adverse effects on invertebrate organisms such as mussels, given their contribution to water filtration.
- **Sediment quality regulation:** Lethal and/or sub-lethal effects related to hazardous substances can impair to varying degrees the ability of marine ecosystem components to provide sediment quality regulation, for example through the death of components such as reefs, and the death of or adverse effects on invertebrate organisms such as mussels, given their contribution to water filtration.
- **Nursery population and habitat maintenance:** Hazardous substances exert mainly negative impacts on the provision of this service by affecting species of biodiversity importance, such as corals, biogenic reefs, sand eels, and those of commercial importance, such as lobster, crab, cod and mackerel, leading to changes in the assemblages of such species (e.g., more short-lived species).
- **Coastal protection:** Considering the contribution of biotic elements such as coral reefs, microphytobenthos, kelp forests and infauna to processes such as erosion control, and thus to coastal protection, their degradation and possible death as a result of exposure to or ingestion of hazardous substances potentially compromise the provision of this ecosystem service.
- **Global climate regulation:** Marine ecosystems help to regulate the chemical composition of the atmosphere and the ocean, affecting the local and global climate through the accumulation and retention of carbon dioxide and other GHGs (e.g., methane, nitrous oxide).

R – Response

Many regulations have been put in place to prevent contamination, both internationally by OSPAR and the EU, and nationally by each Contracting Party. Changes in public behaviour and industrial practices also play a role (**Table R.1**).

OSPAR measures. The OSPAR Convention and its predecessors (the 1972 Oslo Convention and the 1974 Paris Convention) were the first international agreements on marine contamination. Under the Paris Convention, the Contracting Parties agreed to eliminate pollution by several substances (including organohalogen compounds, mercury, and cadmium) and to limit several other substances such as lead, arsenic, and copper. For offshore chemicals, a harmonised mandatory control system for offshore chemicals (HMCS) was first adopted in 1996 and promoted the continued shift towards the use of less hazardous substances in the petroleum industry. Within OSPAR, initiatives are taking place to bring this regulation in line with the European REACH regulation (see: Offshore Industry Thematic Assessment Response section).

EU regulations. EU regulations have become increasingly important and effective. Since 2006, the REACH regulation has ensured that manufacturers, importers, and customers are aware of the health and safety impact of products supplied. This allows retailers to work with the manufacturing base to substitute or remove potentially harmful substances from products. The Water Framework Directive (2000) set water and biota standards with thresholds from 2008, applying pressure on Member States to decrease pollution. Some classes of substances have also been regulated or banned at the EU level, such as PBDEs. Several EU Members are currently proposing to prohibit PFAS.

Global treaties. The most important global treaties on contamination are the Stockholm Convention on Persistent Organic Pollutants (effective from 2004), the International Convention on the Control of Harmful Anti-fouling Systems on Ships (which calls for a global prohibition of organotins by 2008) and the Minamata Convention on Mercury (which entered into force in 2017).

National legislation. In many cases, national legislation has regulated or banned chemicals before legislation is brought in at the international level, as with the restrictions on the use of PCBs in the 1970s and 1980s. Another example is the restrictions imposed on the use of neonicotiniods in some EU countries before the main neonicotinoids were banned in the EU from the end of 2018.

Table R.2: Legislation and recommendations/agreements for reducing inputs of hazardous substances

PBDE	The use of pentaBDE and octaBDE mixtures was banned in the European Union in 2004. Under the Stockholm Convention, TetraBDE, pentaBDE, hexaBDE and heptaBDE were regulated in 2009 and decaBDE in 2017.
Hydrocarbons and PAHs	PARCOM Recommendations: 1981 on the Production, collection, regeneration and disposal of waste oils; 1987 on Discharges from reception facilities and oil terminals. In the mid-2000s harmonised reporting and analysis methods were agreed by OSPAR, leading to the 2010 Recommendation on the Prevention of significant acute oil pollution […], and in 2017 to agreement on monitoring guidelines for the environmental impact of offshore oil and gas activities.
PCB	Restrictions in use during the 1980s through the Stockholm Convention. PARCOM Decision in 1992 on the phasing-out of PCBs and hazardous PCB substitutes.
Organotins	Banned locally on pleasure boats from 1980s, ratified IMO ban from 2008, a few Caribbean countries had still not ratified IMO ban in 2022.
Arsenic	
Cadmium	Paris Convention from 1974 reduced land inputs; a number of recommendations for reducing cadmium pollutions issued in the 1980s, followed by further OSPAR agreement on programmes and measures for mercury and cadmium batteries in 1990 (PARCOM Decision 90/2)
Chromium	
Copper	OSPAR Best Environmental Practice for the Primary Non-Ferrous Metal Industry 1998
Mercury	Step-wise usage bans in OSPAR area from 1974 Paris Convention; a range of agreements during the 1980s banning use of mercury in dental products, thermometers and batteries and limiting water-borne emissions; then expansion in the 1990s and 2000s with more restrictions on crematoriums and paper industries. Worldwide Minamata Convention signed in 2013, aimed at working towards total ban on mining of mercury by 2020.

