Waterborne nitrogen and phosphorus inputs and water flow to the Baltic Sea 1995-2018

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Key Message

Annual water flow in 2018 to the Baltic Sea was approximately 14,300 $m^3 s^{-1}$ which is about 9% lower than the average of 1995-2018. Annual waterborne input (inputs via rivers and direct point sources discharging directly into the sea) of total nitrogen was approximately 530,000 tonnes in 2018 or 21% lower than the average of 1995-2018. The corresponding annual total phosphorus input amounted to approximately 21,900 tonnes, which was 32% lower than the average.

Inputs of nitrogen and phosphorus from direct point sources have decreased with approximately 60% and 84% since 1995, respectively. In 2018, inputs from direct point sources constituted 5% of the corresponding total waterborne input to the Baltic Sea. In 1995, the proportions of the direct inputs were 8% for TN and 15% for TP, respectively.

Annual flow weighted riverine TN concentration decreased significantly (95% confidence) to the Bothnian Sea, the Baltic Proper, the Danish Straits and the Kattegat, and for TP to the Bothnian Sea, the Baltic Proper, the Gulf of Finland, the Gulf of Riga and the Danish Straits since 1995. Both TN and TP concentrations decreased significantly for the total riverine inputs to the Baltic Sea.

[1] The authors want to thank colleagues contributing to data reporting, quality assuring and data management related to this BSEFS:
Damian Bojanowski (State Water Holding Polish Waters), Peeter Ennet, (Estonian Environment Agency), Dmitry Frank-Kamenetsky (HELCOM Secretariat), Juuso Haapaniemi (HELCOM Secretariat), Katarina Hansson (IVL Swedish Environmental Research Institute), Ilga Kokorite (Latvian Environment, Geology and Meteorology Center), Pekka Kotilainen (Finnish Environment Agency, SYKE), Julian Mönnich (German Environment Agency), Natalia Oblomkova (Institute for Engineering and Environmental Problems in Agricultural Production, Russia), Svajunas Plunge (Lithuanian Environmental Protection Agency), Jan Pryzowicz (State Water Holding Polish Waters), Antti Räike (Finnish Environment Agency, SYKE), Alexander Sokolov (Baltic Nest Institute, Stockholm University), Lars Sonesten (Department of Aquatic Sciences and Assessment, Swedish University of Agricultural Science), Henrik Tornbjerg (Institute of Bioscience, Aarhus University) and Antje Ullrich (German Environment Agency).

Results and Assessment

Relevance of nutrient input time-series for describing developments in the environment

This fact sheet includes information on annual water flow and inputs of nitrogen and phosphorus via rivers (riverine inputs) and point sources discharging directly to the sea (direct inputs) together comprising the waterborne inputs to the Baltic Sea sub-basins during 1995-2018. The inputs are the actual (not discharge-normalized) annual inputs. A separate annual BSEFS on atmospheric nitrogen inputs is delivered by EMEP (e.g. Gauss et al., 2018).

The normalized waterborne inputs combined with the corresponding atmospheric nutrient inputs are annually evaluated in the HELCOM core pressure indicator: "Inputs of nutrients to the sub-basins of the Baltic Sea" (the latest is HELCOM 2019a), although with about six months delay compared to this fact sheet.

Eutrophication in the Baltic Sea is largely driven by excessive inputs of the nutrients nitrogen and phosphorus due to accelerating anthropogenic activities during the 20th century. Nutrient over-enrichment (eutrophication) and/or changes in nutrient ratios in the aquatic environment cause elevated levels of algal and plant biomass, increased turbidity, oxygen depletion in bottom waters, changes in species composition and nuisance blooms of algae.

The majority of nutrient inputs originate from anthropogenic activities on land and at sea and enters the Baltic Sea either as waterborne inputs or as atmospheric deposition on the Baltic Sea. Waterborne inputs enter the sea via riverine inputs and direct point source discharges. The main sources of waterborne inputs are diffuse sources (agriculture, managed forestry, scattered dwellings, storm overflows etc.), natural background sources, and point sources (as waste water treatment plants, industries and aquaculture)[2]. In addition, excess nutrients stored in bottom sediments can enter the water column and enhance primary production of plants. Waterborne inputs are the major input pathways, e.g. providing approximately 75% of >TN and 93% of TP input in 2017 (HELCOM, 2019a).

We need time series with information on annual nutrient inputs to follow up the long-term changes in the nutrient inputs to the Baltic Sea. Quantified input data is a prerequisite to interpret, evaluate and predict the state of the marine environment and related changes in the open sea and coastal waters. Change in nutrient inputs combined with quantification of inputs from land-based sources and retention within the catchment, is crucial for determining the importance of different sources of nutrients for the pollution of the Baltic Sea as well as for assessing the effectiveness of measures taken to reduce the pollution inputs.

