Inputs of Mercury, Cadmium and Lead via Water and Air to the OSPAR Maritime Area

Common Indicator Assessment

OSPAR

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OSPAR's Quality Status Report 2023

Inputs of Mercury, Cadmium and Lead via Water and Air to the OSPAR Maritime Area

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Citation

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Contents

Key Message

Total inputs of the heavy metals mercury, cadmium and lead have reduced since 1990. However, improved analytical procedures for mercury and cadmium since 1990 make it difficult to be certain what proportion of observed changes are due to reduced discharges and emissions.

Background (brief)

OSPAR's strategic objective from NEAES 2030 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 with the ultimate aim of achieving and maintaining concentrations in the marine environment at near background values for naturally occurring hazardous substances and close to zero for human made hazardous substances. Heavy metals are hazardous because they can cause adverse biological effects on an organism's activity, growth, metabolism, reproduction, or survival. Three of the most toxic heavy metals – mercury, cadmium, and lead – are on OSPAR's List of Chemicals for Priority Action owing to their high toxicity and potential to cause harm to marine life.

Mercury, cadmium, and lead are emitted through a range of natural, industrial, and agricultural processes, for example fertiliser can be a source of cadmium (**Figure 1**). Heavy metals are most often transported as, or tightly bound to, fine particles and the particles can be blown into the air from exposed soils and earth, and also from the surface of the sea. As a result, heavy metals are subsequently transported via the atmosphere. Unlike other heavy metals, mercury can also evaporate and be transported as a gas. In addition, mercury and cadmium can accumulate in the food chain (**Figure 2**), whereas lead does not.

Waterborne inputs of mercury, cadmium and lead are monitored by OSPAR countries. Atmospheric inputs are modelled by OSPAR countries (**Figure 3**), based on annual emissions reported under European Union Emissions Directives and the United Nations Convention on Long-range Transboundary Air Pollution.

Figure 1: Mineral fertiliser is a significant source of cadmium in many parts of Europe. © https://www.shutterstock.com

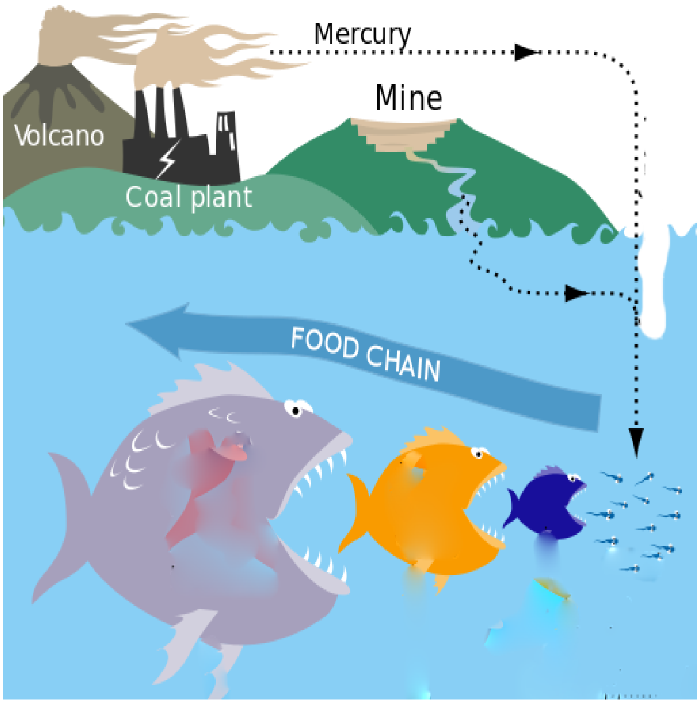

Figure 2: Mercury from coal-fired power plants and other sources is transported through the atmosphere and water. Mercury, in the form of methylmercury, can bioaccumulate through the marine food web reaching high concentrations in top predators

Figure 3: An atmospheric monitoring station. © https://www.shutterstock.com

Background (extended)

The effects of high levels of heavy metals on humans can include: decreased learning ability (lead, mercury); reduced bone strength (cadmium), and damage to the central nervous system (mercury, lead). This has resulted in restrictions on most uses of heavy metals and strict bans on mercury use. Mercury and cadmium accumulate in the food chain and are considered the most toxic heavy metals.

In the Roman Empire, lead was used for water pipes, as a sweetener in wine (lead-acetate) and as colouring for skin-cream. In modern times, it has been used in car batteries and until 2000 in leaded petrol for motor vehicles, as an engine lubricant and anti-knock agent. This was the main source of lead pollution in air and water during the 1970s until its ban (Larsen *et al.,* 2012). It has also been used as a softener in poly(vinyl chloride) (PVC) piping and insulation. Mercury was used in medicine as an antibacterial agent, and as a liquid anode in electrolysis in the paper industry. It has also been used in dental fillings, in thermometers and other scientific instruments. The Minamata Convention is an international global legally binding instrument banning the use of mercury, which was adopted in 2013 and entered into force on 16 August 2017 with 128 parties ratifying the Convention by 2021. Mercury has uses as a liquid anode in electrolysis in the paper and chlor-alkali industry. Mercury use in chlor-alkali factories is subject to OSPAR Recommendations and EU regulations which have resulted in the adoption of other techniques.

Figure a: Amalgam filling containing mercury. OSPAR works to reduce mercury losses from dentistry and also atmospheric mercury from crematoria *https://commons.wikimedia.org/wiki/File:Filling.jpg?uselang=en (Author: Kauzio, Wikimedia Commons) .*

Cadmium is used in batteries and electronics, and previously in certain red paints and plastics. It is found in minerals mined for zinc, copper and lead and is a minor constituent of all products of these metals. As it is taken up from soil by plants, it is also concentrated in plants, especially tobacco leaves, sunflower, and linseed.

Both mercury and cadmium are suspected carcinogens, either in some other chemical form or as particles in the lungs.

OSPAR's Coordinated Environmental Monitoring Programme (CEMP) requires OSPAR countries to monitor heavy metals, including mercury, cadmium, and lead. OSPAR's monitoring work on hazardous substances comprises monitoring and assessment of the sources and pathways of contaminants and their concentrations and effects in the marine environment. In addition to heavy metal inputs, concentrations in biota and sediment are monitored under OSPAR CEMP.

OSPAR has a long history of coordinating and agreeing measures to reduce heavy metal inputs to the North-East Atlantic. As early as 1980, Recommendations to limit heavy metal concentrations in sewage sludge and Decisions about mercury concentrations in organisms were agreed. Further Recommendations to limit mercury pollution came in 1981, 1982, 1989, 1990, 1993 and 2003. Recommendations to limit cadmium emissions were adopted and implemented between 1985 and 2010.

