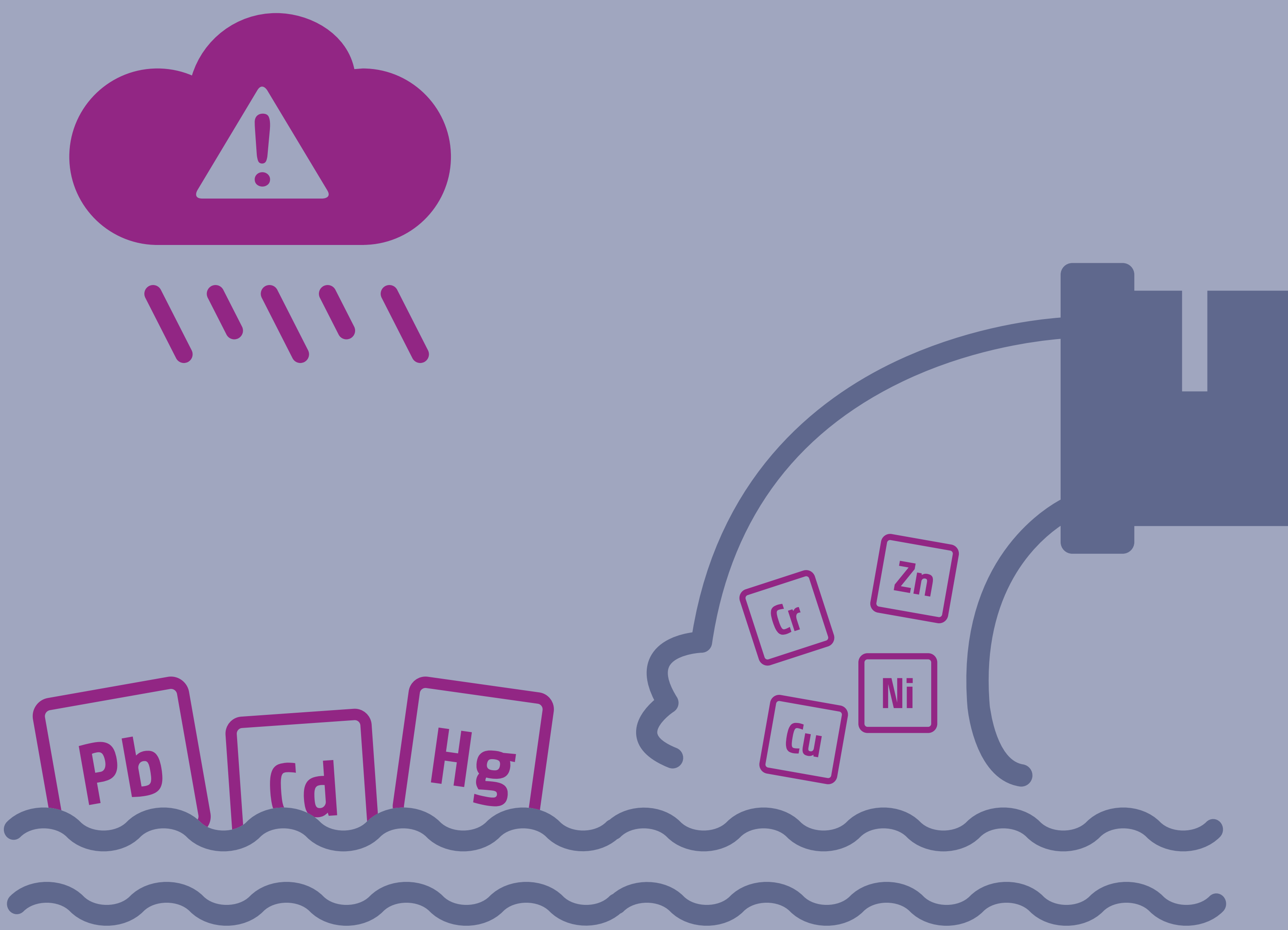
PLC-8

Inputs of hazardous substances to the Baltic Sea

Baltic Marine Environment Protection Commission

Hazardous substances

Baltic Sea Environment Proceedings n°197



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Introduction

Excessive amounts of contaminants in the environment may lead to risk for biota including a risk for human health. Hazardous substances like metals and organic substances may originate from natural or anthropogenic sources, although organic contaminants tend to be more commonly of anthropogenic origin. The inputs to the Baltic Sea are considered to be mainly waterborne via rivers and direct point sources, and via atmospheric deposition, depending on the substance and data availability.

The waterborne inputs of pollutants are monitored and reported according to the PLC-Water guidelines (HELCOM 2022a). The guidelines are most extensively elaborated for the nutrient inputs, but it also includes some metals. In contrast to the monitoring and reporting of waterborne pollutants, the programme for monitoring air pollution and precipitation, the airborne inputs include both metals and some organic contaminants. Due to this inconsistency between the monitoring and reporting of the different sources, fair estimates for the total inputs are at the moment only possible for some countries and for some metals that are included in both programmes. This assessment is focused on the inputs of the metals in the above-mentioned monitoring programmes. In addition, to the assessment of these metals also the atmospheric deposition of some selected organic contaminants commissioned by HELCOM to the European Monitoring and Evaluation Programme (EMEP) has been included. These substances are benzo(a)pyrene (BaP), polybrominated diphenyl ethers (BDE-99), and hexachlorobenzene (HCB). EMEP has also evaluated the possibilities to model hexabromocyclododecane (HBCDD), polychlorinated naphthalenes (PCNs) and pentachlorobenzene (PeCB), but concluded that presently the available information is not enough to be used for detailed deposition modelling (Gauss *et al.* 2022).

1. Inputs of heavy metals to the Baltic Sea

Presently the HELCOM core indicators on metal pollution in the Baltic Sea consist of mercury, cadmium, lead and copper, and high levels of these metals have been detected in sediments and in biota (HELCOM 2023a, b, c, d, e). Soil properties, industrial activity, high population density, the exploitation of minerals and other natural resources, the application of fertilizers in agricultural areas as well as atmospheric deposition from local and distant emission sources are the main factors that contribute to heavy metal inputs. Shipping and leisure boats are also important routes of entry to the Baltic, especially for copper that may be used as an antifouling agent (HELCOM 2023e).

Limitations in national monitoring programmes and/or lack of proper laboratory resources have in some cases prevented the reporting of heavy metal input data. As a result, only an indication on the inputs of mercury, cadmium and lead entering the Baltic Sea could be established in PLC-6, and the PLC-7 assessment was further improved with more data and the inclusion of the voluntary reported metals chromium, copper, nickel, and zinc. Nevertheless, there are still issues regarding reporting completeness for some CPs, as well as data quality issues and the possibilities to quantify the metals at ambient level. In line with the two previous assessment reports on metal inputs the results from the present PLC-8 reporting ought to be seen as mainly indicative (cf. "Data handling and quality control"). Unfortunately, no data are available on the atmospheric deposition for chromium, nickel, and zinc, as they have, at least so far, not been included in the commission to EMEP regarding modelling of metal deposition on the Baltic Sea. However, since the PLC-7 assessment EMEP have modelled the deposition of copper, which is included in the present report. In addition, it should be noted that in cases where there are upstream countries, the transboundary metal loads are included in the metal inputs to the Baltic Sea from the HELCOM Contracting Parties (CPs) that encompass the river mouth as it has not been possible to correct for these upstream inputs as there only have been a very limited amount of reporting by Ukraine, and no reporting on metal inputs by Belarus at all.

According to the PLC-Water guidelines, mercury, cadmium, and lead are mandatory parameters that should be reported, whereas copper, zinc, nickel, and chromium may be reported on a voluntary basis. The request is on the total load of the named metals, although most CPs are analysing on filtered samples (cf. "Data handling and quality control"). The PLC-Water guidelines indicate methods for making estimates from measurements below the quantification limits (HELCOM 2022). The reporting obligations for MWWTPs and industrial point sources are on the other hand regulated by the size of the MWWTPs and if the monitoring is a part of the permissions for a specific industrial plant. Due to the size regulation for the WWTPs, the inputs from smaller facilities are most probably underestimated as they often are not obliged to report metals.

1.1. Data handling and quality control

Metal data have been reported by the Contracting Parties within the framework of the annual Pollution Load Compilations. The assessment is based on the data content in the Helcom Plus database at the end of August 2023[1]. The reported data has been compiled and assessed as far as possible, and the HELCOM Contracting Parties have been asked to verify their data, especially suspicious outliers, and to fill in potential data gaps. Anyhow, there remain issues regarding the temporal and spatial coverage for several CPs. Also, it has been challenging to assure the data quality, as some observations appear to be suspiciously high or low in comparison to observations in time-series from a single CP or compared to inputs from other CPs.

1 After the data extraction, the Estonian data have been updated, but it was not possible to include the revised data in the present work.

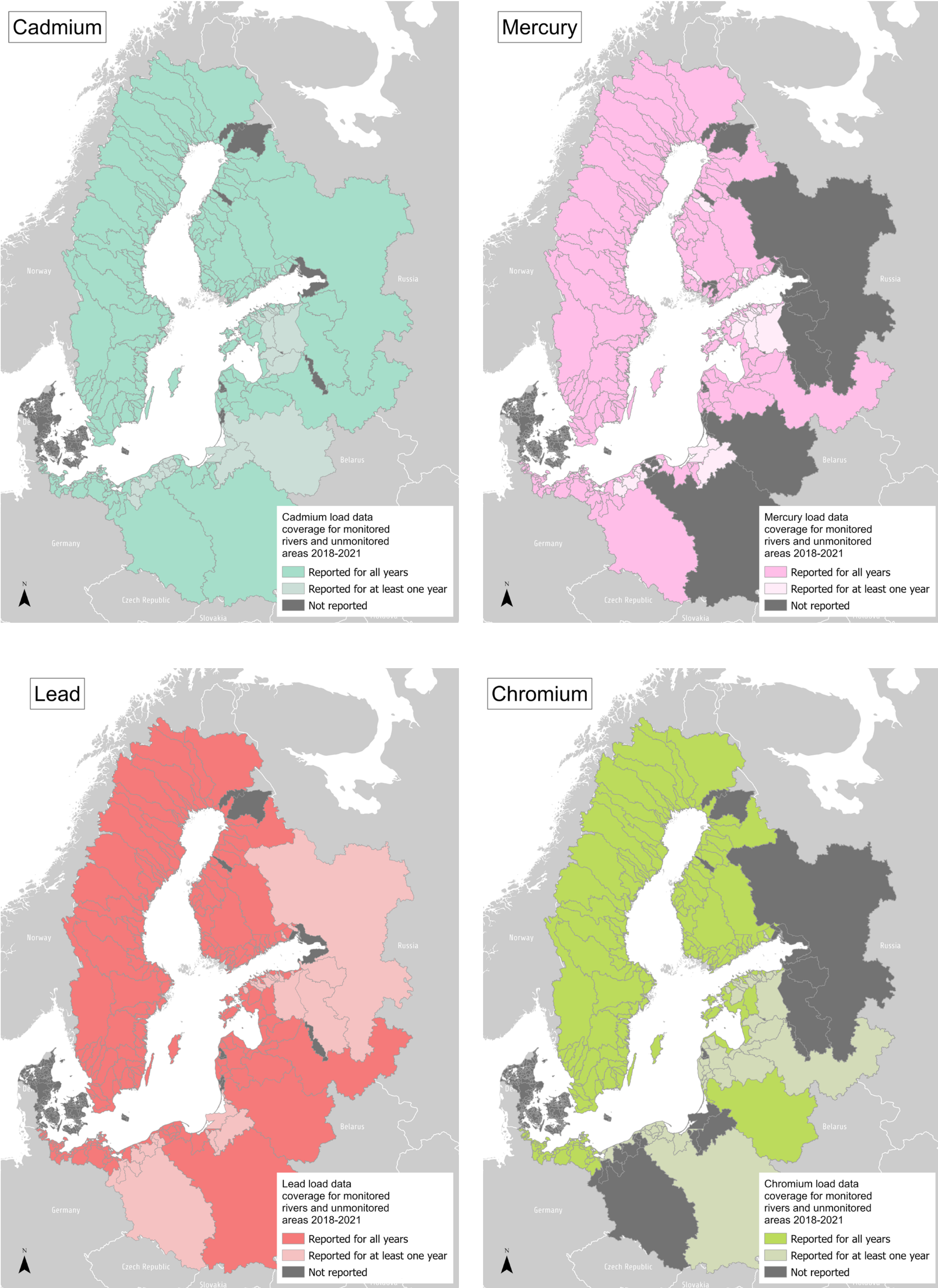
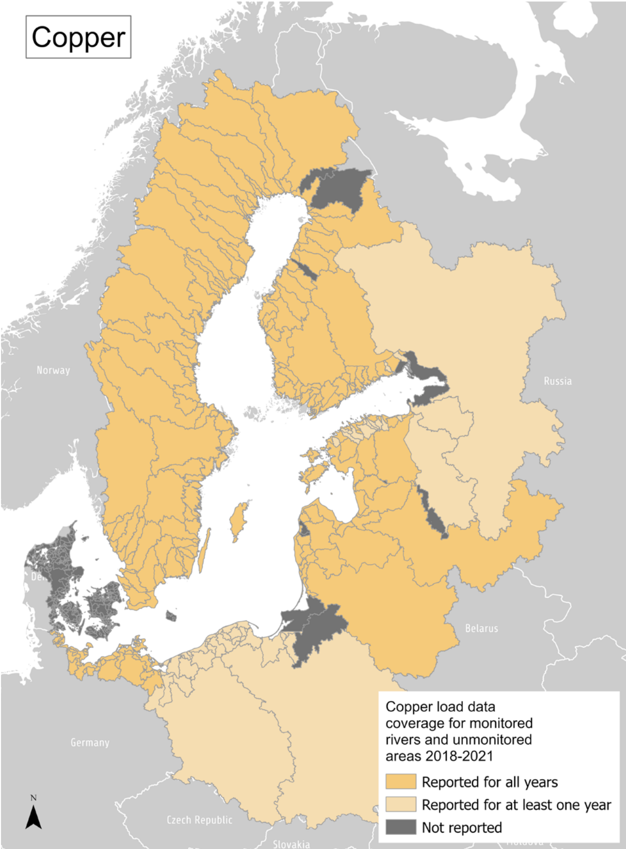
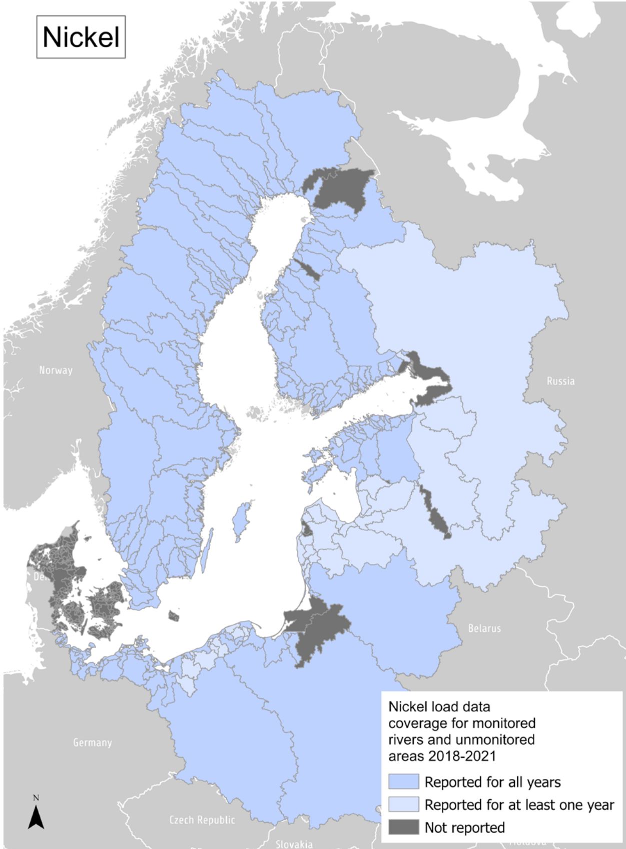