Assessment

The assessment dataset is produced by the Baltic Nest Institute (BNI), Stockholm University together with the Danish Centre for Environment and Energy (DCE), Aarhus University. It is based on the data on riverine and direct sources flow, total nitrogen (TN) and total phosphorous (TP) annually reported by Contracting Parties to the Helsinki Convention. Reported data are checked for outliers, data gaps are filled, and other validations procedures performed by BNI and DCE before an assessment dataset with nutrient inputs to each Baltic Sea sub-basin and from each country to each sub-basin is established. The assessment data set covers all known waterborne inputs from the entire Baltic Sea catchment area.

This fact sheet provides information on the actual annual TN and TP waterborne inputs (sum of riverine and direct inputs) entering to the seven main sub-basins (Figure 1). We focus mainly on riverine inputs as they constituted more than 95% of both TN and TP waterborne inputs to the Baltic Sea in 2018,

[2] The main sectors contributing to atmospheric inputs are combustion in energy production and industry as well as transportation for oxidized nitrogen and agriculture for reduced nitrogen. A large proportion of atmospheric inputs originate from distant sources outside the Baltic Sea region. Emissions from shipping in the Baltic and North seas also contribute significantly to atmospheric inputs of nitrogen.

respectively. In the evaluation of progress towards MAI and CART as published in HELCOM (2019a) (MAI) and Svendsen et al. (2018) (CART), we use (flow-)normalized nutrient inputs to allow for comprehensive statistical analysis for trends, break points, remaining or extra reduction as compared with reduction targets /inputs ceilings (Larsen & Svendsen, 2019).

Table 1 provides key information on the annual water flow, total waterborne TN and TP inputs, flow-weighted annual TN and TP concentration of riverine inputs (mg l^{-1}) to the sub-basins and total to the Baltic Sea in 2018 as compared with the average 1995-2018. Further, the catchment and sea surface areas of the sub-basins are provided allowing for calculation of area specific flow (l s^{-1} km^{-2}), and for TN and TP inputs per catchment area and per sea area. Flow to the Baltic Sea in 2018 was about 9% lower than the 1995-2018 average. The flow was particularly lower to the Gulf of Riga (31%), the Kattegat (21%) and the Baltic Proper (17%) compared with the average, while it was higher only to the Gulf of Finland (11%). Waterborne TN inputs in 2018 were 529,600 tons or 21% lower than average, and the corresponding TP inputs with 21,930 tons were 32% lower than average. Lower than average flow usually implies lower waterborne TN and TP inputs, but the nutrient input levels also reflect an overall reduction in TN and particularly in TP inputs since 1995. The pattern is however complex since both interannual flow variations and long-term trends in nutrient inputs varies across sub-basins. TN inputs in 2018 were between 21% (Danish Straits) and 31% (Gulf of Riga) lower than average for six sub-basins. Even for the Gulf of Finland where the flow in 2018 was higher than average, the waterborne TN inputs were slightly lower than the average 1995-2018. For waterborne TP inputs, the 2018 input was between 22% (Bothnian Bay) and 37% (Gulf of Finland) lower than average. Notably, the strongest anomaly was found for the Gulf of Finland despite the higher than average flow.

Annual flow-weighted riverine concentration (calculated by dividing annual riverine nutrient input with the corresponding water flow[3]) in 2018 to the Baltic Sea was 1.17 mg N l^{-1} or 13% lower than the average TN concentration, and for TP it was 0.049 mg P l^{-1} or 25% lower than average. Flow-weighted TN concentrations to the Bothnian Bay and the Bothnian Sea were 20% and 18%, respectively, lower than average, while for the Gulf of Riga 2018 concentration was quite similar to the average. For TP the biggest deviation to the average was to the Gulf of Finland (-43%) but for the Gulf of Riga it was more or less equal to average. Thus, the low flow to the Gulf of Riga in 2018 (31% lower than average of 1995-2018) seems to be the main reason for lower than average nutrient inputs.

Area specific waterborne catchment inputs in 2018 were highest to the Danish Straits (1,106 kg N km^{-2}, 34 kg P km^{-2}), reflecting high population density and high agricultural land-use. The lowest area specific inputs are for the Bothnian Bay and the Bothnian Sea (approximately 140-170 kg N km^{-2} and 6.9-7.4 kg P km^{-2}), catchments reflecting overall rather low population densities and high percentages of pristine or forested areas and rather low pressure from agriculture. On the other hand, specific waterborne inputs per sea area are highest to the Gulf of Finland (3,549 kg N km^{-2}, 145 kg P km^{-2}) and lowest to the Bothnian Bay (492 kg N km^{-2}, 20 kg P km^{-2}).