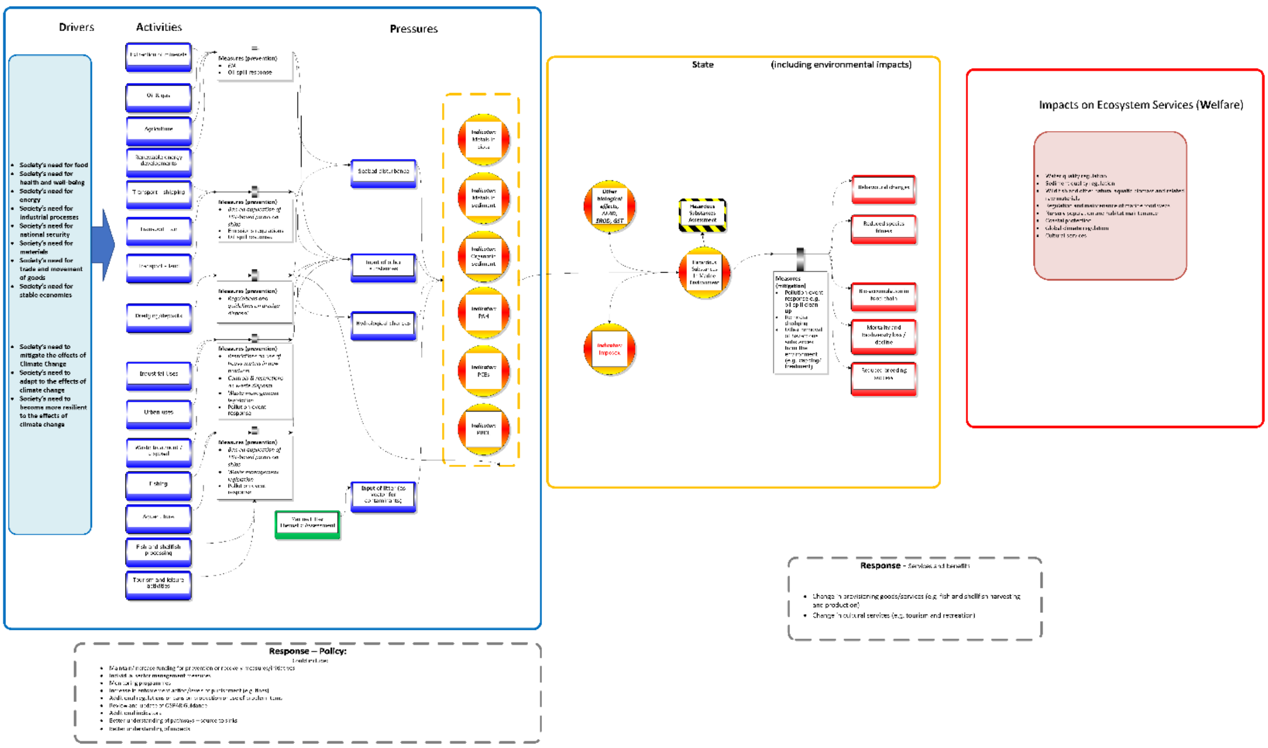
Nickel	OSPAR Best Environmental Practice for the Primary Non-Ferrous Metal Industry 1998
Lead	OSPAR Best Environmental Practice for the Primary Non-Ferrous Metal Industry 1998 Ban on leaded fuels effective worldwide except in African continent during 1990s; finally phased out worldwide in 2022.
Zinc	OSPAR Best Environmental Practice for the Primary Non-Ferrous Metal Industry 1998
PFAS	EU phase-out of 200 PFAS substances in 2021, aiming for a general ban later.
Dredging	1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (updated by London Protocols of 1996 and 2006) 1984 OSCOM Selection and Monitoring of Dumping Grounds 1986 OSCOM Control of the Execution of Dumping Operations at Sea 1989 OSPAR Monitoring of Dumping Grounds OSPAR collects yearly information on dumping at sea using the OSPAR Reporting Format for Dumping at Sea, last revised in 2018.