Figure 1. The spatial data coverage 2018–2021 of reported riverine inputs of mandatory metals Cd, Hg and Pb, and voluntary metals Cr, Cu, Ni, Zn.





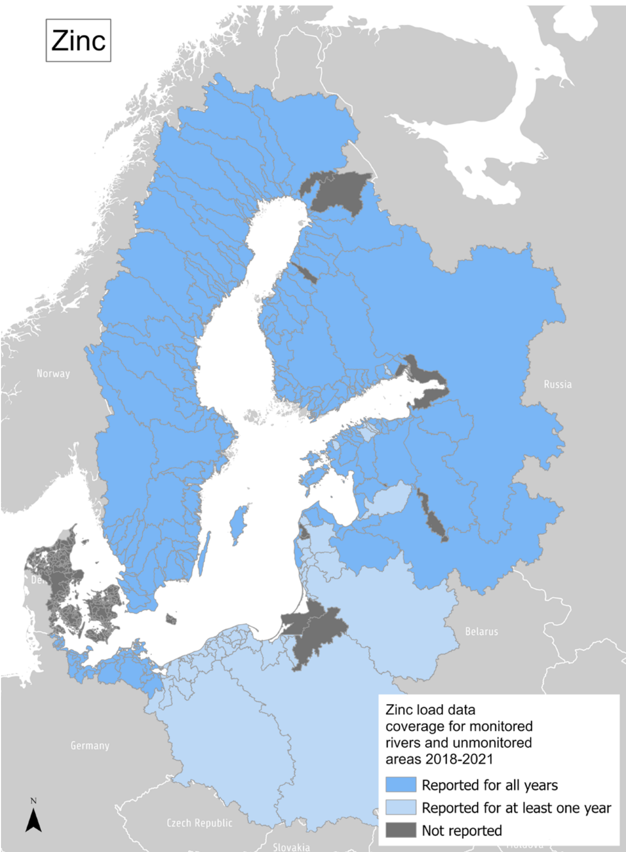


Figure 1. (Continued). The spatial data coverage 2018–2021 of reported riverine inputs of mandatory metals Cd, Hg and Pb, and voluntary metals Cr, Cu, Ni, Zn.

1.2. Data coverage

The assessment of heavy metal inputs to the Baltic Sea has focused on the period 2018-2021 as these are the recent years with the most complete data coverage in the HELCOM PLC database. It is mandatory to report cadmium, mercury and lead inputs, whereas chromium, copper, nickel and zinc are voluntary to report. However, the spatial coverage is far from complete and varies between the metals (Figure 1). The very limited data on riverine inputs from Denmark has not been included due to very poor coverage. The coverage of heavy metal inputs from direct point sources is certainly not fully covered. For instance, Sweden only can report metal inputs from the larger MWWTs, as the smaller plants seldom have reporting obligations on metals in their permits. Maps with the positions of MWWTs and industrial point sources with reported metal loads are given in Figure 2.

In addition, most CPs are analysing the metals on filtered riverine samples although the request according to the PLC-Water Guidelines are on the total loads. This is mainly an adaptation to the Water Framework Directive that requests data on biologically available metals. Among the HELCOM countries, only Finland is actually measuring the total metal concentration (EE analyses both total and filtered metals, but reports dissolved metals), whereas Sweden is analysing acid soluble metals that include dissolved metals and metals adsorbed to particulate matter. Except for Lithuania, all other CPs are analysing filtered samples. In Lithuania Cd, Hg, Pb, and Ni are analysed on filtered samples, whereas total concentrations are analysed for Cr, Cu, and Zn. Consequently, the data reported and assessed are in regard to the total metal inputs in most cases an underestimate as the metals associated to particulate matter are not included. The underestimation is higher the higher fraction of a transported metal that is normally particle bound. Hence, due to the very high particle affinity for especially lead and copper, the inputs of these metals are most probably prone to be seriously underestimated.

As in previous PLC metal input assessment, Danish riverine inputs are not included in this assessment due to a very limited metal monitoring. Hence, this will of course result in an underestimate of the total metal inputs to the Baltic Sea. The metal inputs via the border river Torne älv/Tornionjoki have been set as 50% of the average of the reported Swedish and Finnish inputs, as both countries have been reporting the total inputs by the river, and there is no agreement on any national apportionment of these inputs as there are for the equivalent nutrient inputs.

Table 1. Limits of quantification (LOQ) for metals in river water (μg/l). Data for Contracting Parties from PLC 5.5 (HELCOM 2015) or later, and the recommended LOQs from PLC-Water Guideline (HELCOM 2022a). The values in red are not verified by respective Contracting Parties for this assessment.

Metal	Guideline	DE	DK	EE	FI	LT	LV	PL	RU	SE
Cd	0.01	0.02-0.06	0.009-0.012	0.01-0.02	0.003-0.1	0.05	0.0021-0,024	0.021-0.1	0.1	0.004
Cr	0.05	0.1-0.2	0.03-0.09	0.06-0.5	0.05-2	0.5	0.051-0.8	0.06-1.0	1	0.03
Cu	0.1	0.08-0.5	0.09-0.12	0.1-1	0.0005-0.1	0.5	0.034-0.9	0.9-1.0	1	0.01
Hg	0.005	0.001-0.005	n.a.	0.005-0.015	0.005-0.01	0.03	0.0014-0.01	0.006-0.013	0.01	0.0001
Ni	0.05	0.07-0.5	0.09	0.05-0.1	0.05	1.0	0.034-2	0.1-1.0	5	0.02
Pb	0.05	0.04-0.2	0.075	0.06-0.1	0.01-0.4	1.0	0.029-1	0.36-1.0	2	0.01
Zn	0.5	0.2-0.5	0.09	1	0.5-2	5.0	0.09-3	1.0	2	0.4

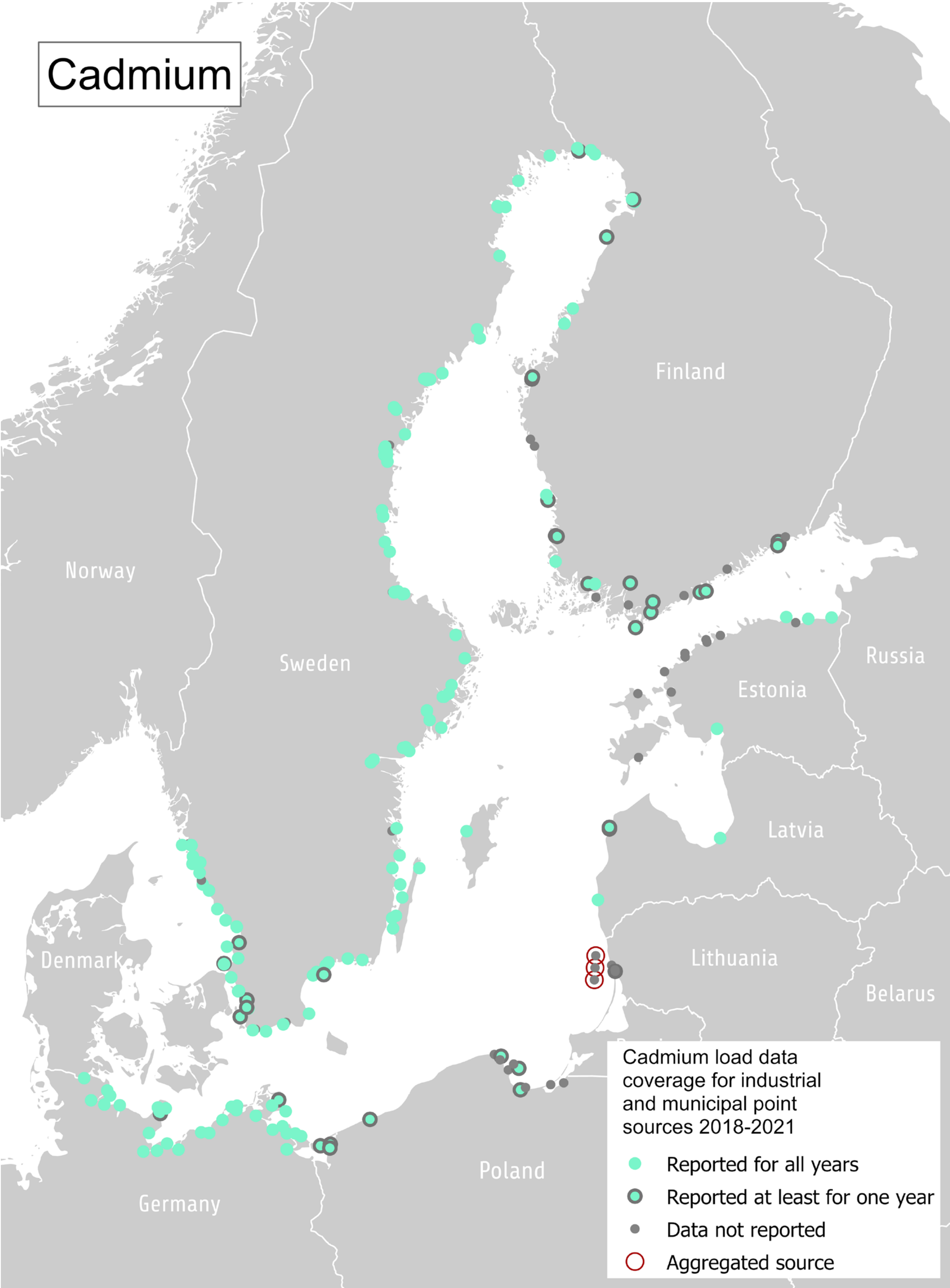


Figure 2. The spatial data coverage 2018–2021 of reported inputs from direct point sources of the mandatory metals Cd, Hg and Pb, and the voluntary metals, Cr, Cu, Ni and Zn. Aggregated point sources are indicated by a red border around the points. The aggregated sources are only positioned on the maps within respective sea basin as the number and location of individual sources are not known.