[3] In accordance with the HELCOM PLC-water Guideline (HELCOM, 2019b), nutrient input data is reported as annual loads for individual rivers. Calculation of annual mean flow-weighted concentrations for the Baltic Sea sub-basins is a simple method to illustrate changes in waterborne nutrient loads smoothening inter annual variation. These back-calculated annual nutrient concentrations differ from originally measured values (e.g. 12 monitored values per year) and should not be mixed up with these.

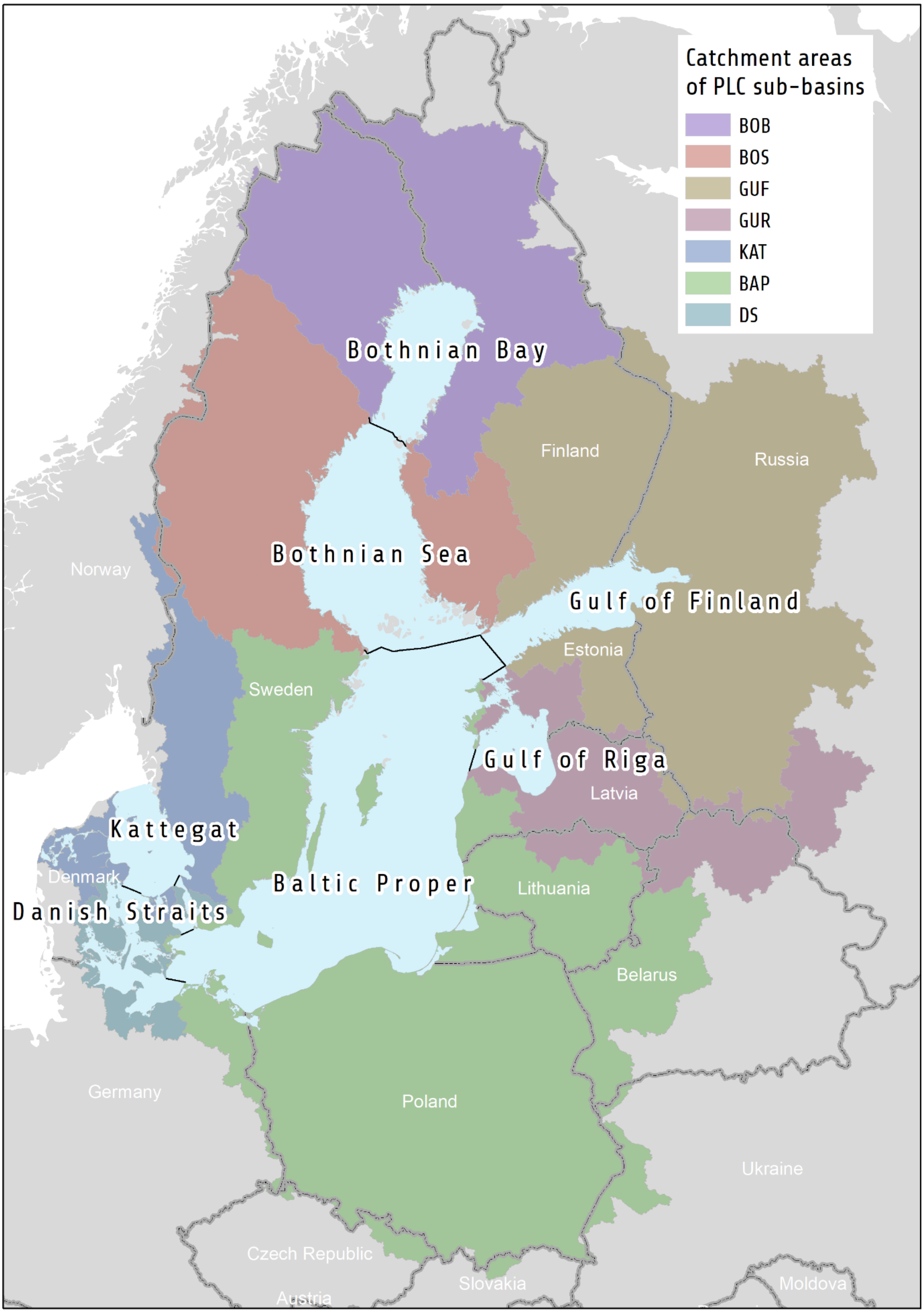
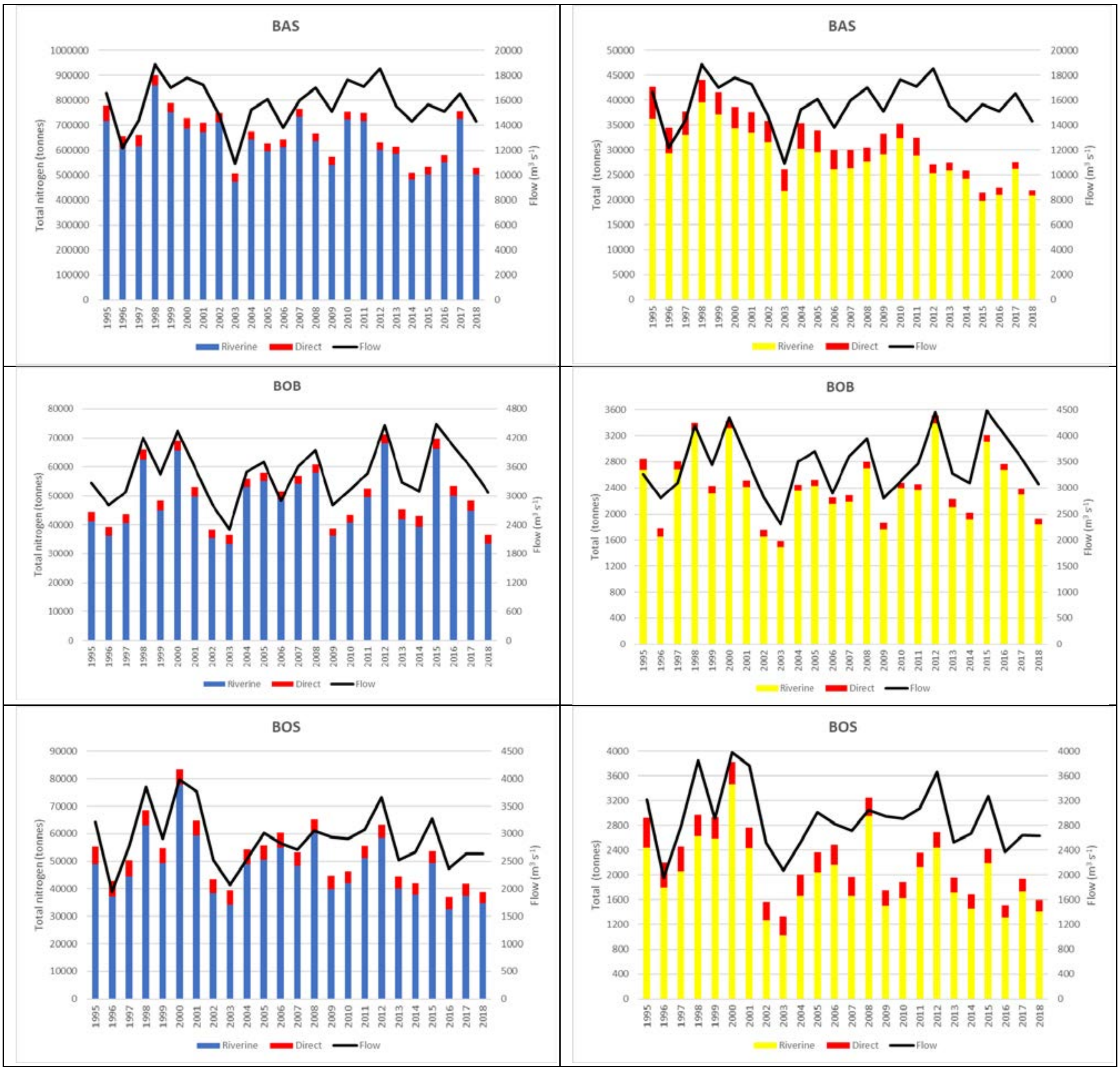