Are these measures working?

Given the declines in the determinants being measured, they do appear to be working to some degree, but sources of contaminants still exist and their extent is still great enough to have an impact.

Human activities and their associated pressures should see new / improved measures be applied / prioritised, e.g., in waste disposal. Coastal development could disturb seabed sediment (e.g., through dredging of contaminated sediments from shipping lanes and harbours).

Cumulative Effects



The bow-tie diagram aligns with the DAPSIR narrative in the Thematic Assessment. Provisional confidence assessment: Medium (Medium Agreement on DAPSIR content + Medium Evidence to support connections) based on the approach described in Agreement 2019-02.

The bow-tie analysis for hazardous substances shows the relationships between the DAPSIR components which need to be considered in a cumulative effects assessment. Some Thematic Assessments have identified human activities which contribute to hazardous substance pressures that have the potential to contribute individually and cumulatively to biodiversity state changes. These Thematic Assessments concern:

Benthic Habitats: Input of other substances. Human activities can introduce a range of hazardous substances and pressures relating to increasing levels of contaminants in sediment (e.g., PBDE, PAH, PCB, metals, organotins), in biota (PBDE, PAH, PCB, metals, organotins, etc). These can lead to changes in state through effects on mortality, reduced breeding success and species fitness, or loss of most sensitive species (e.g., marine snails due to organotin).

Fish; Input of other substances. Synthetic substances and non-synthetic substances can cause physical harm to fish. Fish populations in freshwater environments face the most acute threat of chemical contamination, for example by metals, as a result of industrial or mining activities; these can lead to local population extinctions (Hamilton et al., 2016). In the marine environment, chemical contamination is a threat in coastal fisheries where pollutant levels are highest, particularly from oil run-off, production and transportation; petroleum; heavy metal contamination; and synthetic substances from agriculture and urbanisation (e.g., pharmaceuticals in sewage) (Hamilton et al., 2016). Food web transfer and bioaccumulation of pollutants in fish tissues (e.g., metals, persistent organic pollutants and organochlorine contaminants) can adversely impact fish in all aquatic environments in terms of reproduction, development and/or survival of offspring, and cause population declines (Hamilton et al., 2016).

Marine Birds; Input of other substances. In bird species, the input of other substances into their environment can cause contamination of the food web. Examples:

Polybrominated diphenyl ethers (PBDE) contamination in biota can impact behaviour, learning and hormonal function.

Polychlorinated biphenyl (PCB) concentrations in biota can cause genotoxic effects, immune suppression, inflammatory response and endocrine effects.

Eggshell thickening leads to reduced hatching.

PBDE and PCB both cause reduced reproduction and bioaccumulation in benthic, fish, bird and mammal species.

Marine Mammals; Input of other substances. Synthetic substances and non-synthetic substances can cause physical harm to marine mammals. Marine mammals are often predators at the top of the food web, and are sensitive to bioaccumulation, whereby toxic contaminants build up throughout the food web, with the highest concentration found in its top predators. Examples:

PCBs can lead to reduced reproduction success or complete failure of the reproductive organs. Some contaminants in high amount can even cause death.

Mercury can cause the formation of cancer, decreased learning abilities and damage to the nervous system.

Lead is highly toxic and can cause cancer and decreased learning ability.

Cadmium can also cause cancer and further reduces bone strength.

Other persistent organic pollutants, such as PBDEs, can be found in high concentration in marine mammals. While the decreased fecundity in those species has not yet been attributed to these substances, they have known effects on other species.

These all potentially cumulatively impact the abundance, demography, and distribution of marine mammals.