One of the OSPAR North-East Atlantic Strategy objectives 2010-2020 was "a steady reduction in heavy metal inputs" with the ultimate aim that heavy metal inputs should be close to background values (OSPAR Agreement 2010-03). The magnitude of background inputs has yet to be determined in line with the OSPAR NEAES 2030 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 with the ultimate aim of achieving and maintaining concentrations in the marine environment at near background values for naturally occurring hazardous substances and close to zero for human made hazardous substances".

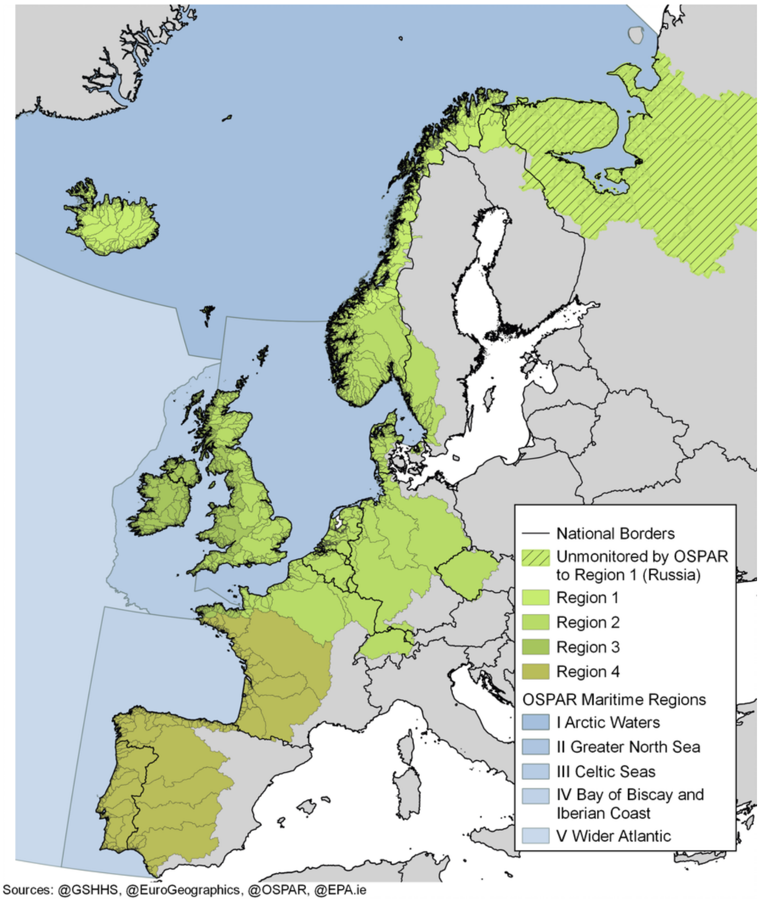

Figure b: Riverine catchment areas supplying mercury, cadmium and lead to the OSPAR convention area

Assessment Method

Heavy metals concentrations are measured in OSPAR's Riverine Inputs and Direct Discharges Monitoring Programme (RID) (OSPAR Agreement 2014-04). These measurements are combined with high frequency freshwater discharge observations to give the total riverine inputs at the river mouth. Inputs are attributed to the country where the water enters the sea, although catchment areas often extend across national borders. These inputs are then supplemented by national reports of waterborne discharges from industry (OSPAR Agreement 2014-04), which European Union Member States also report under the Industrial Emissions Directive and the European Pollutant Release and Transfer Register (E-PRTR) - Environment . Losses from unmonitored areas, between monitored riverine discharge points, are determined by modelling.

Atmospheric input data have been modelled and produced by EMEP–MSC-E (European Monitoring and Evaluation Programme – Meteorological Synthesising Centre East) based on national reporting of emissions to the air under the UNECE Convention on Long-range Transboundary Air Pollution (UNECE, 1983). Emissions data are reported to EMEP, the resulting transport and deposition is then modelled using atmospheric chemistry and meteorological models, together with estimates of 'background' heavy metal emissions due to re-suspension from exposed soils and earth or in the case of mercury, emission from the sea surface. Source apportionment allows the relative contributions of OSPAR countries and 'natural' sources, as well as sources outside the OSPAR Maritime Area, to be assessed. EMEP model results are validated against EMEP (often including the OSPAR Comprehensive Atmospheric Monitoring Programme, CAMP (OSPAR Agreement 2015-04) observations of heavy metal deposition. More detailed information about EMEP MSC-E modelling is available (Ilyin et al., 2022).

Results (brief)

Although inputs of mercury, cadmium and lead to the Greater North Sea appear to have more than halved since the start of the 1990s (**Figure 4**), advances in analytical methods resulting in improved (lowered) detection limits mean that while there is a downward trend in inputs, the change is certainly overestimated. However, it is not possible to determine by how much. Overestimation occurred in the past because the limit of quantification for an analysis was higher than the actual concentration of the substance in the environment. Similarly, some countries have changed their metal analysis, for example from total metals to dissolved metals, since the introduction of the European Union Water Framework Directive in 2000. This has also resulted in an apparent input reduction. It is unclear whether similar issues affect the atmospheric deposition data, which are dependent on the quality of reported emissions, the accurate description of meteorological and chemical processes, and the quality of the validation data.

Mercury inputs via water have approximately halved between 1990 to 1995 and 2010 to 2014 and have decreased slowly thereafter. Air inputs have reduced by approximately one-third, noting a proportion of this is likely to be due to improved analytical techniques. Cadmium inputs via air and water have both reduced by two-thirds. Waterborne lead inputs have more than halved while airborne lead deposition is less than a third of the level it was in 1990.

Figure 4: Estimated total inputs (waterborne – blue - and atmospheric - yellow) of mercury, cadmium, and lead to OSPAR Regions I – IV in 1990–1995, 2010–2014 and 2015 - 2019. Values are in tonnes)

All OSPAR countries have made substantial reductions in waterborne mercury inputs since 1990 to 1995 with the waterborne inputs now smaller than atmospheric inputs in the Greater North Sea. The Netherlands and Germany have made the greatest reductions in waterborne lead inputs, accounting for half the total waterborne reduction between them.

Airborne inputs of all three heavy metals have reduced significantly since 1990. The Intermediate Assessment 2017 showed mercury inputs due to Contracting Parties' emissions to be significantly lower than inputs from 'non-OSPAR' countries. These non-OSPAR inputs come from outside the OSPAR Maritime Area as well as from re-

suspended material; such as from exposed soils, and urban, arable, and marine surfaces both within and outside the OSPAR Maritime Area.
There is moderate confidence in the methods and low confidence in the data used for this assessment.