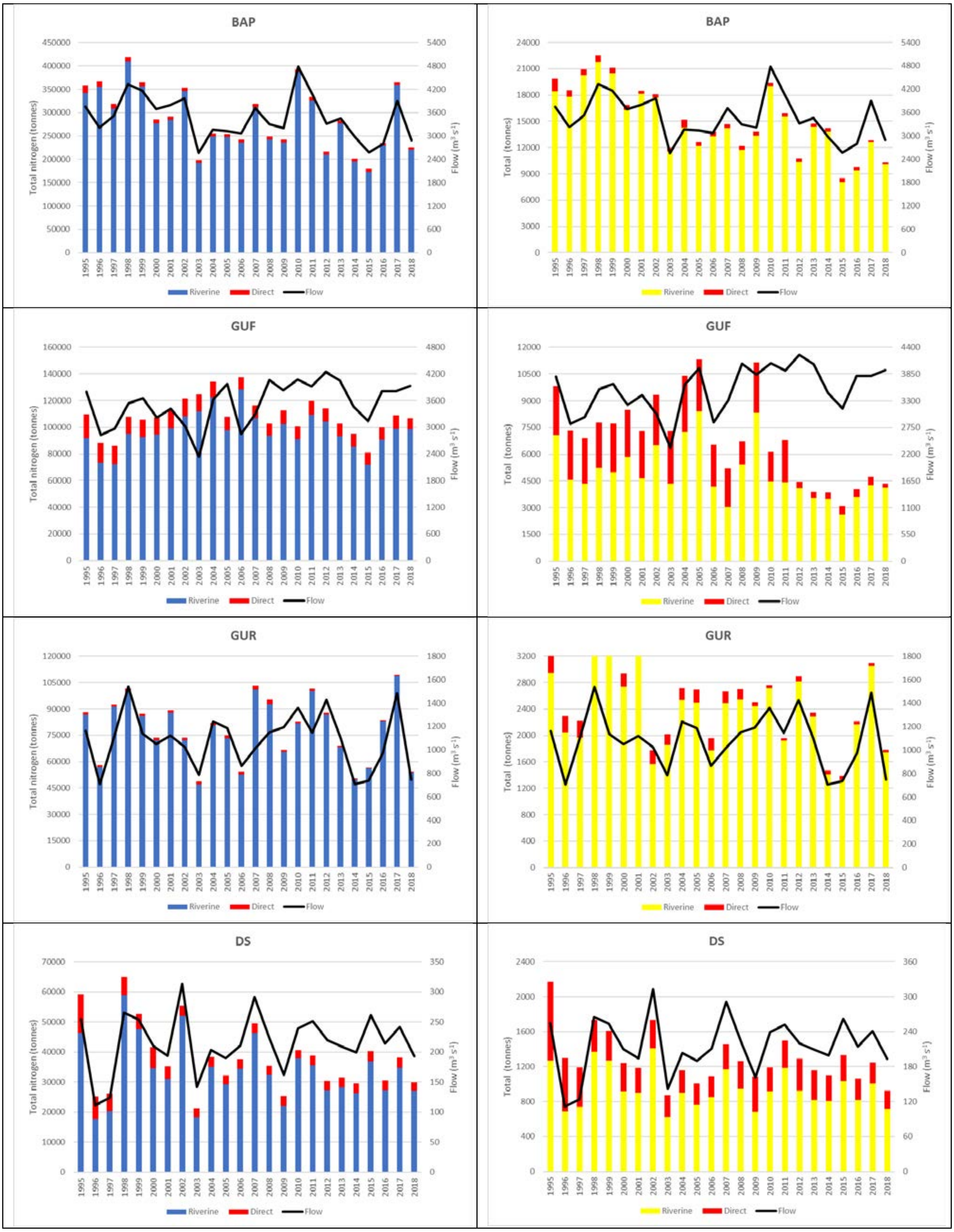
Figure 1. The catchment of the Baltic Sea is shared by 9 HELCOM member states - Denmark (DK), Estonia (EE), Finland (FI), Germany (DE), Latvia (LV), Lithuania (LT), Poland (PL), Russia (RU) and Sweden (SE) and 5 transboundary countries (Belarus, Czech Republic, Slovakia, Norway and Ukraine). For the purposes of assessment of nutrient load, the Baltic Sea (BAS) is divided into 7 main sub-basins: Bothnian Bay (BOB); Bothnian Sea (BOS) with Archipelago Sea; the Gulf of Finland (GUF); the Gulf of Riga (GUR); Baltic Proper (BAP); Danish Straits (DS) consisting of the Sound and the Western Baltic and the Kattegat (KAT).