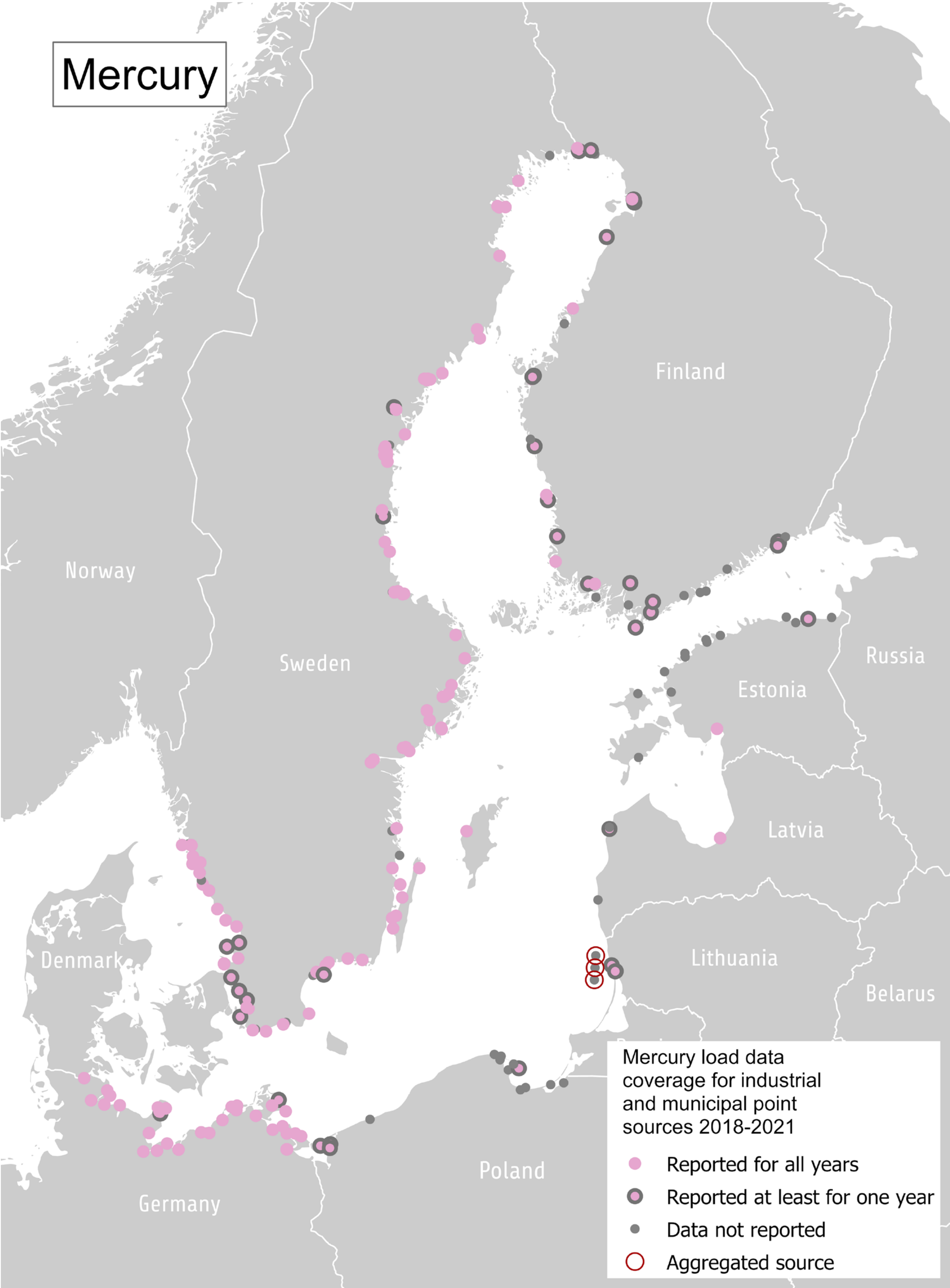
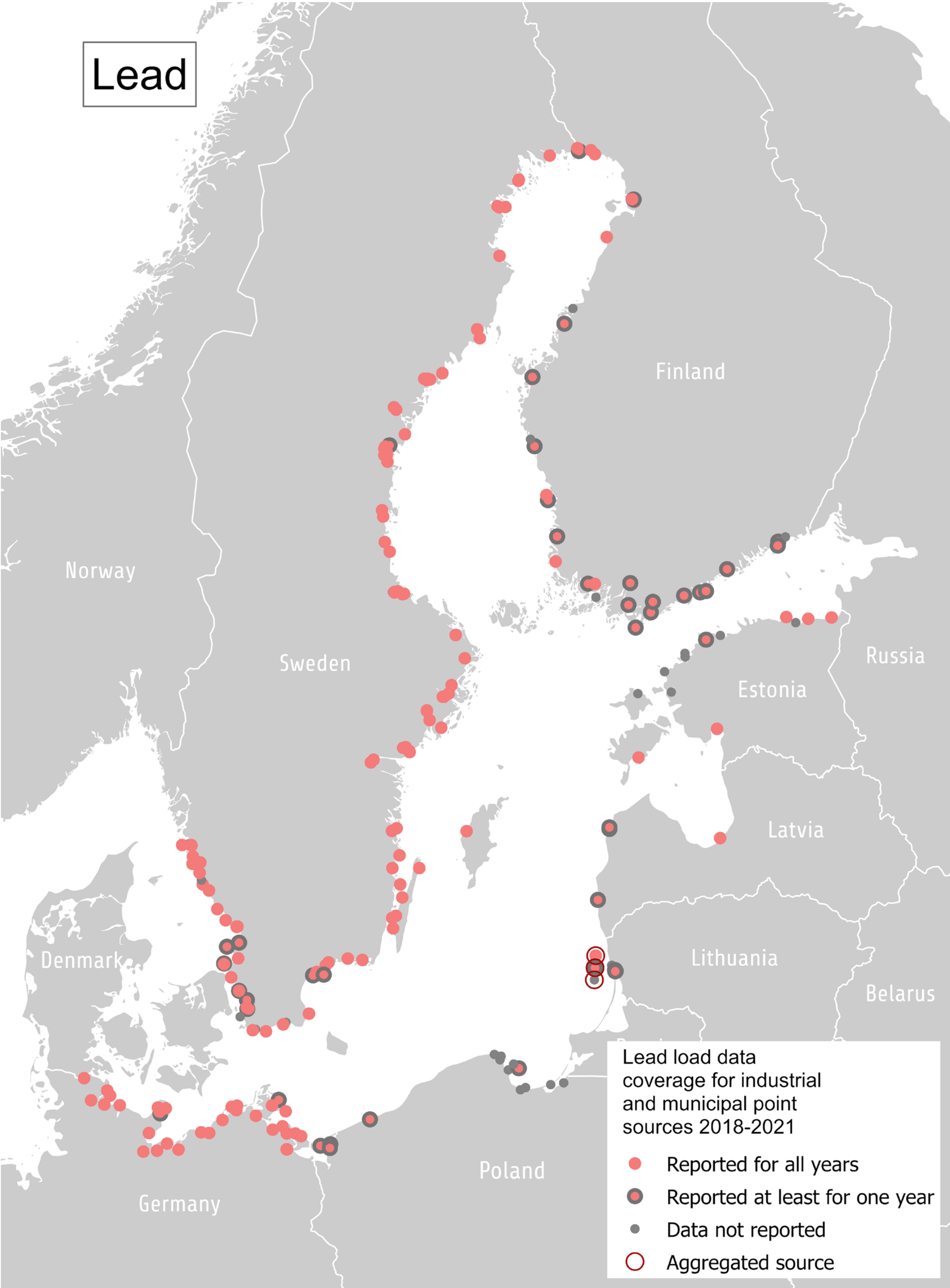


Figure 2. (Continued). The spatial data coverage 2018–2021 of reported inputs from direct point sources of the mandatory metals Cd, Hg and Pb, and the voluntary metals, Cr, Cu, Ni and Zn. Aggregated point sources are indicated by a red border around the points. The aggregated sources are only positioned on the maps within respective sea basin as the number and location of individual sources are not known.



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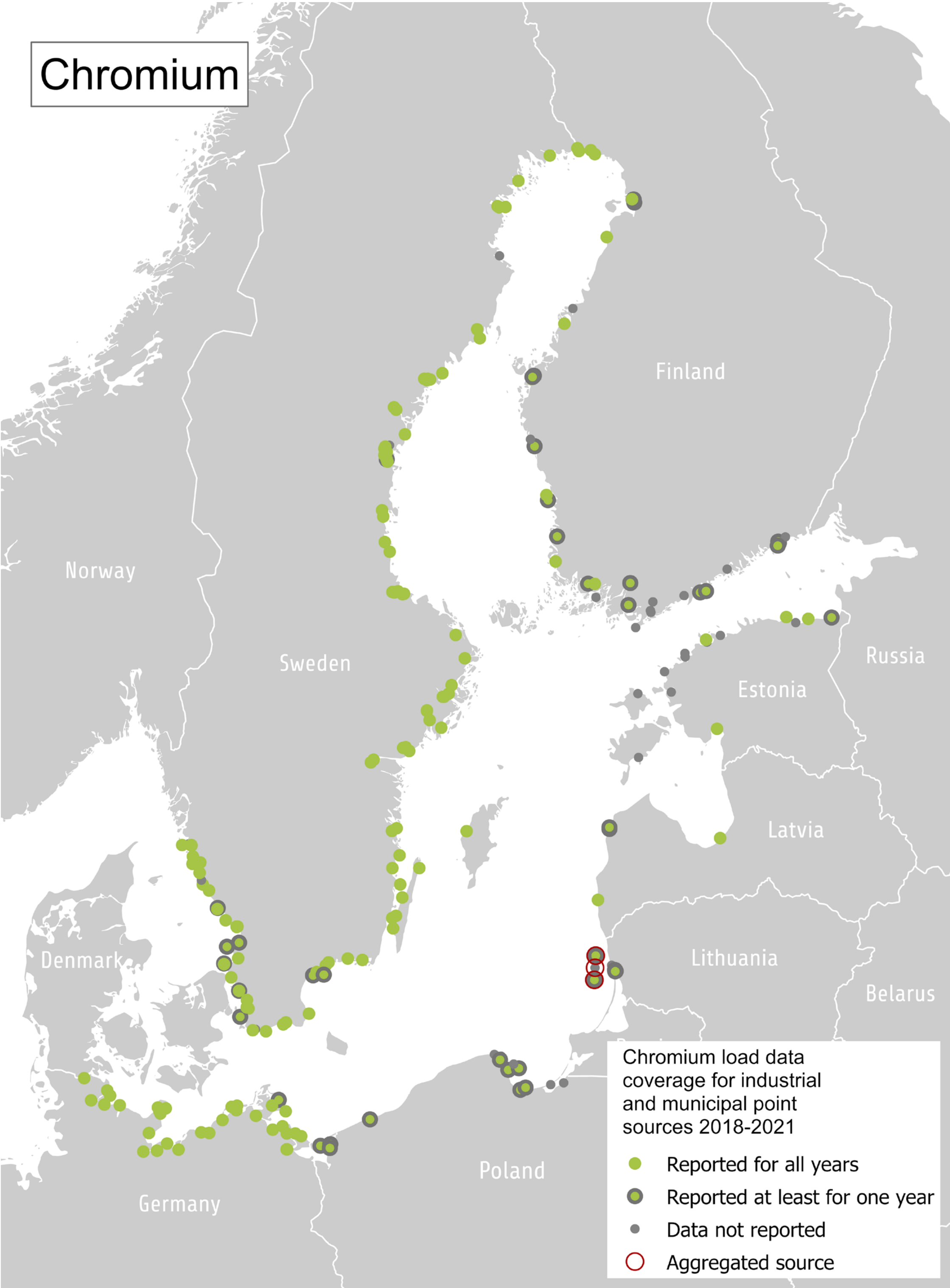

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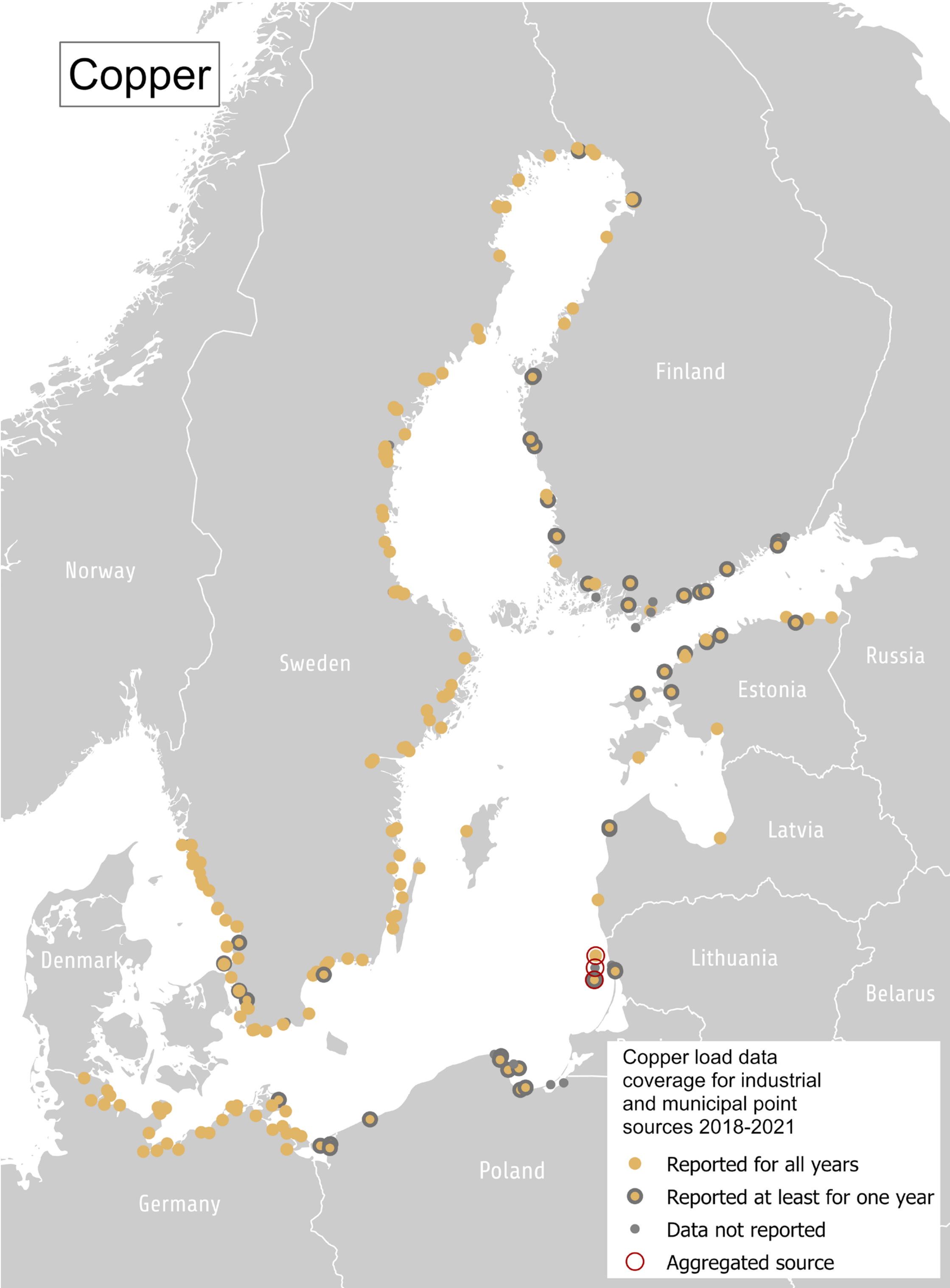