Results (extended)

Changes and improvements in analytical methods make it difficult to determine the exact scale of the input reductions for mercury, cadmium, and lead. **Figure c, Figure d, Figure e, Figure f, Figure g**, **Figure h, Figure i, Figure j, Figure k, Figure l, Figure m, Figure n, Figure o, Figure p** and **Figure q** suggest that mercury inputs have decreased by one-third since the early 1990s, cadmium by a half and lead by almost two-thirds. Atmospheric input calculations, based on reported emissions and atmospheric transport and chemistry models have decreased by a similar amount. These results appear to be reflected in the Status and Trend for Heavy Metals (Mercury, Cadmium and Lead) in Fish, Shellfish and Sediment indicator assessment, which describe concentrations in sediment as "decreasing or show no significant change in the majority of areas assessed" and concentrations in mussels and fish as "decreasing or show no significant change in all assessed areas". Despite this, the relevant objective of the OSPAR North-East Atlantic Environment Strategy 2010-2020, that concentrations are at natural background levels, has not yet been met.

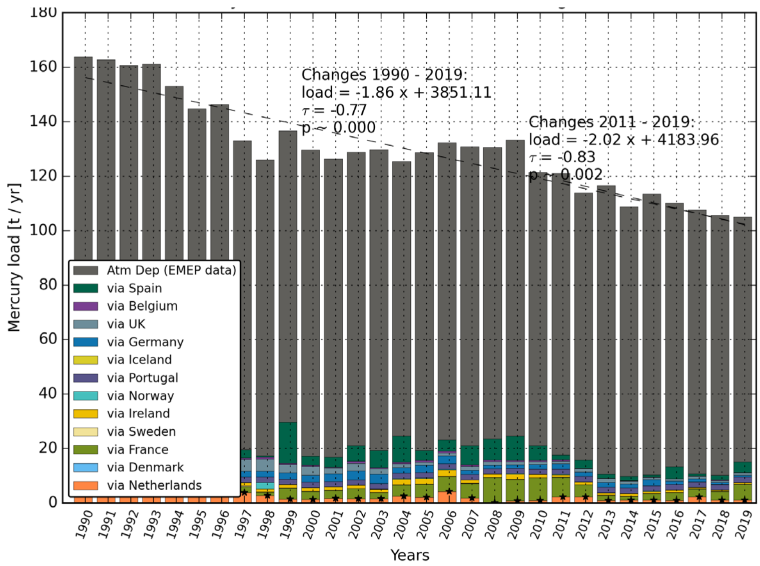

Figure c: Total mercury inputs to the OSPAR Maritime Area

This comprises waterborne inputs from OSPAR countries and modelled estimates of atmospheric deposition. Waterborne data have been flow normalised to the average riverine input 1990 - 2019. Notes: French data do not show actual inputs because limits of quantification are too high; Belgian data include a change from measuring total mercury to dissolved mercury; only two years of Danish data were available, which were excluded at Denmark's request. Flow normalisation is at the level of individual rivers which can mean that some national totals include mean values for missing rivers.