Table 1. Catchment area to and sea area of the seven sub-basins of the Baltic Sea (km^2). Annual waterborne flow ($m^3\ s^{-1}$), area specific flow ($l\ s^{-1}\ km^{-2}$), waterborne total nitrogen and phosphorus inputs (tonnes) in 2018 and on average for 1995-2018. Flow weighted TN and TP concentrations ($mg\ l^{-1}$) of annual riverine inputs in 2018 and on average for 1995-2018. Further, waterborne inputs of TN and TP were given as specific inputs per km^2 catchment area and per sea area (kg N, P km^{-2}), respectively. For an explanation of abbreviations, see the caption to figure 1.

	Catchm. area km^{-2}	Sub-basin sea area km^{-2}	Flow 2018 $m^3\ s^{-1}$	Flow 1995-2018 $m^3\ s^{-1}$	Flow 2018 $l\ s^{-1}km^{-2}$	Flow 1995-2018 $l\ s^{-1}km^{-2}$	TN water-borne 2018 tonnes	TN water-borne 1995-2018 tonnes	TN flow-weight. conc. 2018 $mg\ l^{-1}$	TN flow-weight. conc. 1995-2018 $mg\ l^{-1}$	TN water-borne /catch. area 2018 $kg\ km^{-2}$	TN water-borne /sea area 2018 $kg\ km^{-2}$	TP water-borne 2018 tonnes	TP water-borne 1995-2018 tonnes	TP flow-weight. conc. 2018 $mg\ l^{-1}$	TP flow-weight. conc. 1995-2018 $mg\ l^{-1}$	TP water-borne /catch. area 2018 $kg\ km^{-2}$	TP water-borne /sea area 2018 $kg\ km^{-2}$
BOB	261000	36000	3079	3456	11.8	13.2	36563	51049	0.377	0.468	140	1016	1930	2488	0.020	0.023	7,4	54
BOS	230000	79000	2633	2912	11.4	12.7	38892	52484	0.468	0.572	169	492	1592	2285	0.019	0.025	6,9	20
BAP	572000	209000	2891	3474	5.1	6.1	225568	289534	2.474	2.643	394	1079	10293	15295	0.113	0.140	18	49
GUF	423000	30000	3934	3535	9.3	8.4	106457	108474	0.858	0.973	252	3549	4350	6861	0.035	0.062	10	145
GUR	130000	19000	747	1083	5.7	8.3	54184	78477	2.300	2.298	417	2852	1781	2545	0.076	0.075	13,7	94
DS	27000	21000	193	216	7.2	8.0	29854	37907	4.897	5.570	1106	1422	922	1288	0.151	0.189	34	44
KAT	87000	24000	848	1076	9.7	12.4	38038	53022	1.423	1.562	437	1585	1067	1469	0.040	0.043	12	44
BAS	**1730000**	**418000**	**14325**	**15752**	**8.3**	**9.1**	**529557**	**670946**	**1.172**	**1.351**	**306**	**1267**	**21934**	**32232**	**0.049**	**0.065**	**13**	**52**

The annual water flow, direct inputs of TN and TP and riverine TN and TP inputs during 1995-2018 to the sub-basins and to the Baltic Sea are shown in Figure 2 as well as in Tables 2-7 in the "Data" section. There are significant reductions in total direct nitrogen inputs from 1995 to 2018 to the Baltic sea (60%). Reduction of direct TN inputs is seen to all sub-basins, except for Bothnian Bay. The highest reduction in direct TN inputs is seen to Danish Straits (79%), Baltic Proper (71%) and to Gulf of Riga (65%). There are significant reductions of direct TP inputs to all sub-basins, the highest to Gulf of Finland (92%), Gulf of Riga (89%) and Baltic proper, resulting in a total reduction of 84% in the Baltic sea, although data on direct inputs are more uncertain in the beginning of the time series. Even though 2018 direct inputs to the Baltic Sea constitute only 5% of the waterborne TN and TP waterborne TP inputs, they provide large proportions of the nutrient inputs to some sub-basins e.g. the Bothnian Bay (11%) for TN and the Danish Straits (22%) for TP in 2018.




BAP
Total nitrogen (tonnes)
Flow (m³ s⁻¹)
Riverine
Direct
Flow
BAP
Total (tonnes)
Flow (m³ s⁻¹)
Riverine
Direct
Flow
GUF
Total nitrogen (tonnes)
Flow (m³ s⁻¹)
Riverine
Direct
Flow
GUF
Total (tonnes)
Flow (m³ s⁻¹)
Riverine
Direct
Flow
GUR
Total nitrogen (tonnes)
Flow (m³ s⁻¹)
Riverine
Direct
Flow
GUR
Total (tonnes)
Flow (m³ s⁻¹)
Riverine
Direct
Flow
DS
Total nitrogen (tonnes)
Flow (m³ s⁻¹)
Riverine
Direct
Flow
DS
Total (tonnes)
Flow (m³ s⁻¹)
Riverine
Direct
Flow