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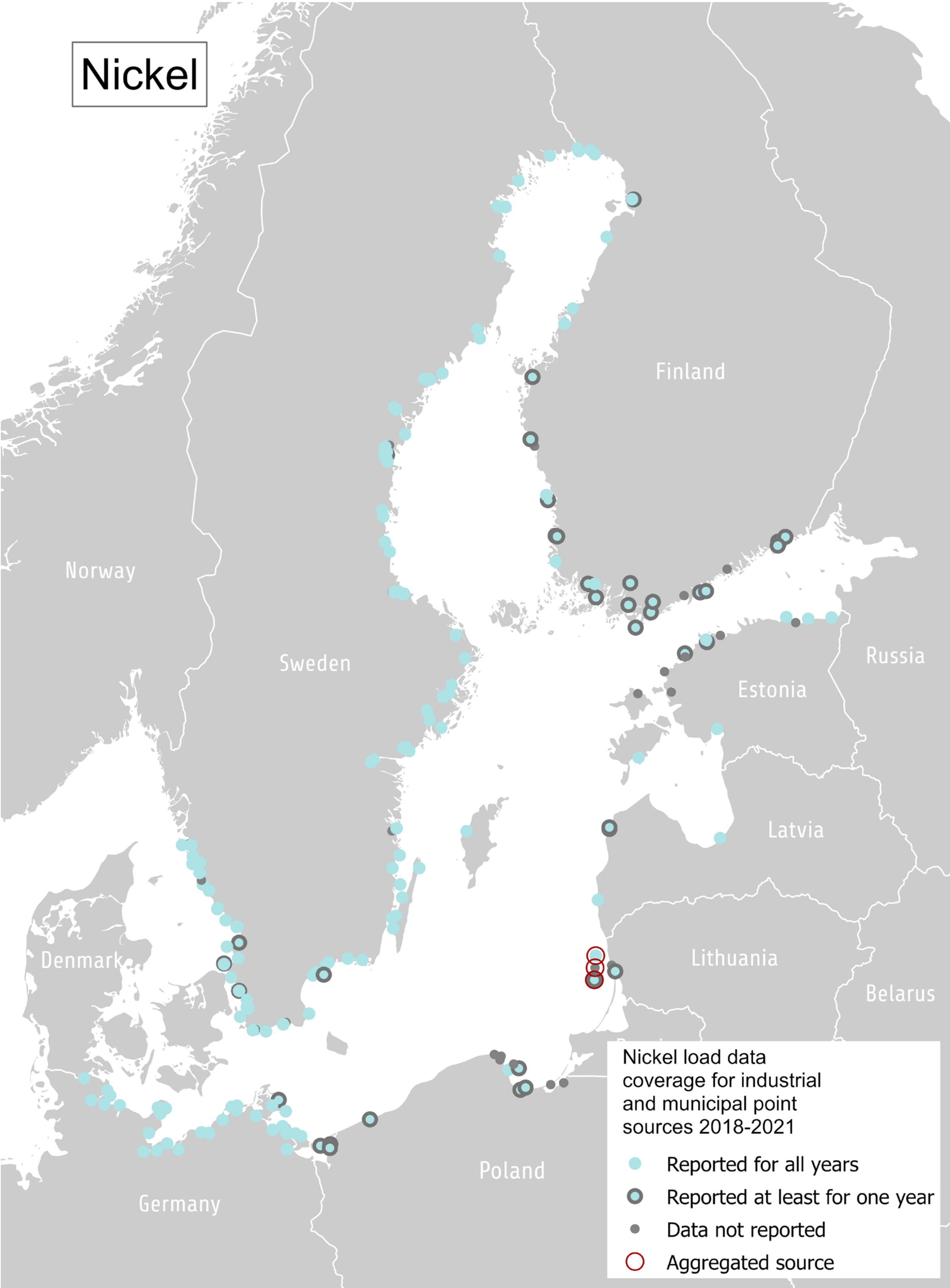

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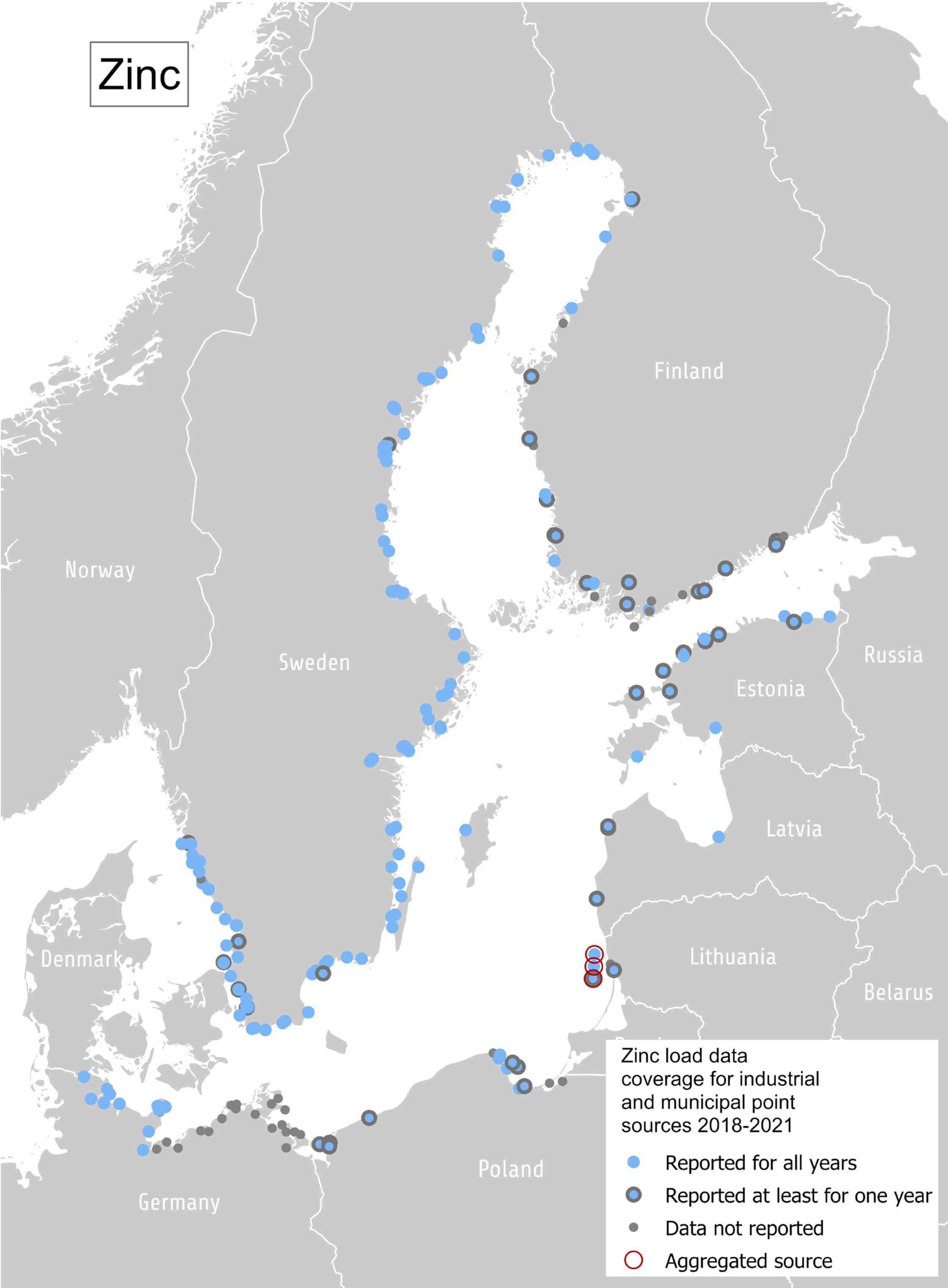

Figure 2. (Continued). The spatial data coverage 2018–2021 of reported inputs from direct point sources of the mandatory metals Cd, Hg and Pb, and the voluntary metals, Cr, Cu, Ni and Zn. Aggregated point sources are indicated by a red border around the points. The aggregated sources are only positioned on the maps within respective sea basin as the number and location of individual sources are not known.

In the quality control of the reported metal data comparisons have mainly been performed in time series for the total metal inputs for a Contracting Party regarding annual riverine data, as well as on data from direct point-sources such as municipal waste water treatment plants and industrial facilities. Potential high or low outliers have subjectively been noted, and the CPs have been notified and asked to verify the outliers. Atypical values may be caused by natural causes, like large variation in water flow due to drought or flooding events, or by anomalies in the data handling or in the laboratory analysis. Loads that are considerably higher than expected might result from estimates based on contaminated samples. In the metal input assessment within PLC-6 the flow-normalised riverine metal inputs were used as a tool to reveal inconsistencies (cf. HELCOM 2018). Unfortunately, due to problems to link the metal inputs to corresponding annual mean water discharges, this quality assurance procedure has not been possible after the PLC-6 assessment.

In many cases too high limits of quantification are used in the laboratory analysis of samples that cause serious implications in making reliable input estimates. In these cases, the estimates will be extra sensitive if the quite common procedure to use LOQ/2 to estimate levels below the limit is applied. That is especially problematic if the estimate is based on a large proportion of observations with levels below the limit. A more realistic weighted approach is recommended in the PLC- Water Guidelines (HELCOM 2022a), but this procedure is not always used by CPs. However, this procedure may also create unreliable input estimates when a large part of the observations is below the LOQ. This is especially true for older data reported before the implementation of the present PLC-Water Guidelines (2022a), in which it is stated that the weighted approach only may be used when at least half of the observations are above the LOQ otherwise the LOQ/2 is to be used. This is to avoid that the estimated input will be "artificially" close to 0 due to lack of quantifiable metal levels caused by too high LOQ levels. In the assessment reported zero inputs have been removed as these originate from no quantifiable metal concentrations at all during the actual year, but most certainly by using a too low LOQ. The usage of recommended LOQs in the PLC Water Guidelines ought to ensure that quantifiable levels can be detected, and consequently also more reliable input estimates. To include zeros would also have an unacceptable impact on the calculated time period averages as they would seriously underestimate the average inputs.

Calculations of the area-specific metal inputs to the Baltic Sea reveal that in general there is a rather good agreement between the inputs from the different countries, although there are some suspiciously low inputs that most probably are not correct (Table 2). For some countries like Latvia and Lithuania the inter-annual variability of the riverine inputs are often in the range of an order of magnitude, but in some cases even more than two orders of magnitude (Table 4). Hence, data for individual countries ought to be handled by care. In this assessment it has not been possible to verify the area covered by the Russian metal input estimates, and consequently no area-specific estimates are given for the Russian inputs.

Recent metal input data are generally believed to give better estimates of the inputs, as the data coverage is in general better compared to earlier years, but also the data quality appears to be better. In spite of this, there are still some concerns about specific estimates, but the data have been quality assured by the CPs and verified as correct. To avoid too high impact of variable data coverage or individual atypical observations mainly the annual average metal inputs for the period 2018-2021 are assessed in this evaluation as these are judged to give the best estimates of the metal inputs to the Baltic Sea. When total annual average inputs have been calculated these are based on the sum of the annual average individual sources (Table 3) or the country specific average annual inputs (Table 4) rather than the average of the included years as the latter would be much more sensitive to missing observations due to poor data coverage. The most striking example on the difference is on the copper inputs in Table 3, where the average of the two years that also contain atmospheric deposition 2018-2019 will only give a total annual average of less than half the annual average for the whole period 2018-2021 since those two years are lacking Cu input data for Russia (cf. Cu in Table 4).

Table 2. Area–specific riverine inputs of cadmium, chromium, copper, mercury, nickel, lead, and zinc from HELCOM Contracting Parties to the Baltic Sea, as well as the area covered by the estimated inputs, and the coverage of the total area of the specific country. The inputs include possible transboundary inputs from upstream countries, and consequently data for individual countries ought to be handled by care.

CP	Cd (kg/km^2)					Area (km^2)	Coverage (%)
	2018	2019	2020	2021	2018-2021		
DE	0.0034	0.0018	0.0026	0.0025	0.0026	23276	81
DK							
EE	0.0002	0.0009	0.0017	0.0037	0.0016	43802	100
FI	0.0037	0.0062	0.0094	0.0062	0.0064	316941	100
LT		0.0106		0.0232	0.0169	47349	73
LV	0.0055	0.0096	0.0060	0.0004	0.0054	65874	100
PL	0.0019	0.0025	0.0029	0.0012	0.0021	304801	98
RU							
SE	0.0031	0.0033	0.0041	0.0035	0.0035	454259	100

Table 2. (Continued). Area-specific riverine inputs of cadmium, chromium, copper, mercury, nickel, lead, and zinc from HELCOM Contracting Parties to the Baltic Sea, as well as the area covered by the estimated inputs, and the coverage of the total area of the specific country. The inputs include possible transboundary inputs from upstream countries, and consequently data for individual countries ought to be handled by care.

CP	Cr (kg/km²)					Area (km²)	Coverage (%)
	2018	2019	2020	2021	2018-2021		
DE	0.039	0.016	0.036	0.037	0.032	23276	81
DK							
EE	0.008	0.017	0.029	0.063	0.029	43802	100
FI	0.180	0.189	0.293	0.224	0.221	316941	100
LT	0.194	0.032	0.061	0.106	0.098	47349	73
LV	0.015	0.008	0.193	0.011	0.057	65874	100
PL	0.014	0.014	0.014		0.014	304801	98
RU							
SE	0.092	0.073	0.106	0.090	0.090	454259	100

CP	Cu (kg/km²)					Area (km²)	Coverage (%)
	2018	2019	2020	2021	2018-2021		
DE	0.335	0.112	0.159	0.193	0.198	23276	81
DK							
EE	0.434	0.525	0.297	0.411	0.411	43802	100
FI	0.366	0.467	0.669	0.505	0.502	316941	100
LT	0.972	0.359	0.317	0.296	0.486	47349	73
LV	0.653	0.653	0.683	0.035	0.501	65874	100
PL	0.180	0.167	0.230		0.194	304801	98
RU							
SE	0.295	0.291	0.372	0.359	0.330	454259	100

CP	Hg (kg/km²)					Area (km²)	Coverage (%)
	2018	2019	2020	2021	2018-2021		
DE	0.0005	0.0001	0.0002	0.0003	0.0003	23276	81
DK							
EE	0.0012	0.0002	0.0006	0.0016	0.0009	43802	100
FI	0.0004	0.0005	0.0009	0.0008	0.0007	316941	100
LT						47349	73
LV	0.0137	0.0125	0.0024	0.0001	0.0072	65874	100
PL	0.0003	0.0002	0.0008	0.0014	0.0007	304801	98
RU							
SE	0.0006	0.0007	0.0009	0.0009	0.0008	454259	100

Table 2. (Continued). Area-specific riverine inputs of cadmium, chromium, copper, mercury, nickel, lead, and zinc from HELCOM Contracting Parties to the Baltic Sea, as well as the area covered by the estimated inputs, and the coverage of the total area of the specific country. The inputs include possible transboundary inputs from upstream countries, and consequently data for individual countries ought to be handled by care.