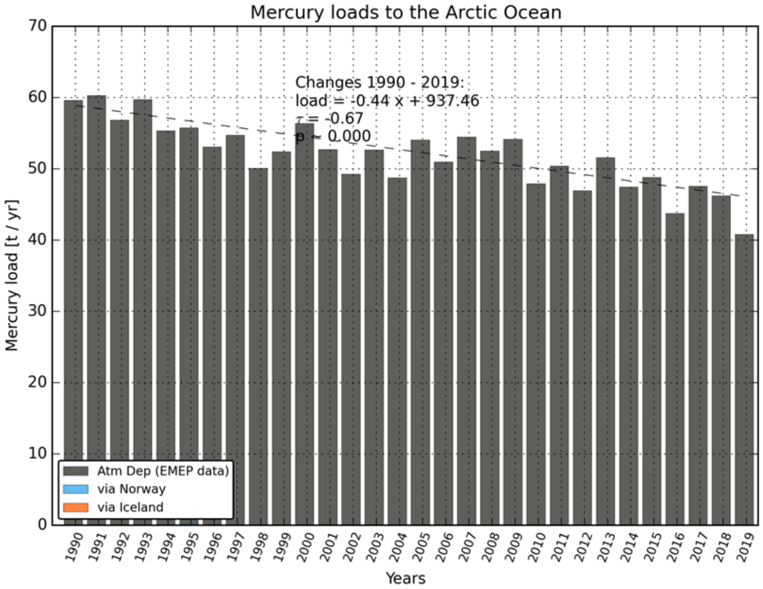

Figure d: Total mercury inputs to the Arctic Ocean

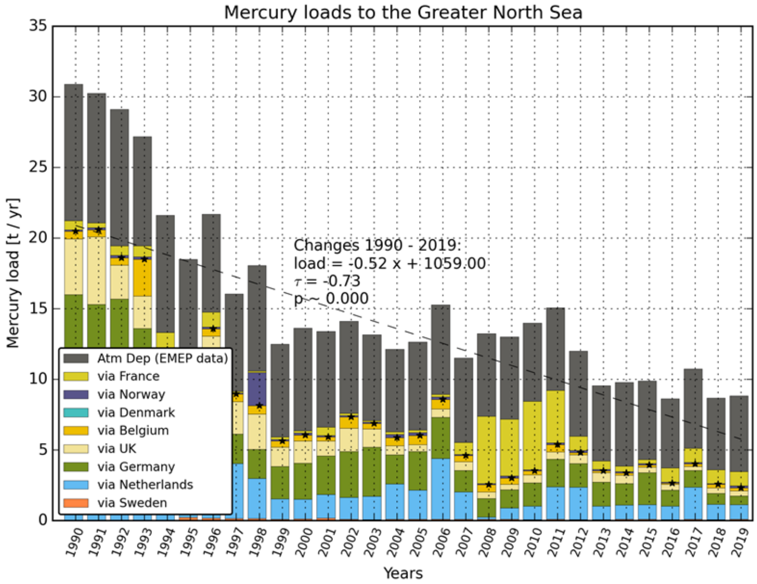

Figure e: Total mercury inputs to the Greater North Sea

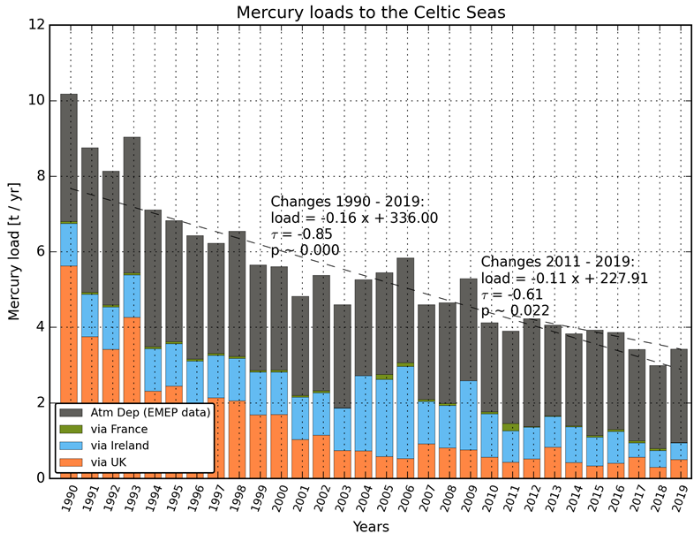

Figure f: Total mercury inputs to the Celtic Seas

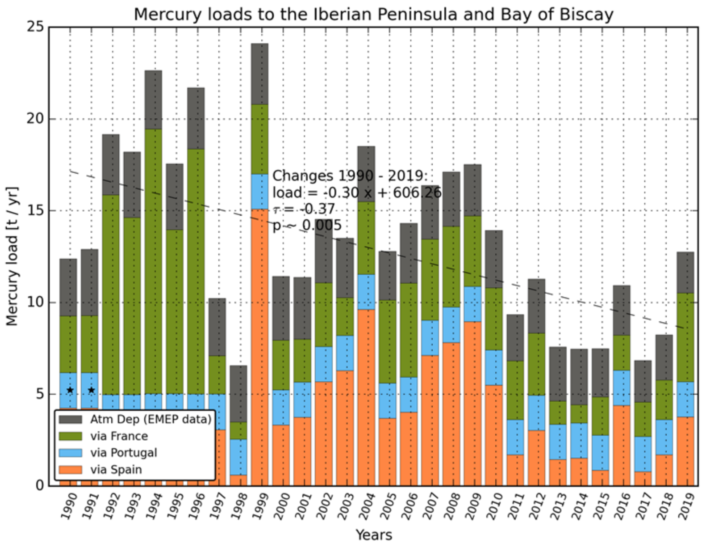

Figure g: Total mercury inputs to the Iberian Peninsula and Bay of Biscay

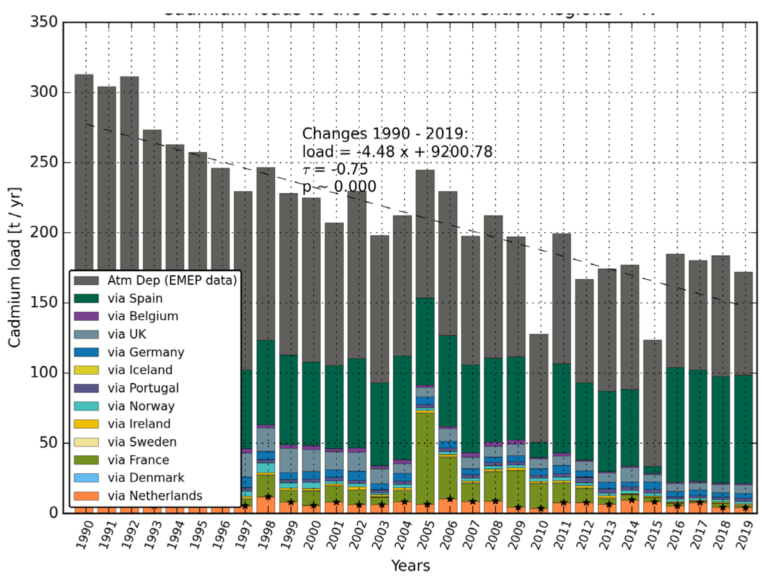

Figure h: Total cadmium inputs to the OSPAR Maritime Area

This comprises waterborne inputs from OSPAR countries and modelled estimates of atmospheric deposition. Waterborne data have been flow normalised to the average riverine input 1990 - 2019. Notes: French data do not show actual inputs because limits of quantification are too high; only two years of Danish data were available, which were excluded at Denmark's request. Flow normalisation is at the level of individual rivers which can mean that some national totals include mean values for missing rivers.