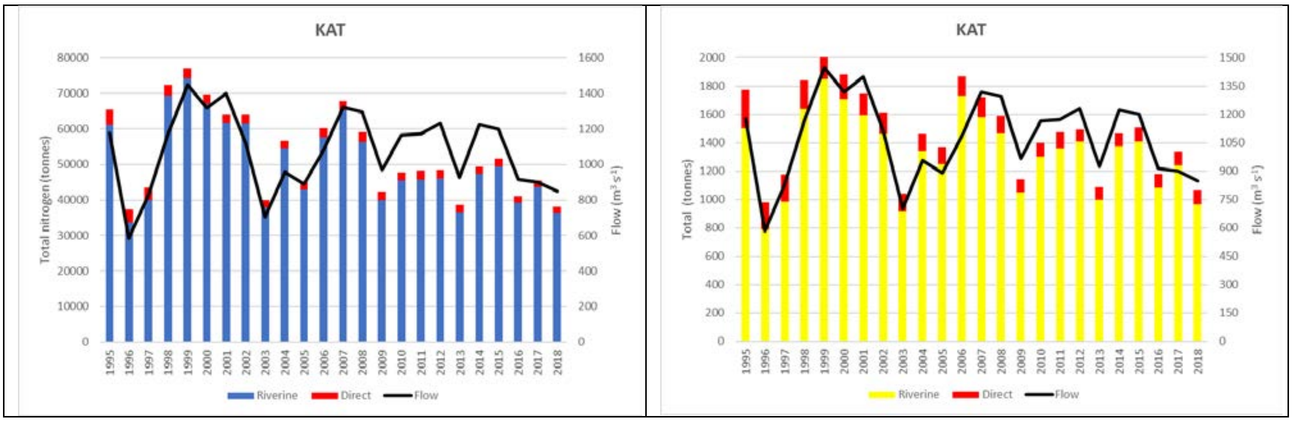
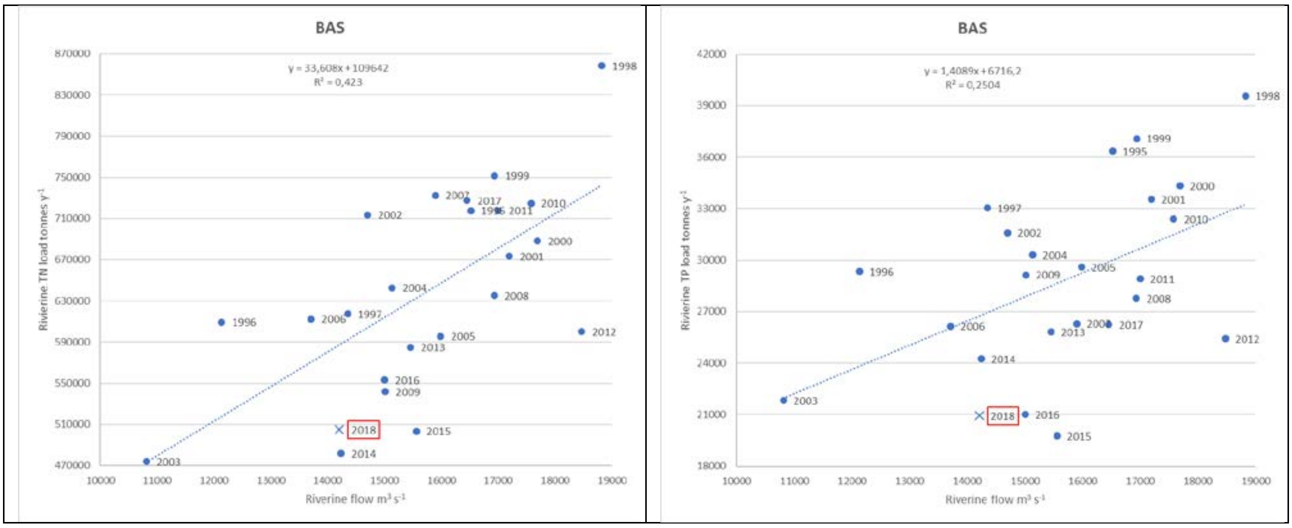


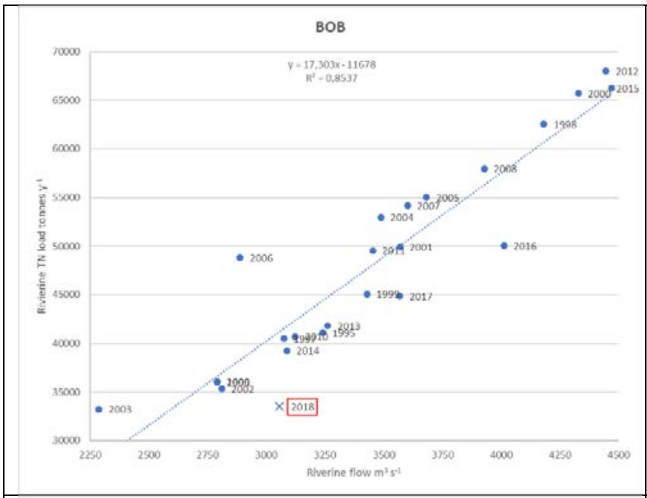
Figure 2: Annual riverine and direct inputs of total nitrogen (figures in the left column) and total phosphorus (figures in the right column) in tonnes and annual waterborne flow (m^{-3} s^{-1}) to the seven Baltic Sea sub-basin and to the Baltic Sea in 1995-2018. Data behind the figures are shown in Tables 2-7. For an explanation of abbreviations, see the caption to Figure 1.