CP	Ni (kg/km²)					Area (km²)	Coverage (%)
	2018	2019	2020	2021	2018-2021		
DE	0.357	0.103	0.129	0.146	0.185	23276	81
DK							
EE	0.228	0.320	0.274	0.228	0.274	43802	100
FI	0.527	0.726	1.054	0.713	0.754	316941	100
LT	0.275	0.120	0.186	0.824	0.359	47349	73
LV	0.00005	0.00006	0.00008	0.028	0.007	65874	100
PL	0.171	0.171	0.217	0.285	0.210	304801	98
RU							
SE	0.218	0.216	0.277	0.247	0.240	454259	100

CP	Pb (kg/km²)					Area (km²)	Coverage (%)
	2018	2019	2020	2021	2018-2021		
DE	0.034	0.013	0.034	0.026	0.026	23276	81
DK							
EE	0.009	0.030	0.023	0.037	0.025	43802	100
FI	0.063	0.063	0.120	0.082	0.082	316941	100
LT	0.006	0.040	0.042	0.194	0.072	47349	73
LV	0.334	0.319	0.380	0.021	0.273	65874	100
PL	0.008	0.007	0.007	0.043	0.016	304801	98
RU							
SE	0.066	0.062	0.086	0.073	0.070	454259	100

CP	Zn (kg/km²)					Area (km²)	Coverage (%)
	2018	2019	2020	2021	2018-2021		
DE	0.60	0.39	0.49	0.47	0.52	23276	81
DK							
EE	0.53	1.74	1.99	1.55	1.44	43802	100
FI	1.27	1.82	2.71	1.84	1.91	316941	100
LT	9.19	0.09	0.02	0.84	2.53	47349	73
LV	0.88	0.44	0.83	0.05	0.55	65874	100
PL	0.15	0.20	0.43		0.26	304801	98
RU							
SE	0.91	0.97	1.25	1.12	1.06	454259	100

1.3. Total inputs of assessed metals to the Baltic Sea 2018–2021

The total amounts of the different monitored metals that enter the Baltic Sea every year are quite variable, as is also the main route of entry. Of course, for the metals with no information on the atmospheric deposition, i.e. chromium, nickel, and zinc, the full picture on routes of entry is not known. For cadmium, copper, and mercury, where deposition estimates for the assessed time period are available, it is estimated that the total average annual inputs to the Baltic Sea 2018-2021 have been 34, 1088, and 4.8 tonnes per year, respectively (Table 3). Mercury and lead are characterised as metals for which the atmospheric deposition is an especially important route of entry to the Baltic Sea (HELCOM 2021a). The mercury deposition constituted about 58% of the total inputs to the sea in 2018-2021 (Figure 3), which is even more than the estimated 47% for the period 2015-2017 (HELCOM 2021a). For copper the atmospheric deposition is of less importance, with slightly less than 8% of the total inputs in the present period. No deposition data is available for lead for the present assessment period, but the atmospheric input was estimated to be about 40% in the former period (op.cit.). On the other hand, for cadmium the predominant route of entry is via riverine inputs (87%) with only some 11.5% of the total inputs from the atmosphere and 1.5% from direct point-sources. For all assessed metals, the direct point sources make the smallest contribution to the total inputs (about 1-4%), although the point sources might be slightly underestimated as e.g. Sweden only can report metal inputs from larger MWWTs, as smaller plants seldom have reporting obligations on metals in their permits. Anyhow, the direct point sources may be regarded to be substantially less important than the other two routes of entry.

As previously mentioned, there is no atmospheric deposition estimates available for chromium, nickel, and zinc. Hence, the complete picture of the routes of entry for these metals is not known. However, as with the previously mentioned metals, also for these metals the direct point-sources comprise only a minor part (1-3%) of the total waterborne inputs (Table 3, and Figure 4).

Table 3. Inputs of cadmium, chromium, copper, mercury, nickel, lead, and zinc to the Baltic Sea from direct point sources, via rivers, total waterborne, and atmospheric deposition 2018–2021. Atmospheric deposition only available for Cd, Hg and Pb. Annual average inputs 2018–2021 are also given.

Source	Cd (tonnes/year)				Annual average
	2018	2019	2020	2021	2018-2021
Direct point sources	0.55	0.57	0.45	0.4	0.49
Riverine	17	27	49	28	30
Waterborne	17	27	49	29	31
Deposition[a]	4	3	3		4
Total	**21**	**30**	**53**		**35**

Source	Cr (tonnes/year)				Annual average
	2018	2019	2020	2021	2018-2021
Direct point sources	4.1	3.9	4.0	3.6	3.9
Riverine	120	100	163	121	131
Waterborne	124	104	167	125	135
Deposition[a]					
Total					

Source	Cu (tonnes/year)				Annual average
	2018	2019	2020	2021	2018-2021
Direct point sources	14	17	15	17	16
Riverine	431	417	1105	855	987
Waterborne	445	434	1120	872	1003
Deposition[a]	85	85			85
Total	**530**	**519**			**1088**

Table 3. (Continued). Inputs of cadmium, chromium, copper, mercury, nickel, lead, and zinc to the Baltic Sea from direct point sources, via rivers, total waterborne, and atmospheric deposition 2018–2021. Atmospheric deposition only available for Cd, Hg and Pb. Annual average inputs 2018–2021 are also given.

Source	Hg (tonnes/year)				Annual average
	2018	**2019**	**2020**	**2021**	**2018-2021**
Direct point sources	0.065	0.137	0.059	0.063	0.081
Riverine	1.5	2.0	2.2	1.8	2.0
Waterborne	1.6	2.1	2.2	1.8	2.0
Deposition[a]	2.8				2.8
Total	**4.4**				**4.8**

Source	Ni (tonnes/year)				Annual average
	2018	**2019**	**2020**	**2021**	**2018-2021**
Direct point sources	8.6	13.3	10.4	10.9	10.8
Riverine	353	402	747	645	628
Waterborne	362	415	757	655	639
Deposition[a]					
Total					

Source	Pb (tonnes/year)				Annual average
	2018	**2019**	**2020**	**2021**	**2018-2021**
Direct point sources	1.67	1.85	1.75	1.54	1.7
Riverine	76	102	151	135	127
Waterborne	78	104	153	136	129
Deposition[a]					
Total					

Source	Zn (tonnes/year)				Annual average
	2018	**2019**	**2020**	**2021**	**2018-2021**
Direct point sources	83	111	70	74	85
Riverine	5160	2966	3715	2736	3690
Waterborne	5243	3077	3786	2810	3765
Deposition[a]					
Total					

[a] Deposition data from EMEP (HELCOM 2022b for Cd, HELCOM 2021b for Hg, HELCOM 2020 for Pb).

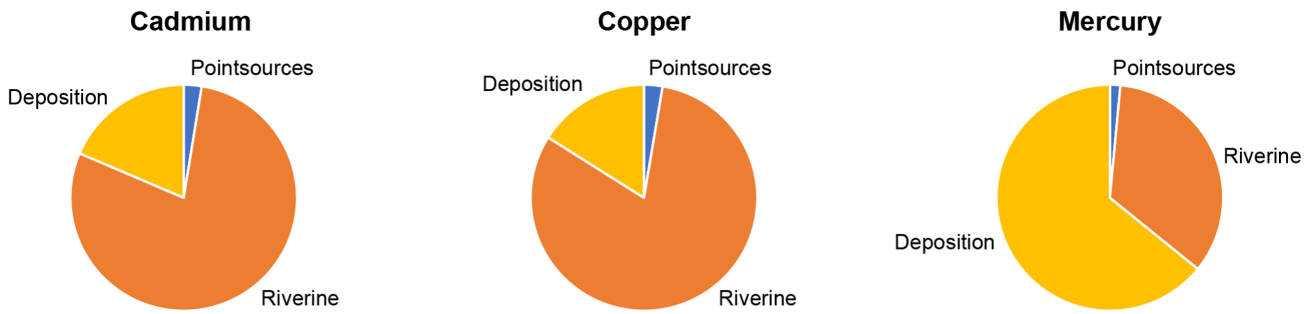

Figure 3. The division of inputs of cadmium, copper and mercury from point sources, via rivers, and atmospheric deposition to the Baltic Sea based on average inputs 2018–2021.

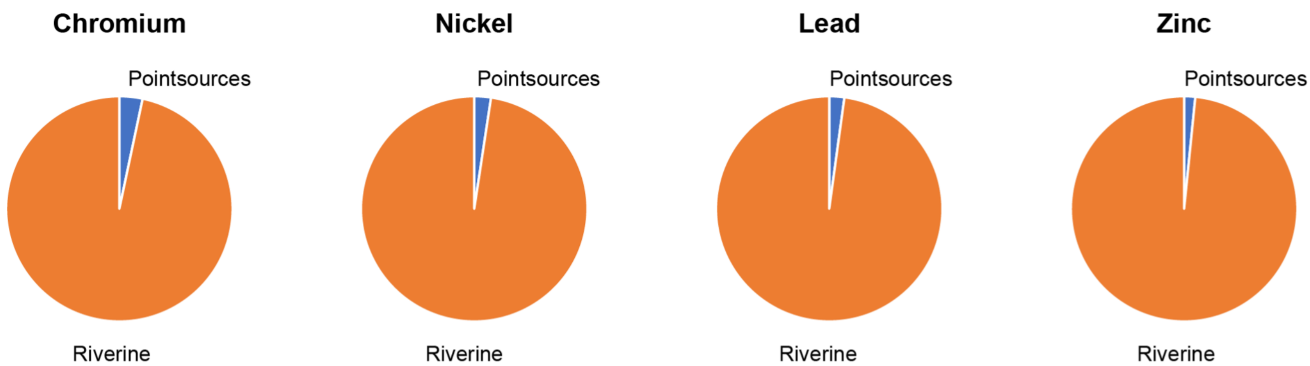

Figure 4. The division of inputs of chromium, nickel, lead and zinc, from point sources and via rivers to the Baltic Sea based on average inputs 2018–2021.

1.4. Inputs of metals via rivers and direct point-sources 2018–2021

In general, CPs with large flow to the Baltic Sea, due to either large rivers and/or large surface area, naturally tend to have larger riverine as well as total waterborne metal loads (Tables 4 and 5). This is in line with the conclusions in the previous section, where it was shown that the metal inputs from direct point-sources in general are quite low compared to the riverine inputs and the inputs via atmospheric deposition for the metals with deposition data available. This is also evident when the load data is presented per contracting party (Tables 4 and 5). It is more difficult to draw any general conclusions on the differences in impact by point sources between the CPs as it is more complicated than just e.g. the number of inhabitants, as it also includes industrial release directly to the Baltic Sea. Also, the composition of waste water, including its origin, is of importance as this will influence the amount of metals in the incoming water to the waste water treatment plants, although the majority of the metals will end-up in the sewage sludge due to their predominantly high particle affinity. In addition, the proportion of inland point sources compared to direct point sources to the Sea is quite important, as the former will be included in the riverine inputs rather than direct point sources.

Table 4. Annual **riverine inputs** of cadmium, chromium, copper, mercury, nickel, lead, zinc to the Baltic Sea 2018–2021. Annual average inputs 2018–2021 are also given.

Country	Cd (tonnes/year)				Annual average
	2018	2019	2020	2021	2018-2021
BY					
DE	0.079	0.042	0.06	0.059	0.06
DK[a]					
EE[b]	0.008	0.041	0.075	0.162	0.072
FI	1.18	1.96	2.99	1.95	2.02
LT[b]		0.5		1.098	0.799
LV[b]	0.362	0.634	0.397	0.028	0.355
PL	0.583	0.767	0.887	0.362	0.65
RU[c]	12.9	21.1	42.5	22.9	24.9
SE	1.40	1.50	1.85	1.60	1.59
Total	**17**	**27**	**49**	**28**	**30**[d]

Country	Cr (tonnes/year)				Annual average
	2018	2019	2020	2021	2018-2021
BY	5.5				5.5
DE	0.91	0.37	0.83	0.87	0.74
DK[a]					
EE[b]	0.35	0.76	1.29	2.77	1.29
FI	57	60	93	71	70
LT[b]	9.2	1.5	2.9	5.03	4.66
LV[b]	1.0	0.5	12.74	0.75	3.74
PL	4.24	4.21	4.27		4.24
RU[c]					
SE	42	33	48	41	41
Total	**120**	**100**	**163**	**121**	**131**[d]

Country	Cu (tonnes/year)				Annual average
	2018	2019	2020	2021	2018-2021
BY	11		8.3		10
DE	7.8	2.6	3.7	4.5	4.6
DK[a]					
EE[b]	19	23	13	18	18
FI	116	148	212	160	159
LT[b]	46	17	15	14	23
LV[b]	43	43	45	2.3	33
PL	55	51	70		59
RU[c]			568	494	531
SE	134	132	169	163	150
Total	**431**	**417**	**1105**	**855**	**987**[d]

Table 4. (Continued). Annual **riverine inputs** of cadmium, chromium, copper, mercury, nickel, lead, zinc to the Baltic Sea 2018–2021. Annual average inputs 2018–2021 are also given.