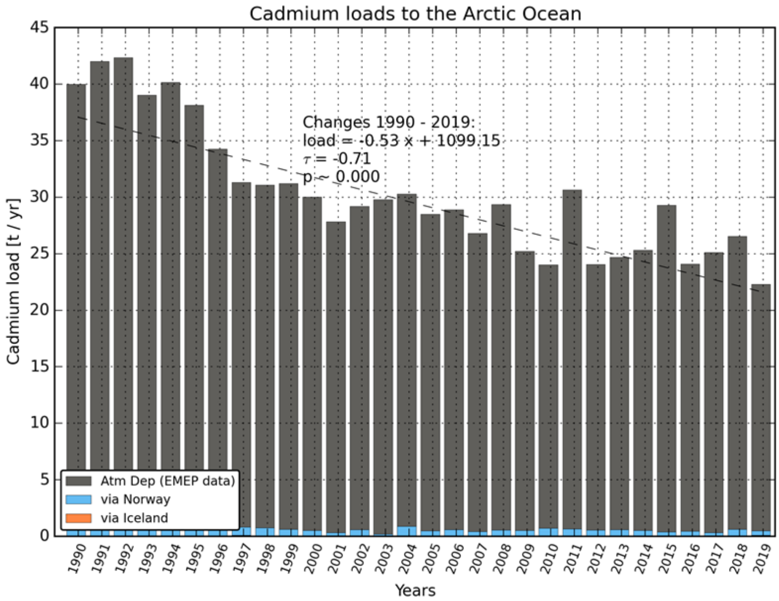

Figure i: Total cadmium inputs to the Arctic Ocean

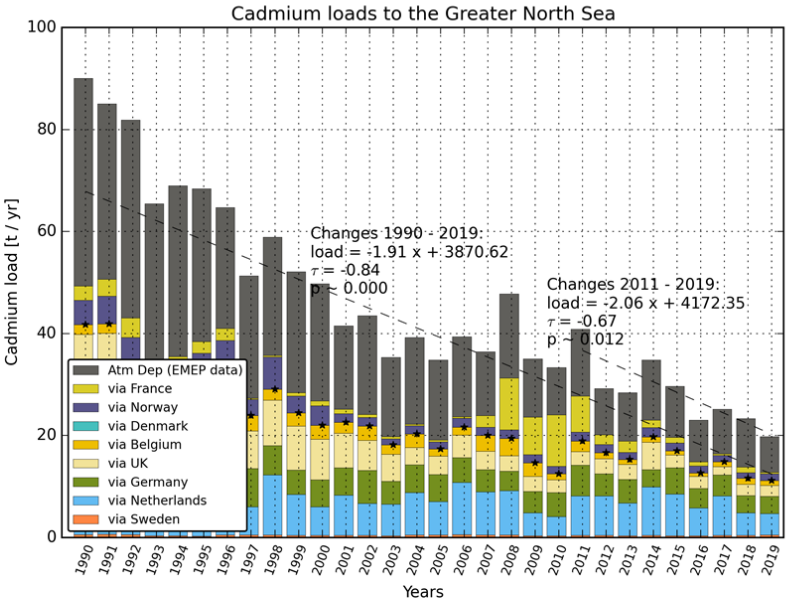

Figure j: Total cadmium inputs to the Greater North Sea

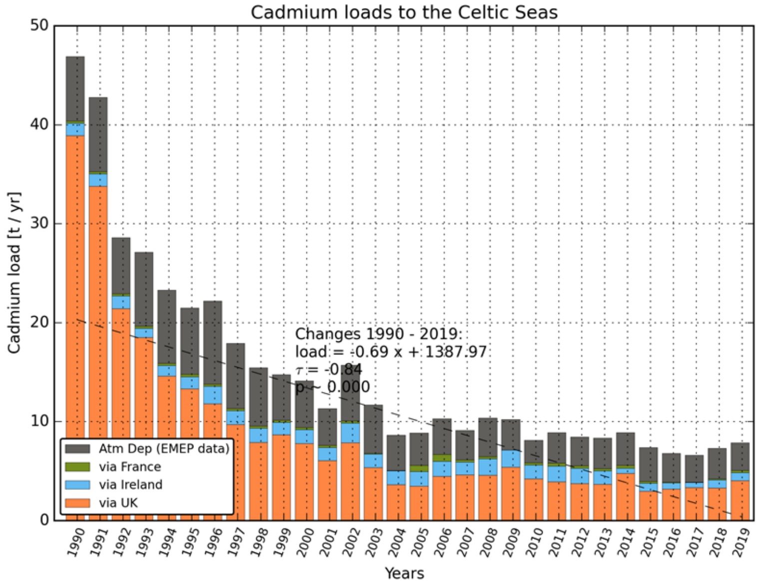

Figure k: Total cadmium inputs to the Celtic Seas

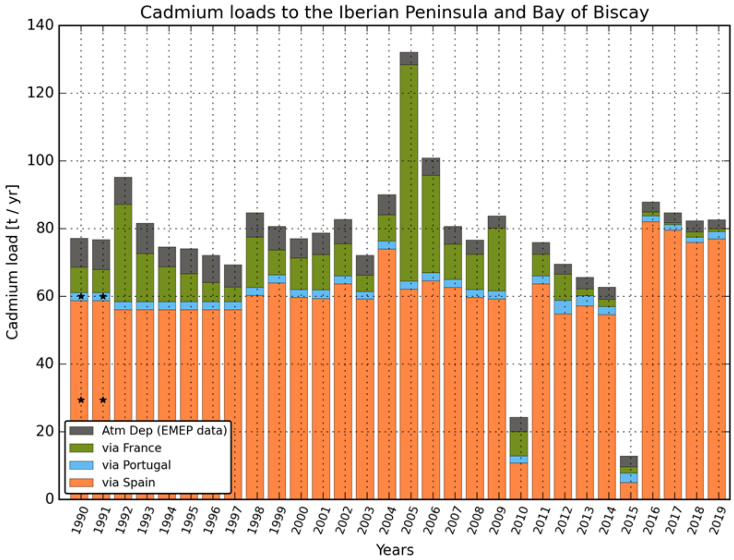

Figure l: Total cadmium inputs to the Iberian Peninsula and Bay of Biscay

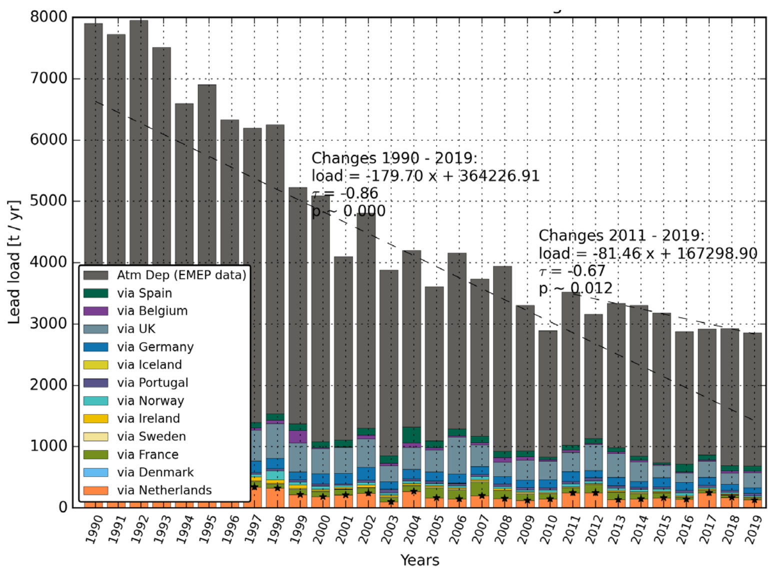

Figure m: Total lead inputs to the OSPAR Maritime Area

This comprises waterborne inputs from OSPAR countries and modelled estimates of atmospheric deposition Waterborne data have been flow normalised to the average riverine input 1990 - 2019. Notes: only two years of Danish data were available, which were excluded at Denmark's request. Flow normalisation is at the level of individual rivers which can mean that some national totals include mean values for missing rivers.