The State section describes the potential ecological impacts associated with hazardous substances in the marine environment. Input levels, frequency of occurrence, spatial extent, and exposure to different human activities all collectively contribute to the extent to which hazardous substances pressures are exerted on benthic habitats, fish, marine birds and marine mammals. To undertake a full quantitative analysis of cumulative effects requires consideration of the exposure pathways and ecological impacts. Further analyses and evidence of ecological impacts are required in order to progress the assessment of cumulative effects.

Hazardous substances can also combine with other pressures to collectively affect marine species and habitats. The assessment of cumulative effects is considered in the biodiversity thematic assessments (Benthic Habitats, Fish, Marine Bird and Marine Mammal Thematic Assessments).

Climate Change

The QSR 2010 did not include any climate change issues in relation to hazardous substances. The Climate Change Thematic Assessment in this QSR places hazardous substances into the more general framework of climate change effects.

In general, temperature increases result in higher chemical reaction rates and could therefore lead to higher biological uptake, because of the higher growth rate in warmer waters and the higher reaction rates for contaminants. As a rule of thumb, an increase of 10˚C roughly doubles the reaction rates, so the expected temperature increase of around 2˚C would increase reaction rates by about 20%. Increased temperature alone has been shown to affect the volatilisation of pesticides and of POPs such as Dioxins, DDT, PCDD/Fs, PCBs and PAHs, but also degradation (e.g., hydrolysation of pesticides), thereby increasing global mobility and transportability (Kibria et al., 2021). The side effect of temperature rise is more rain, which leads to floods and higher run-offs of metals and POPs. Another side effect is the introduction of pest species in agricultural land, which can increase demand for pesticides in colder regions and thus increase their run-off to the marine environment. Finally, increased wind speeds and storms lead to the erosion of coastal landfill sites, the resuspension of coastal sediments and the erosion of coastline in general, releasing the hazardous substances they store into the marine environment.

Decreasing pH in seawater could lead to higher release of metals from sediment– since most metals are more soluble at lower pH– into the water phase and the biological community. The effects would probably not be great, given that most seawaters are above pH 7,5 and thus not inherently acidic. The pH change would most likely mainly be a problem in freshwater, where there is low buffer capacity.

For mercury, it has been suggested that the increasing temperatures, with related increasing hypoxia, forest fires and reduced ocean circulation, will increase methylmercury production in sediments, leading to higher releases from anoxic sediments to the overlying water columns. Forest fires increase the release of mercury stored in soils on land, and higher atmospheric residence time and winds increase the long-range transportation of mercury from tropical and subtropical regions to the Arctic regions (Krabbenhoft and Sunderland, 2013; Kibria *et al.*, 2021).

The risks posed by climate change induced increases in pressures and contaminant concentration levels are reducing the effects of the efforts to reduce inputs, particularly that from the historic contaminants stored in sediments. These could be a contributing factor in inhibiting progress towards better status in the marine environment where the effects of hazardous substances are concerned.

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Thematic Metadata

Field	Data Type	Explanation
Linkage	URL	https://www.amap.no/documents/doc/amap-assessment-2021-mercury-in-the-arctic-uncorrected-proofing-draft/3581 https://www.unep.org/news-and-stories/press-release/era-leaded-petrol-over-eliminating-major-threat-human-and-planetary
Relevant OSPAR Documentation	Text	OSPAR Recommendation 2006-02 Amending OSPAR Recommendation 2003/4 on Controlling the Dispersal of Mercury from Crematoria OSPAR Agreement 2014-06 Guidelines for the Management of Dredged Material at Sea OSPAR Recommendation 2006-05 on a Management Regime for Offshore Cuttings Piles OSPAR Decision 2000-03 on the Use of Organic-Phase Drilling Fluids (OPF) and the Discharge of OPF-Contaminated Cuttings OSPAR Recommendation 2010-18 on the prevention of significant acute oil pollution from offshore drilling activities Agreement 2016-04 CEMP guidelines for coordinated monitoring for hazardous substances

OSPAR's Quality Status Report 2023

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Our vision is a clean, healthy and biologically diverse North-East Atlantic Ocean, which is productive, used sustainably and resilient to climate change and ocean acidification.

Publication Number: 986/2022