Country	Hg (tonnes/year)				Annual average
	2018	2019	2020	2021	2018-2021
BY					
DE	0.012	0.003	0.005	0.006	0.006
DK[a]					
EE[b]	0.052	0.007	0.026	0.068	0.038
FI	0.138	0.166	0.283	0.268	0.214
LT[b]					
LV[b]	0.904	0.822	0.156	0.009	0.473
PL	0.09	0.057	0.251	0.414	0.203
RU[c]		0.607	1.059	0.607	0.758
SE	0.295	0.296	0.405	0.395	0.348
Total	**1.5**	**2.0**	**2.2**	**1.8**	**2.0**[d]

Country	Ni (tonnes/year)				Annual average
	2018	2019	2020	2021	2018-2021
BY	4.3		4.8		4.6
DE	8.3	2.4	3	3.4	4.3
DK[a]					
EE[b]	10	14	12	10	12
FI	167	230	334	226	239
LT[b]	13	5.7	8.8	39	17
LV[b]	0.003	0.004	0.005	1.9	0.468
PL	52	52	66	87	64
RU[c]			192	165	179
SE	99	98	126	112	109
Total	**353**	**402**	**747**	**645**	**628**[d]

Country	Pb (tonnes/year)				Annual average
	2018	2019	2020	2021	2018-2021
BY			2		2
DE	0.8	0.3	0.8	0.6	0.6
DK[a]					
EE[b]	0.4	1.3	1	1.6	1.1
FI	20	20	38	26	26
LT[b]	0.3	1.9	2	9.2	3.4
LV[b]	22	21	25	1.4	18
PL	2.5	2.2	2	13	4.9
RU[c]		27	41	50	39
SE	30	28	39	33	32
Total	**76**	**102**	**151**	**135**	**127**[d]

Table 4. (Continued). Annual **riverine inputs** of cadmium, chromium, copper, mercury, nickel, lead, zinc to the Baltic Sea 2018–2021. Annual average inputs 2018–2021 are also given.

Country	Hg (tonnes/year)				Annual average
	2018	2019	2020	2021	2018-2021
BY					
DE	0.012	0.003	0.005	0.006	0.006
DK[a]					
EE[b]	0.052	0.007	0.026	0.068	0.038
FI	0.138	0.166	0.283	0.268	0.214
LT[b]					
LV[b]	0.904	0.822	0.156	0.009	0.473
PL	0.09	0.057	0.251	0.414	0.203
RU[c]		0.607	1.059	0.607	0.758
SE	0.295	0.296	0.405	0.395	0.348
Total	**1.5**	**2.0**	**2.2**	**1.8**	**2.0**[d]

Country	Zn (tonnes/year)				Annual average
	2018	2019	2020	2021	2018-2021
BY	34				34
DE	14	9	11.3	11	12
DK[a]					
EE[b]	23	76	87	68	63
FI	402	576	860	583	605
LT[b]	435	4.4	1	40	120
LV[b]	58	29	55	3.2	36
PL	46	61	132		80
RU[c]	3735	1770	2002	1521	2257
SE	412	440	566	510	482
Total	**5160**	**2966**	**3715**	**2736**	**3690**[d]

Note! [a]Denmark only has a very limited amount of data that is not possible to extrapolate to the whole country, and consequently no data is given here. [b]The spatial and/or temporal coverage of load data from EE, LT and LV is not complete. [c]Inputs from Russia may be overestimated due to the used estimation method based on high LOQ's. [d]Note that the annual average of the total metal input is not the same as the mean of the four different years, as the sum of the different annual averages for the CPs are not influenced by missing observations.

Table 5. Annual inputs of cadmium, chromium, copper, mercury, nickel, lead and zinc from **point sources** to the Baltic Sea 2018–2021. Annual average inputs 2018–2021 are also given.

Country	Cd (tonnes/year)				Annual average
	2018	2019	2020	2021	2018-2021
DE	0.005	0.004	0.004	0.004	0.004
DK[a]	0.012				0.012
EE	0.015	0.014	0.009	0.012	0.012
FI	0.093	0.079	0.059	0.064	0.074
LT				<0.001	<0.001
LV	0.075	0.027	0.024	0.028	0.038
PL	0.022	0.01	<0.001	0.001	0.008
RU[a]	<0.001				<0.001
SE	0.338	0.432	0.357	0.292	0.355
Total	**0.56**	**0.57**	**0.45**	**0.4**	**0.5**

Country	Cr (tonnes/year)				Annual average
	2018	2019	2020	2021	2018-2021
DE	0.162	0.189	0.157	0.15	0.164
DK[a]	0.304				0.304
EE	0.054	0.057	0.048	0.043	0.051
FI	1.99	1.84	1.8	1.52	1.79
LT		0.005	0.001	<0.001	0.002
LV	0.176	0.165	0.209	0.25	0.2
PL	0.011	0.004	0.202	0.063	0.07
RU[a]					
SE	1.72	1.6	1.55	1.61	1.62
Total	**4.4**	**3.9**	**4**	**3.6**	**4.2**[b]

Country	Cu (tonnes/year)				Annual average
	2018	2019	2020	2021	2018-2021
DE	0.645	0.578	0.623	0.576	0.605
DK[a]	0.764				0.764
EE	0.259	0.357	0.457	0.496	0.392
FI	3.41	3.62	2.81	3.89	3.43
LT	0.008	0.013	0.017	0.012	0.012
LV	0.418	0.433	0.824	0.292	0.492
PL	0.692	0.086	0.451	0.539	0.442
RU[a]	1.88				1.88
SE	8.95	11.9	10.2	11	10.5
Total	**17**	**17**	**15**	**17**	**19**[b]

Table 5. (Continued). Annual inputs of cadmium, chromium, copper, mercury, nickel, lead and zinc from **point sources** to the Baltic Sea 2018–2021. Annual average inputs 2018–2021 are also given.

Country	Hg (tonnes/year)				Annual average
	2018	2019	2020	2021	2018-2021
DE	0.0007	0.0009	0.0004	0.0004	0.0006
DK[a]	0.02				0.02
EE	0.0001	0.0001	0.0001	0.0001	0.0001
FI	0.0083	0.0147	0.0172	0.0183	0.0146
LT	0.0006	0.0003	0.0007	0.0005	0.0005
LV	0.0227	0.0073	0.0071	0.0039	0.0102
PL	<0.0001	0.0002	<0.0001	0.0001	0.0001
RU[a]	0.0001				0.0001
SE	0.0324	0.1135	0.034	0.0394	0.0548
Total	**0.085**	**0.137**	**0.059**	**0.063**	**0.101**[b]

Country	Ni (tonnes/year)				Annual average
	2018	2019	2020	2021	2018-2021
DE	0.381	0.398	0.354	0.328	0.365
DK[a]	1.24				1.24
EE	0.23	0.275	0.257	0.186	0.237
FI	3.07	3.66	3.45	4.8	3.75
LT	0.009	0.017	0.009	<0.001	0.009
LV	0.406	0.368	0.722	0.466	0.49
PL	0.061	0.043	1.595	0.391	0.523
RU[a]	0.18				0.18
SE	4.41	8.53	4.06	4.7	5.42
Total	**10**	**13.3**	**10.4**	**10.9**	**12.2**[b]

Country	Pb (tonnes/year)				Annual average
	2018	2019	2020	2021	2018-2021
DE	0.015	0.015	0.018	0.022	0.017
DK[a]	0.737				0.737
EE	0.02	0.029	0.02	0.028	0.024
FI	0.196	0.183	0.165	0.255	0.2
LT	0.001	0.002	0.002	<0.001	0.001
LV	0.222	0.169	0.184	0.137	0.178
PL	0.001	0.002	0.173	0.002	0.044
RU[a]	0.01				0.01
SE	1.21	1.45	1.19	1.1	1.24
Total	**2.41**	**1.85**	**1.75**	**1.54**	**2.45**[b]

Table 5. (Continued). Annual inputs of cadmium, chromium, copper, mercury, nickel, lead and zinc from **point sources** to the Baltic Sea 2018–2021. Annual average inputs 2018–2021 are also given.

Country	Hg (tonnes/year)				Annual average
	2018	2019	2020	2021	2018-2021
DE	0.0007	0.0009	0.0004	0.0004	0.0006
DK[a]	0.02				0.02
EE	0.0001	0.0001	0.0001	0.0001	0.0001
FI	0.0083	0.0147	0.0172	0.0183	0.0146
LT	0.0006	0.0003	0.0007	0.0005	0.0005
LV	0.0227	0.0073	0.0071	0.0039	0.0102
PL	<0.0001	0.0002	<0.0001	0.0001	0.0001
RU[a]	0.0001				0.0001
SE	0.0324	0.1135	0.034	0.0394	0.0548
Total	**0.085**	**0.137**	**0.059**	**0.063**	**0.101**[b]

Country	Zn (tonnes/year)				Annual average
	2018	2019	2020	2021	2018-2021
DE	3.14	3.03	3.11	2.99	3.07
DK[a]	10.1				10.1
EE	2.02	2.3	2.24	4.38	2.74
FI	17	19.3	10.2	10.3	14.2
LT	0.089	0.145	0.091	0.09	0.104
LV	2.56	0.848	1.03	1.44	1.47
PL	3.51	1.7	2.89	2.44	2.63
RU[a]	40.1				40.1
SE	54.3	84.1	50.7	52.1	60.3
Total	**133**	**111**	**70**	**74**	**135**[b]

[a]Data according to BSEP179. [b]Note that the annual average of the total metal input is not the same as the mean of the four different years, as the sum of the different annual averages for the CPs are not influenced by missing observations.

1.5. Total inputs of metals per basin 2018–2021

Comparisons on the basin-wise waterborne metal inputs is, like in the two earlier PLC metal assessments (HELCOM 2018b, 2021a), only possible for some of the Baltic Sea basins (Table 6). No data is presented for the southernmost basins mainly due to the lack of total load estimates for Denmark that makes it impossible to make comparisons with the other basins. Although the general picture on the metal pressure on the different basins seem to be acceptable, there are quite substantial inter-annual variability for especially the Gulf of Finland and Gulf of Riga. The large variability is partly due to incomplete reporting, but also to the fact that several of the countries with metal discharge to these two basins often have input estimates based on a considerable number of observations less than the LOQs, and in most cases also have LOQs notably higher than the levels recommended in the PLC Water Guidelines (cf. HELCOM 2022a).

Table 6. Total annual waterborne inputs of cadmium, chromium, copper, mercury, nickel, lead and zinc, to the Baltic Sea basins 2018–2021. Annual average inputs 2018–2021 are also given.

Country	Cd (tonnes/year)				Annual average
	2018	2019	2020	2021	2018-2021
BOB	0.95	1.3	2.29	1.6	1.53
BOS	1.22	1.42	1.69	1.35	1.42
ARC	0.05	0.09	0.15	0.07	0.09
BAP	1.08	6.35	5.98	3.83	4.31
GUF	13.1	16.9	38.1	21.3	22.3
GUR	0.33	0.6	0.4	0.07	0.35
WEB[a]					
SOU[a]					
KAT[a]					

Country	Cr (tonnes/year)				Annual average
	2018	2019	2020	2021	2018-2021
BOB	47.6	41.5	73.4	61.3	55.9
BOS	27.6	20.9	32	29.2	27.4
ARC	5.06	6.96	11.06	4.04	6.78
BAP	24.8	10.1	14.1	10.3	14.8
GUF	11.2	14.7	13.4	10.4	12.4
GUR	0.9	0.98	12.2	1.65	3.93
WEB[a]					
SOU[a]					
KAT[a]					

Table 6. (Continued). Total annual waterborne inputs of cadmium, chromium, copper, mercury, nickel, lead and zinc, to the Baltic Sea basins 2018–2021. Annual average inputs 2018–2021 are also given.

Country	Cu (tonnes/year)				Annual average
	2018	2019	2020	2021	2018-2021
BOB	96.5	97	164	132	122
BOS	77.6	81.6	106	96.4	90.4
ARC	7	13.6	20.6	11	13.1
BAP	148	103	129	49.8	108
GUF	41.6	59.9	610	538	312
GUR	41.9	43.5	47	6.21	34.7
WEB[a]					
SOU[a]					
KAT[a]					

Country	Hg (tonnes/year)				Annual average
	2018	2019	2020	2021	2018-2021
BOB	0.18	0.18	0.321	0.333	0.254
BOS	0.161	0.242	0.226	0.229	0.214
ARC	0.005	0.015	0.021	0.011	0.013
BAP	0.231	0.864	1.395	1.077	0.892
GUF	0.064	0.034	0.035	0.074	0.052
GUR	0.858	0.682	0.15	0.033	0.431
WEB[a]					
SOU[a]					
KAT[a]					

Country	Ni (tonnes/year)				Annual average
	2018	2019	2020	2021	2018-2021
BOB	135	147	257	173	178
BOS	81.9	109	135	107	108
ARC	4.8	8.98	11.8	6.01	7.89
BAP	97.2	81.2	105	156	110
GUF	22.9	44.3	221	189	119
GUR	2.1	3.57	4.28	4.25	3.55
WEB[a]					
SOU[a]					
KAT[a]					

Table 6. (Continued). Total annual waterborne inputs of cadmium, chromium, copper, mercury, nickel, lead and zinc, to the Baltic Sea basins 2018–2021. Annual average inputs 2018–2021 are also given.

Country	Pb (tonnes/year)				Annual average
	2018	2019	2020	2021	2018-2021
BOB	15.9	12.8	25.1	21.3	18.8
BOS	18.5	12.7	19.8	17.2	17
ARC	1.95	3.55	7.82	2.95	4.07
BAP	11.3	31.9	34.4	33.3	27.7
GUF	3.65	15.3	30.5	50.3	24.9
GUR	19.5	17.4	21.7	1.91	15.1
WEB[a]					
SOU[a]					
KAT[a]					

Country	Zn (tonnes/year)				Annual average
	2018	2019	2020	2021	2018-2021
BOB	348	414	758	502	505
BOS	317	360	420	408	376
ARC	24.6	37.5	53.9	22.7	34.7
BAP	596	155	211	115	269
GUF	3805	1935	2154	1636	2383
GUR	65.4	40.5	60.9	19.4	46.5
WEB[a]					
SOU[a]					
KAT[a]					

Note! [a]The data is considered too incomplete to be assessed (DK data only as estimates for point sources, and for in total twelve rivers for three basins).