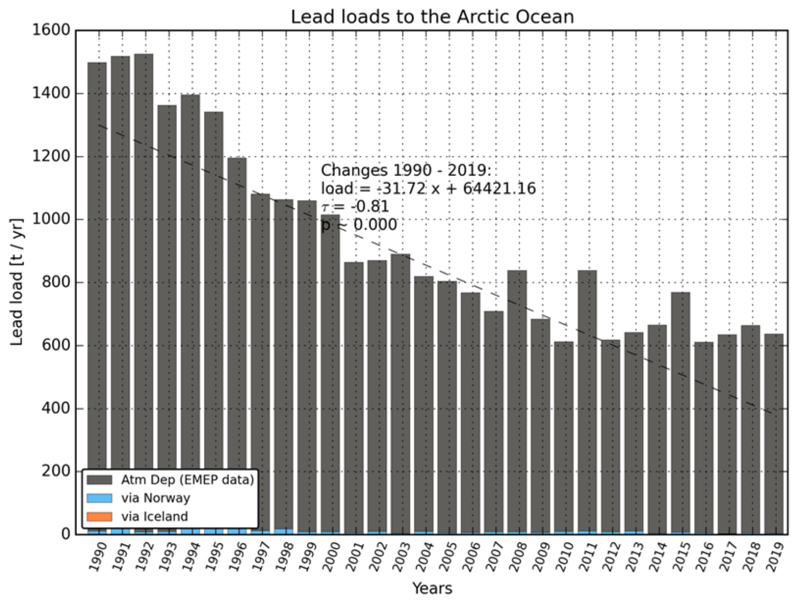

Figure n: Total lead inputs to the Arctic Ocean

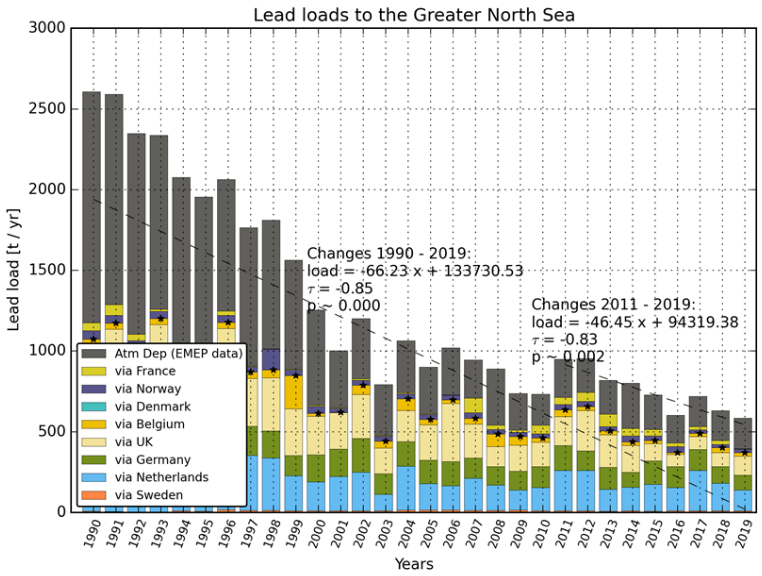

Figure o: Total lead inputs to the Greater North Sea

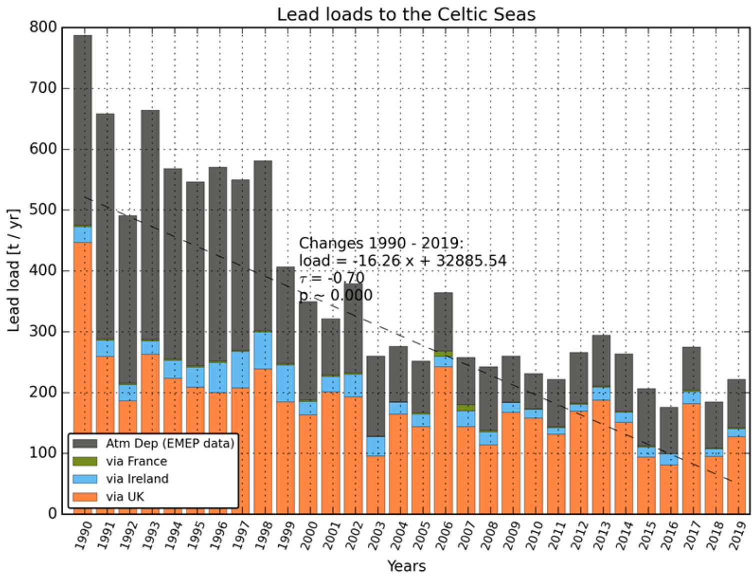

Figure p: Total lead inputs to the Celtic Seas

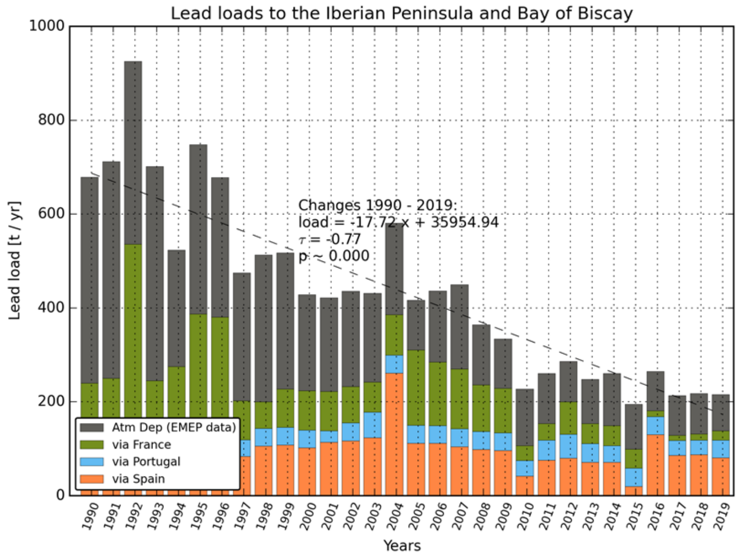

Figure q: Total lead inputs to the Iberian Peninsula and Bay of Biscay

Atmospheric pathways remain important, despite progress made under the 1998 Aarhus Protocol and its 2012 amendment, which introduces the requirement for Best Available Techniques (UNECE, 2012). Re-suspended material and sources from outside the OSPAR Maritime Area are particularly significant sources of mercury and lead.

Although there have apparently been rapid improvements in reducing inputs of mercury (**Figure c , Figure d, Figure e, Figure f and Figure g**), cadmium (**Figure h, Figure i, Figure j, Figure k and Figure l**), and lead (**Figure m, Figure n, Figure o, Figure p and Figure q**) to the OSPAR Maritime Area since 1990, changes since about 2007 have been minor, suggesting that most cost-effective measures have probably now been implemented and achieving further reductions will be challenging.

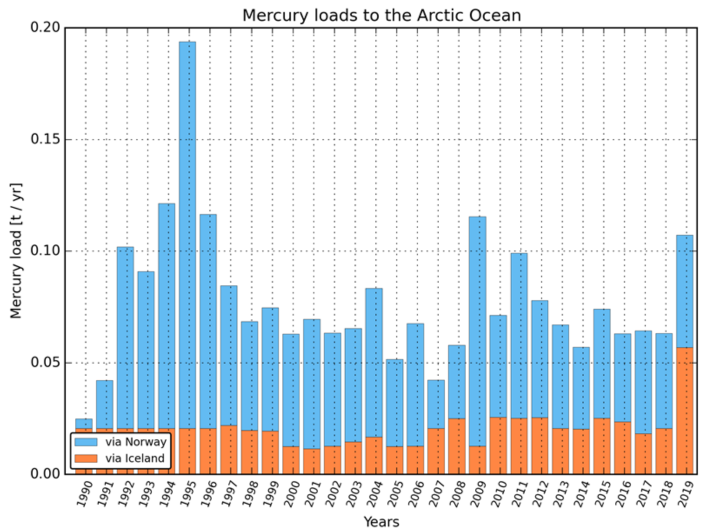

Figure r: Waterborne inputs of mercury to OSPAR's Region I (Arctic Waters)