1.6. Waterborne inputs of cadmium, mercury, and lead to the Baltic Sea 1995–2021

A considerable inter-annual variability in inputs of Cd, Hg, and Pb to the Baltic Sea is shown for most countries during the period 1995-2021 (Figures 5-7). Complete data series with more reasonable inter-annual variability throughout the whole period is available only for a few countries, though in some cases only a few observations may be lacking. More challenging is that for some countries there are considerable problems with the spatial and/or temporal data coverage, especially back in time. Particularly for mercury there is quite a lot of missing data in many time series, probably cause due to it being challenging to sample and analyse at low environmentally relevant levels, as well as it is comparatively expensive. Denmark reported to the corresponding PLC-6 assessment for point sources and in total twelve rivers for the period 2012-2014. This limited data has been excluded in the assessment as it is not possible to extrapolate to estimate the total inputs for Denmark. Taken these data issues into consideration, assessments of the overall waterborne inputs over time can only be done with caution. Especially data in early years in the time series need to be evaluated with care, as even complete time series might be based on estimates with changes over time in spatial coverage, analytical methods and/or LOQs.

The three most complete and consistent time series for the assessed metals, i.e. for Germany, Finland, and Sweden, generally show reduced waterborne inputs or at least stable inputs levels over time for all three metals (Figures 5-7). The input of cadmium and lead for the other countries with more or less complete time series show rather large inter-annual variability obscuring potential trends (Figures 5 and 7). Except for Germany, Finland and Sweden, the variability and/or scatteredness of reported mercury inputs is too large to reveal any tendencies (Figure 6).

Figure 5. The annual waterborne inputs of cadmium from the Contracting Parties to the Baltic Sea (tonnes per year) 1995–2021. The bars show the sum of inputs from rivers and direct point sources. Note! Denmark is excluded due to very limited amount of data. Large inter-annual variability may be due to differences in the number of sources between years, but also on estimate methods used when observations are less than LOQ.

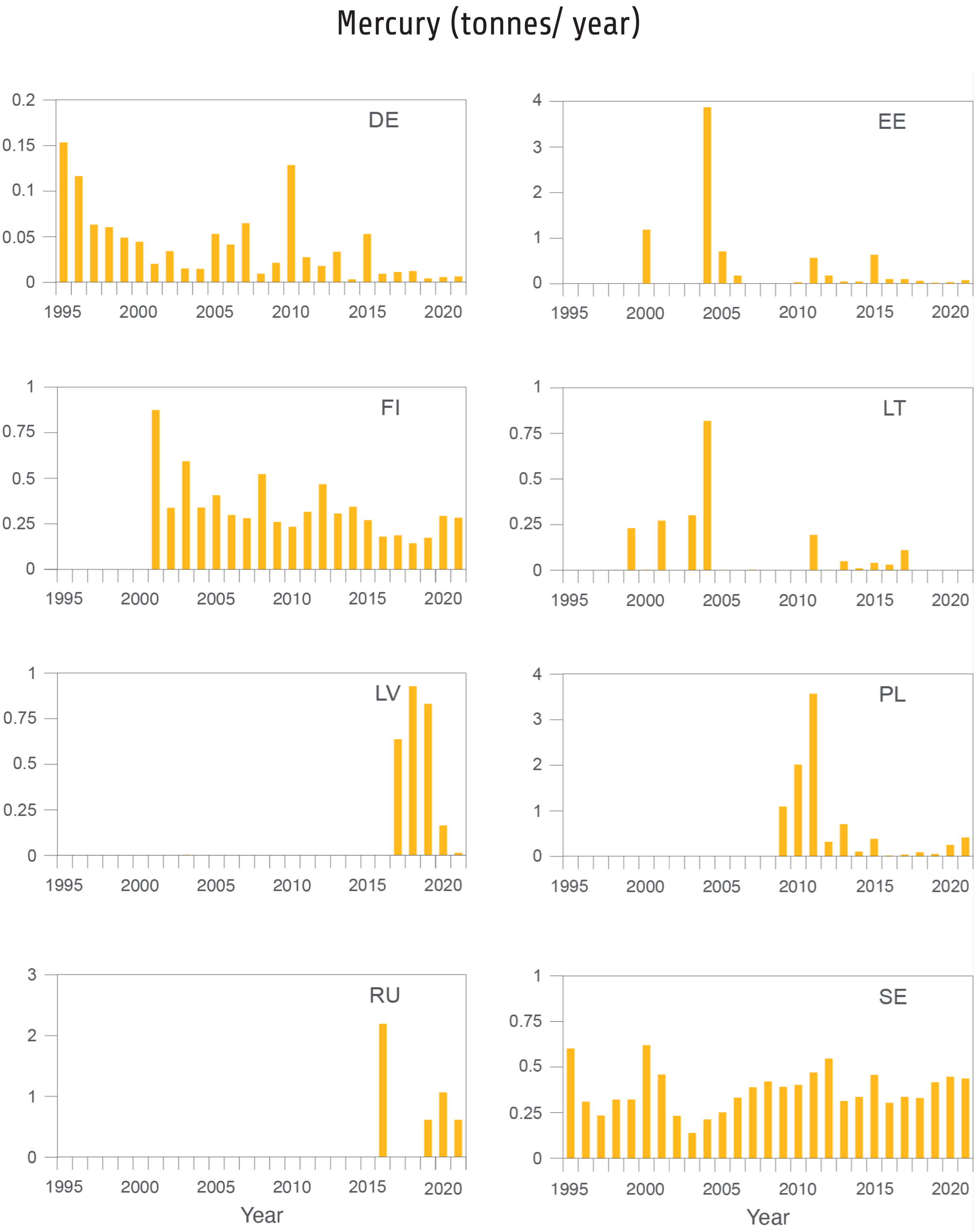

Figure 6. The annual waterborne inputs of mercury from the Contracting Parties to the Baltic Sea (tonnes per year) 1995–2021. The bars show the sum of inputs from rivers and direct point sources. Note! Denmark is excluded due to very limited amount of data. Latvian data only from 2017, and Russian data only for 2016, and 2019–2021. Large inter-annual variability may be due to differences in the number of sources between years, but also on estimate methods used when observations are less than LOQ.

Figure 7. The annual waterborne inputs of lead from the Contracting Parties to the Baltic Sea (tonnes per year) 1995–2021. The bars show the sum of inputs from rivers and direct point sources. Note! Denmark is excluded due to very limited amount of data. Large inter-annual variability may be due to differences in the number of sources between years, but also on estimate methods used when observations are less than LOQ.

1.7. Atmospheric deposition of cadmium, mercury, and lead

For the present PLC-8 assessment of metal inputs to the Baltic Sea is new data on atmospheric metal deposition only available for cadmium and copper. In the PLC-7 assessment was also deposition for mercury (1990-2018) and lead (1990-2017) included (HELCOM 2021a), whereas copper deposition is new to this assessment.

The modelled atmospheric deposition of both cadmium and copper show reducing deposition over time from the start of the time series in 1990 up to present (2020 for cadmium and 2019 for copper), and this is valid for both the annual depositions as well as the weather-normalised annual depositions (Figures 8-9). The cadmium deposition is reduced more than the copper deposition (-79%, and -42% respectively). However, according to the EMEP modelling results (HELCOM 2021b) the decline in copper deposition is not uniform over the Baltic Sea area, where the highest decline is in the norther basins (-53 – -74%), but lower in the southernmost basins (-18 – 24%). These two southernmost basins, The Sound and Western Baltic also have the highest area-specific copper deposition, due to the comparatively high emissions southwest to these basins (Figure 10). The cadmium deposition and emissions show similar spatial pattern, but at lower levels and with less variability than the copper deposition (Figure 11).

Atmospheric cadmium deposition 1990–2020 (tonnes/ year)

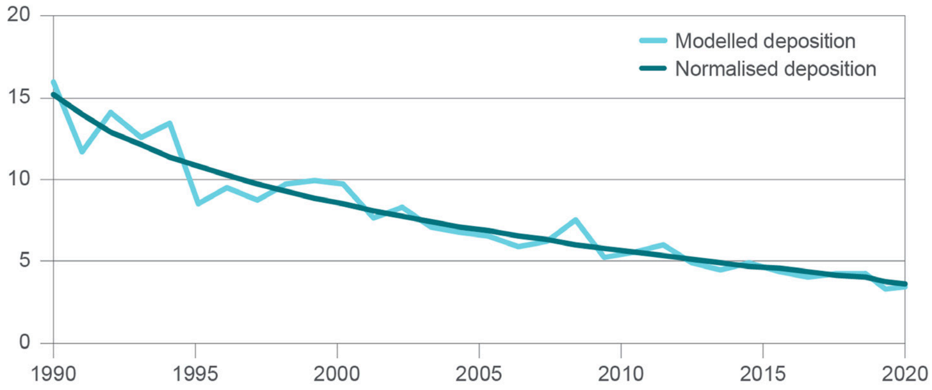

Figure 8. Modelled and normalised atmospheric cadmium deposition (tonnes/year) on the Baltic Sea 1990–2020. Data from EMEP (HELCOM 2022b).

Atmospheric copper deposition 1990–2019 (tonnes/ year)

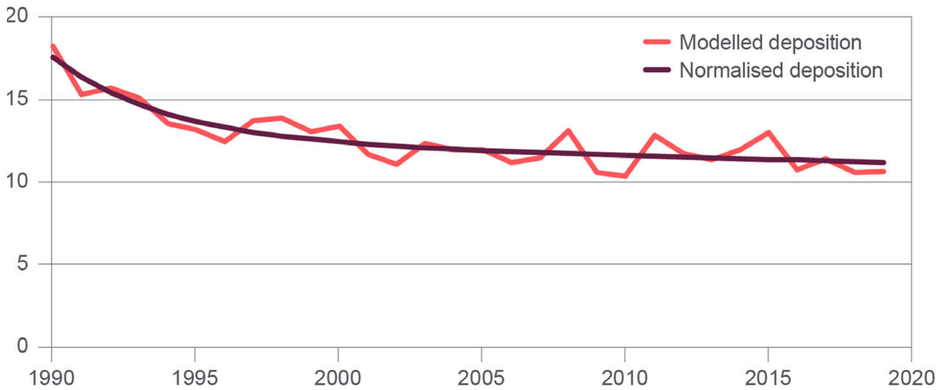

Figure 9. Modelled and normalised atmospheric copper deposition (tonnes/year) on the Baltic Sea 1990–2019. Data from EMEP (HELCOM 2021b).

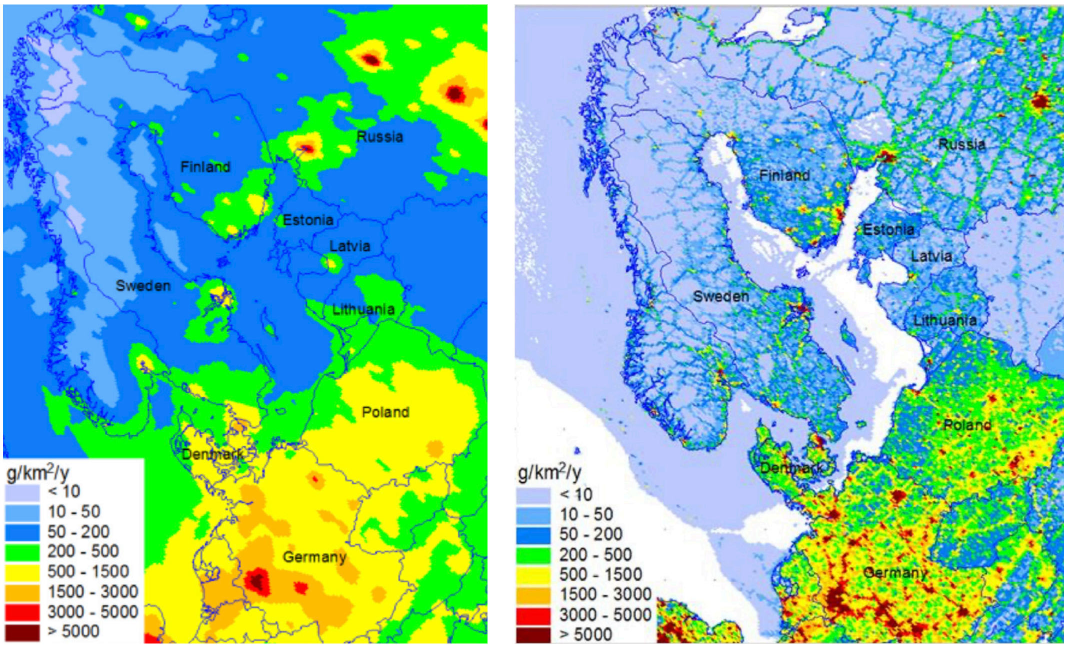

Figure 10. Total annual copper deposition (left) and emissions (right) in 2019, in g/km^2/y. From EMEP (Gauss *et al.* 2021).

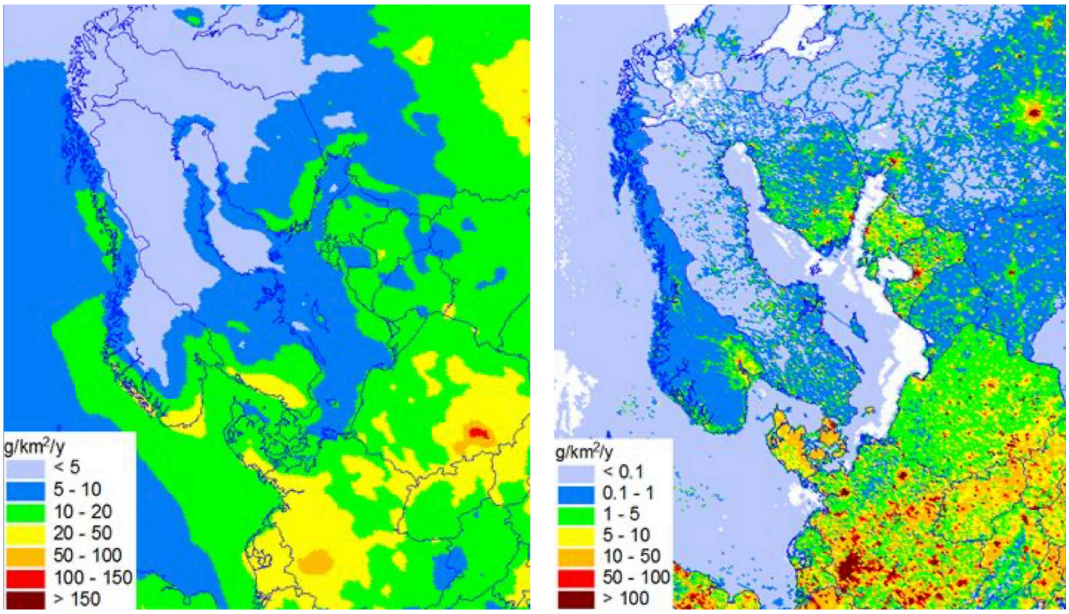

Figure 11. Total annual cadmium deposition (left) and emissions (right) in 2020, in g/km^2/y. From EMEP (Gauss *et al.* 2022).