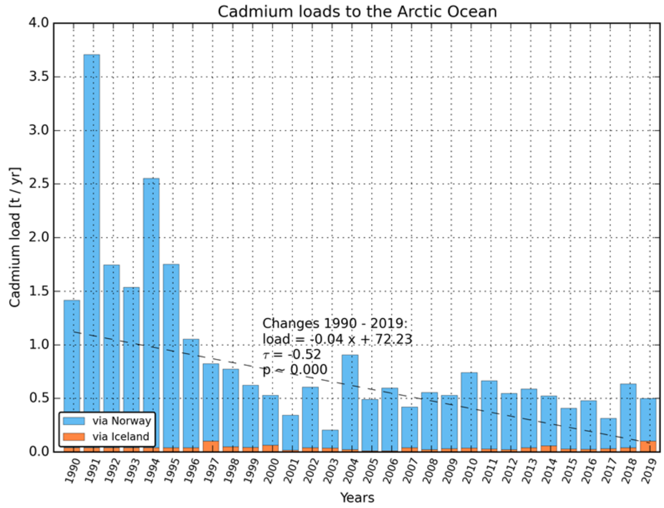

Figure s: Waterborne inputs of cadmium to OSPAR's Region I (Arctic Waters)

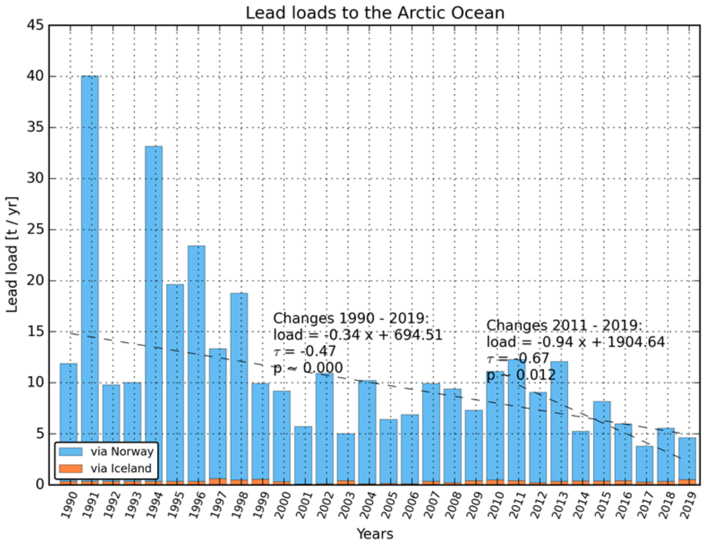

Figure t: Waterborne inputs of lead to OSPAR's Region I (Arctic Waters)

Changing limits of quantification have a substantial effect on the time series, and can result in the generation of an apparent trend unconnected to the actual inputs to the marine environment. **Figure u** shows an example using Belgian data, where greatly improved quantification limits in 2004 give an apparent input reduction compared to the previous period. While inputs may have reduced during this period, any real improvements are masked due to the inputs being overestimated prior to 2002. Overestimation occurs when the limit of quantification for an analysis is higher than the actual concentration of the substance in the environment. In this case, the assumed concentration is taken to be the mid-point between the upper and lower concentration estimates, which is then multiplied by the flow to estimate the input.

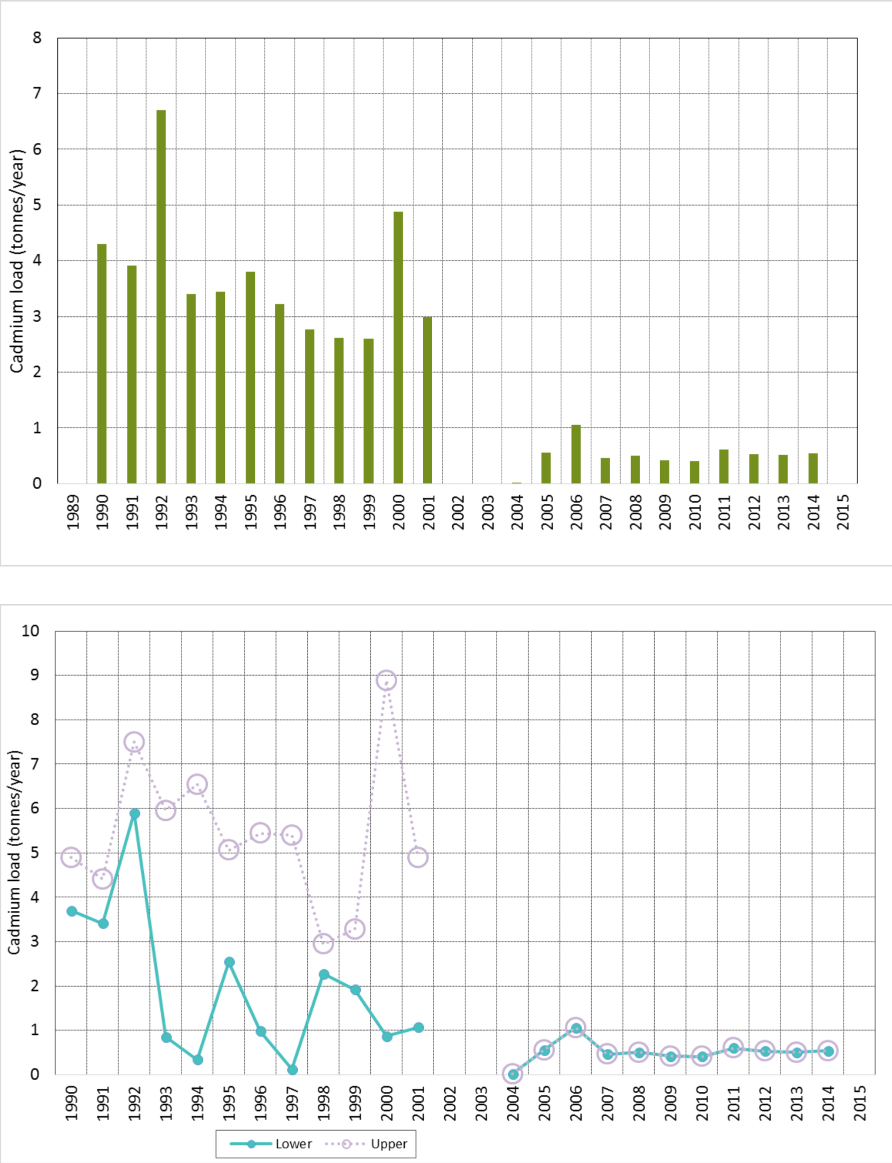

Figure u: Illustration of the effect of changes in limit of quantification on estimated total inputs

Estimated total cadmium inputs to the Greater North Sea 1990–2014 for Belgium (upper panel) based on riverine inputs (lower panel) with upper and lower estimates. The total inputs are calculated from the average of the upper and lower riverine input estimates (plus direct discharges). If the upper estimate is unreasonably high due to poor laboratory quantification limits, then the resulting input estimate is also over-estimated. In this case, this results in an (apparently statistically significant) downward trend that should only be attributed to improved laboratory practice rather than reduced inputs to the environment

A similar problem occurs where some countries have changed analysis matrix since the introduction of the European Union Water Framework Directive (EC, 2000). Environmental Quality Standards for metals under the Water Framework Directive were derived for the liquid fraction only. As a result, some countries have stopped measuring total metal concentrations and concentrate solely on the dissolved phase. This also has the effect of introducing an apparent reduction in inputs affecting the results.