2. Atmospheric deposition of some selected organic contaminants

The European Monitoring and Evaluation Programme (EMEP) has been committed by HELCOM to model and evaluate the deposition of some selected organic contaminants based on available emission data. In the present report benzo(a)pyrene (BaP), polybrominated diphenyl ethers (BDE-99), and hexachlorobenzene (HCB) has been assessed. EMEP has also evaluated the possibilities to model hexabromocyclododecane (HBCDD), polychlorinated naphthalenes (PCNs) and pentachlorobenzene (PeCB), but concluded that presently the available information is not enough to be used for detailed deposition modelling (Gauss et al. 2022).

2.1. Atmospheric deposition of Benzo(a)pyrene to the Baltic Sea

The atmospheric deposition of Benzo(a)pyrene to the Baltic Sea has steadily decreased since 1990 (Figure 12). The spatial pattern of both the deposition and the anthropogenic emissions are rather similar to the patterns for the metals, with a strong south-to-north gradient, and the highest levels in the south to be found in the southern part of Poland (Figure 13). In addition, both the emissions and the deposition tend to be higher on the eastern side of the Baltic Sea, compared to the western side. The main contributor to the B(a)P deposition is the so-called “Residential Combustion” (HELCOM 2022c).

Atmospheric B(a)P deposition 1990–2020 (tonnes/ year)

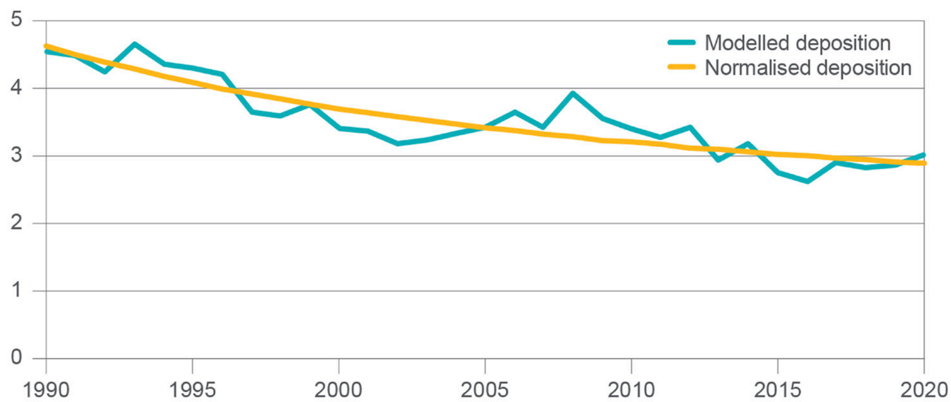

Figure 12. Modelled and normalised atmospheric B(a)P deposition (tonnes per year) on the Baltic Sea 1990–2020. Data from EMEP (HELCOM 2022c).

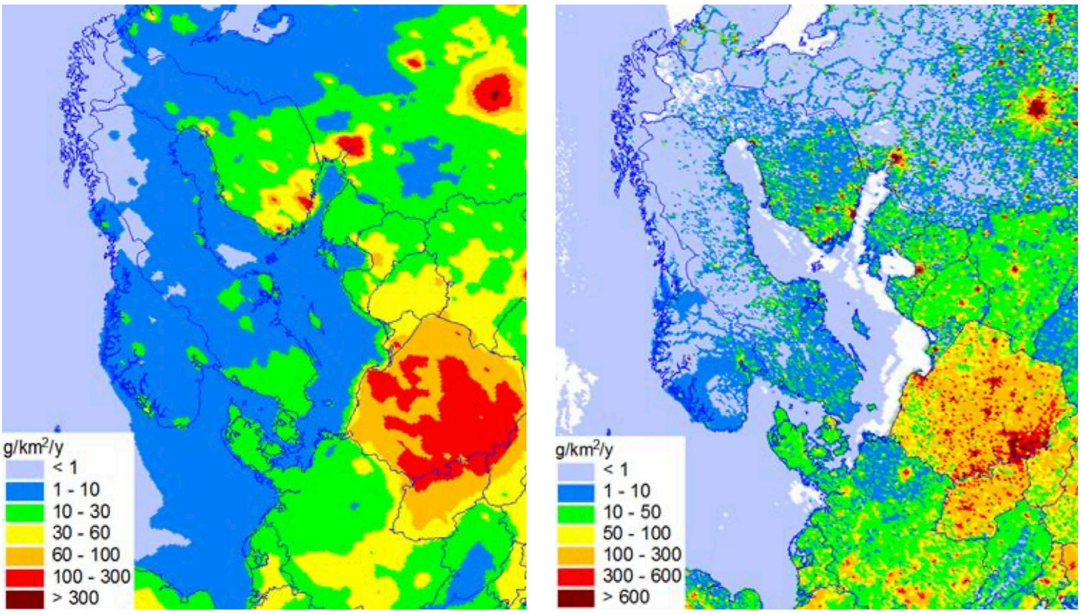

Figure 13. Total annual Benzo(a)pyrene deposition (left) and anthropogenic emissions (right) in the Baltic Sea region 2020 in g/km^2/year. From (HELCOM 2022c, d).

2.2. Atmospheric deposition of polybrominated diphenyl ethers (PBDEs) to the Baltic Sea

The atmospheric deposition of the brominated flame-retardant congener 2,2',4,4',5-pentabromodiphenyl ether (BDE-99) is nowadays about one tenth of the deposition only 20 years ago (Figure 14). The reduction is mainly due to various abatement measures in HELCOM as well as other EMEP countries (HELCOM 2021c) eg. by the EU Restriction of Hazardous Substances Directive (2002/95/EC). The spatial distribution of the BDE-99 depoaition is showing a south-to-north gradient as with most other substances (Figure 15). As the emission used in the EMEP modelling are based on expert estimates no map on the geographical emissions is available, and there are also high uncertainties in the assessment due to the lack of detailed emission data.

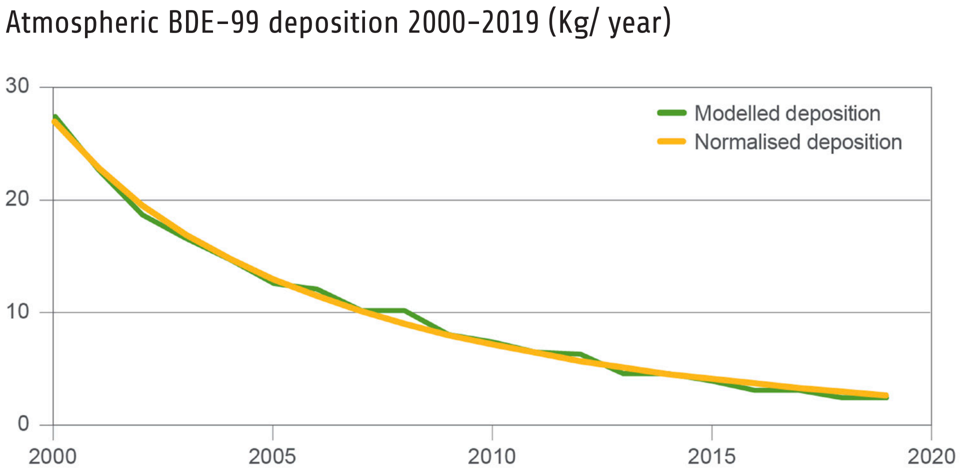

Figure 14. Modelled and normalised atmospheric BDE-99 deposition (tonnes per year) on the Baltic Sea 1990–2019. Data from EMEP (HELCOM 2021c).

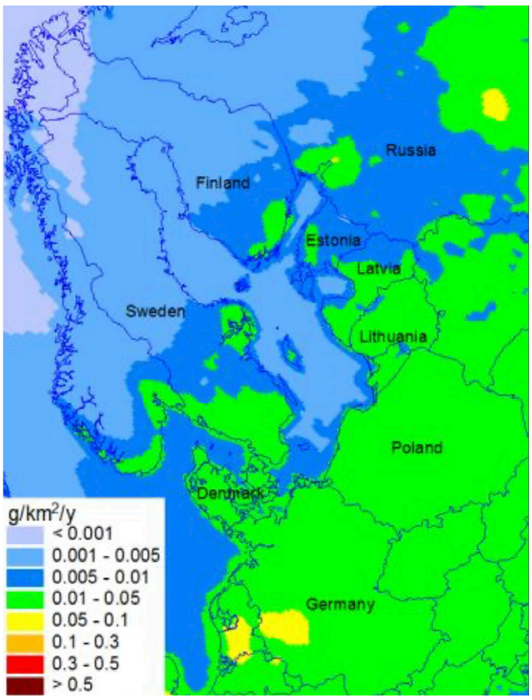

Figure 15. Annual deposition of BDE-99 in the Baltic Sea region 2019 in g/km²/year. From HELCOM (2021c).

2.3. Atmospheric deposition of HCB to the Baltic Sea

The atmospheric deposition of the fungicide hexachlorobenzene (HCB) has reduced by some 95% since 1990 (figure 16). Although the modelled deposition is reduced in quite a uniform pattern, the emissions from most of the HELCOM countries show a drastic reduction around 1999-2002, and especially the drastic decline by the former large emitter Germany (-99% in 2002) is notable (HELCOM BSEFS 2021a). The drastic drop around 2000 is most certainly due to implementation of the policy control of emissions within the framework of UNECE Convention on Long-Range Transboundary Air Pollution (CLRTAP). The slower response on the deposition reductions is probably due to the substance atmospheric long-range pollutant characteristics as well as unintentional releases due to industrial and combustion processes, as well as re-volatilization from land and water surfaces.

Atmospheric hexachlorobenzene deposition 1990–2019 (tonnes/ year)

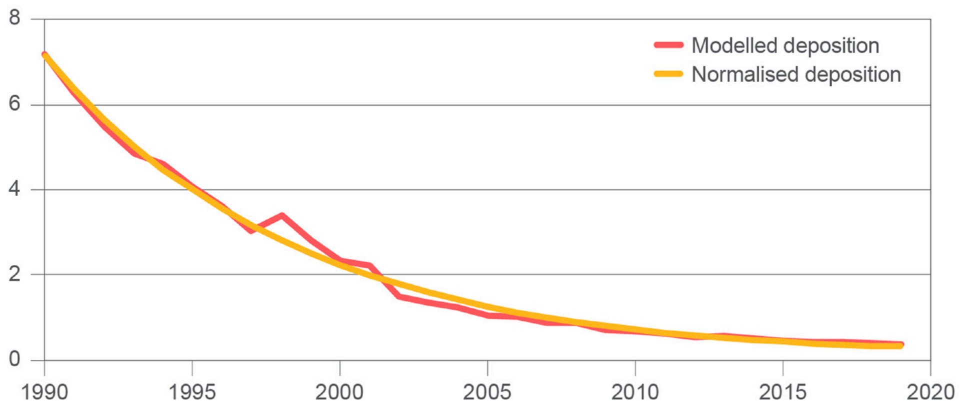

Figure 16. Modelled and normalised atmospheric HCB deposition (tonnes per year) on the Baltic Sea 1990–2019. Data from EMEP (HELCOM 2021d).

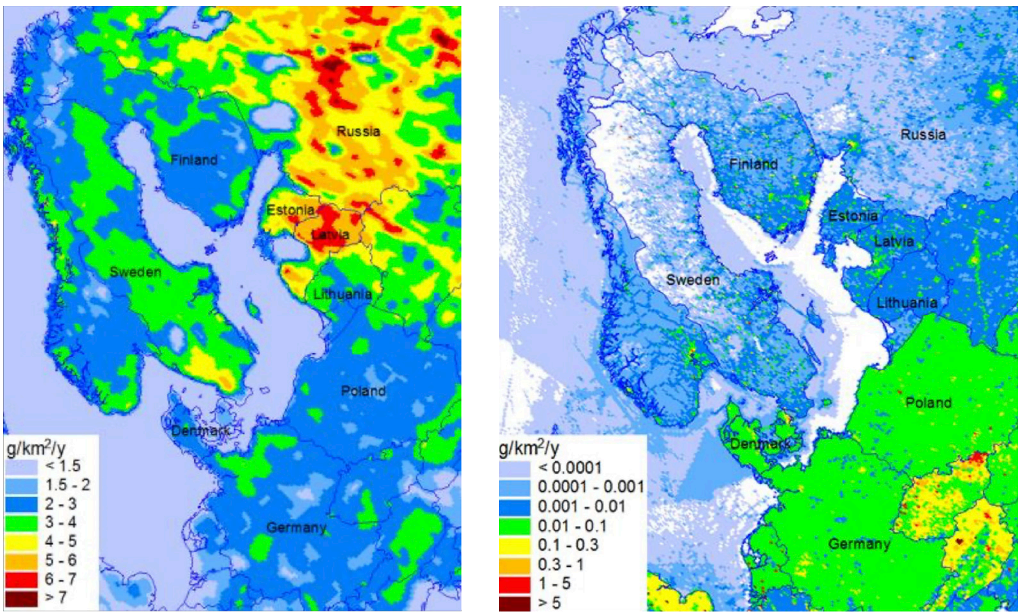

Figure 17. Annual deposition (left) and anthropogenic emissions (right) of hexachlorobenzene (HCB) in the Baltic Sea region 2019 in g/km^2/year. From (HELCOM 2021d, e).