These issues highlight the importance, when changing analysis laboratory or method, to consider whether limits of determination and quantification are maintained, so as not to introduce false trends into time series.

Confidence assessment

There is low confidence in the data used for this assessment. Monitoring, analysis, and reporting are well established throughout the OSPAR area. Despite this, there remain issues with differences in laboratory procedures, insufficient spatial coverage and possible missing sources (especially for direct discharges). In addition, historical data analysed using poorer methods are extremely uncertain, particularly in the case of mercury and cadmium. It is unlikely that Spain is as significant a source of cadmium as the data suggests.

There is moderate confidence in the methodology, which is straightforward, and the same as that used for the Inputs of Nutrients indicator assessment.

Conclusion (brief)

Compared to 1990 OSPAR countries have made significant efforts to reduce emissions and losses of mercury (-40%), cadmium (-45%) and lead (-66%) to the OSPAR Maritime Area . Atmospheric input dominates over the river input for mercury, and measures have been more successful in reducing waterborne inputs than atmospheric. For lead, atmospheric measures have been successful, concerning reductions in lead inputs, that waterborne inputs are now larger, except to the Arctic where atmospheric inputs still dominates.

These results appear to show significant progress towards the OSPAR objective to prevent pollution of the Maritime Area. The reduction of atmospheric input is of great importance.

Conclusion (extended)

In all Regions, inputs of heavy metals via both water and air to the OSPAR Maritime Area have decreased while the total input of atmospheric mercury and lead from the atmosphere remain greater than the waterborne inputs from OSPAR countries. Waterborne pathways for cadmium still dominate over the atmospheric, except in the Arctic. Even waterborne cadmium inputs have been substantially reduced to the Greater North Sea and Celtic Seas (OSPAR Regions II and III) and can be expected to reduce further with the standards proposed in the new EU fertilizers regulations 2019/1009.

OSPAR countries have been most successful in reducing atmospheric lead inputs, which have reduced by approximately 75 - 85% to the Greater North Sea, Celtic Seas and Bay of Biscay and Iberian Coast (OSPAR Regions II, III and IV) between 1990 to 94 and 2015 to 2019. In comparison, waterborne lead inputs to these Regions have "only" reduced 55 – 60% over the same period. Secondary atmospheric pollution from re-suspended material and from sources outside the OSPAR Maritime Area are now the major sources of airborne pollution and there is a need for cooperation beyond OSPAR's boundaries to manage these in addition to the waterborne inputs.

Heavy metal input estimates are very uncertain, particularly for mercury and cadmium. Quantification limits vary between laboratories within countries, and as laboratories or methods change. This causes substantial changes in the estimated inputs. These uncertainties were greater at the beginning of the analysis period. Despite the methodological issues for mercury and cadmium, with measurement techniques that are close to detection limits, the monitoring data for the suite of heavy metals show substantial waterborne input reductions.

Knowledge Gaps (brief)

Strict quality controls are needed in laboratories analysing heavy metal samples. High detection limits can lead to an overestimation of inputs and an inability to detect changes. The effect on quantification limits should be assessed whenever a change in analysis laboratory is considered.

There is a mismatch between the requirements of the European Union Water Framework Directive to measure metal concentrations in the dissolved fraction and the OSPAR Agreement 2014-04 to quantify total heavy metal inputs.

Knowledge gaps remain concerning the retention and export of heavy metals in estuaries, limiting knowledge of the proportion of metals that reach the marine environment.

There is limited knowledge of losses of heavy metals from harbours, shipping, historical dumping, and other potential sources.

Knowledge Gaps (extended)

Reference levels and targets need to be set to quantify the natural background inputs of mercury, cadmium, and lead and to improve harmonisation with the European Union Water Framework Directive.

Data from the Riverine Inputs and Direct Discharges Monitoring (RID) programme (OSPAR Agreement 2014-04) need to be more widely used to ensure that any data problems or gaps are identified and addressed as quickly as possible.

Modelled atmospheric deposition is validated using daily deposition observations from the European Monitoring and Evaluation Programme (EMEP) chemical network. However, this network is land-based and therefore the quality of the model products is less well validated over the sea surface. Overlapping the EMEP observation network are the OSPAR Comprehensive Atmospheric Monitoring Programme (CAMP) monitoring stations. These are coastal stations, which can be considered to be more representative of marine deposition, but with a lower (often monthly) monitoring frequency.

Waterborne inputs are based on a combination of observed (monitoring at the river mouth), modelled (unmonitored areas) and point source inputs. Observations are based on 12 chemical analyses per substance and year combined with modelled or observed flow data. While monitoring and analysis follow OSPAR RID guidelines and can be considered to represent the 'best' input estimate, uncertainties in the relation between chemical concentration and run-off, together with analytical and flow uncertainties mean that estimated uncertainty may be in the region of 100–200%.

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Assessment Metadata

Field	Data Type	
Assessment type	List	Indicator Assessment
SDG Indicator	List	14.1 By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution
Thematic Activity	List	Hazardous Substances
Relevant OSPAR Documentation	Text	OSPAR Agreement 1997-08. Guidelines for the sampling and analysis of mercury in air and precipitation OSPAR Agreement 2010-03. The North-East Atlantic Environment Strategy; Strategy of the OSPAR Commission for the Protection of the Marine Environment of the North-East Atlantic 2010–2020 OSPAR Agreement 2014-04. Riverine Inputs and Direct Discharges Monitoring Programme (RID) applicable from 1 January 2015 OSPAR Agreement 2015-04. Guidance for the Comprehensive Atmospheric Monitoring Programme (CAMP) OSPAR Agreement 2016-01. Coordinated Environmental Monitoring Programme (CEMP), as revised. OSPAR Agreement 2021-01. The North-East Atlantic Environment Strategy; Strategy of the OSPAR Commission for the Protection of the Marine Environment of the North-East Atlantic 2030
Date of publication	Date	2022-06-30
Conditions applying to access and use	URL	https://oap.ospar.org/en/data-policy/
Data Snapshot	URL	https://odims.ospar.org/en/submissions/ospar_heavy_metals_snapshot_2022_06/
Data Results	Zip File	https://odims.ospar.org/en/submissions/ospar_heavy_metals_results_2022_06/
Data Source	URL	https://www.emep.int/

Field	Data Type	
		https://www.nibio.no/en

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.

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