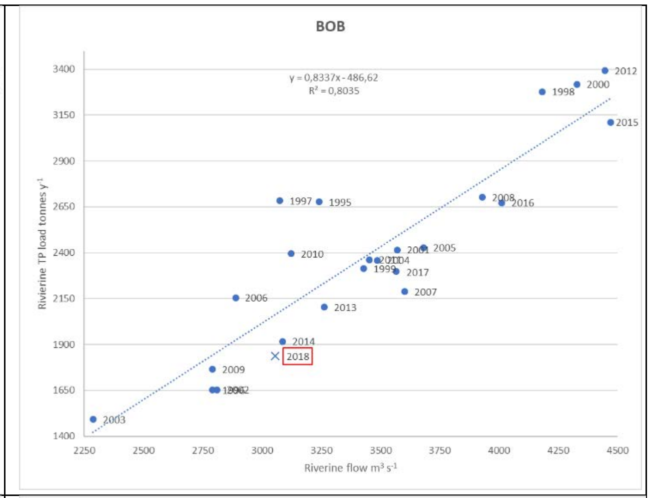
The correlation between the annual riverine TN and TP inputs, respectively, and water flow are shown as scatter and linear regression plots in Figure 3. The linear regression is statistically tested (see caption to Figure 3). The plots allow for characterization and evaluation of the TN and TP riverine inputs 1995-2018 specifically the inputs in 2018. The linear relation between riverine inputs and flow is significant for both TN and TP and for all sub-basins and the Baltic Sea except for the Gulf of Finland. Lack of significant correlation indicates some main challenges with the input data to the GUF that is in large parts estimated both for unmonitored areas and for some rivers for the main part of the time series.

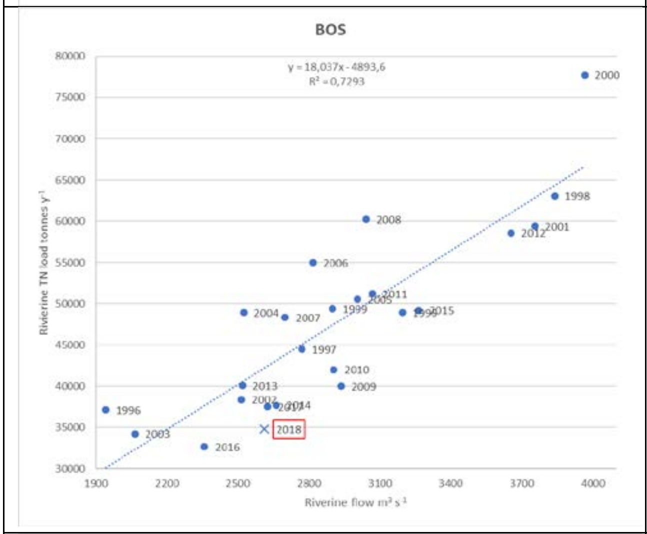
Riverine TN and TP inputs in 2018 were overall markedly lower than corresponding average inputs during 1995-2018 to most sub-basins. Figure 3 shows that in many cases the inputs are below what the regression line indicates for the magnitude of the flow in 2018. However, the scatter indicates a considerable range of nutrient inputs for any particular flow.

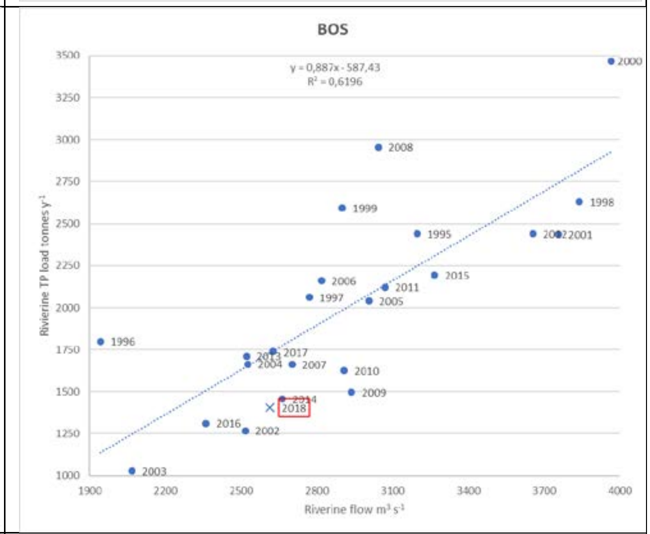
As a rule of thumb, a decrease in riverine TN and/or TP inputs during 1995 to 2018 is significant if most of the inputs of the latest 12-13 years falls below the dotted lines in Figure 3. This is true for many sub-basins. If nutrient inputs from sources with low dependency of flow volume (e.g. as point sources, fertilization) that constituted a high share in the early parts of a times series, have been markedly reduced, values for recent years are plotted below the regression line in Figure 3. It will also give a lower regression coefficient R^2 compared with time series with low share of inputs from point sources.

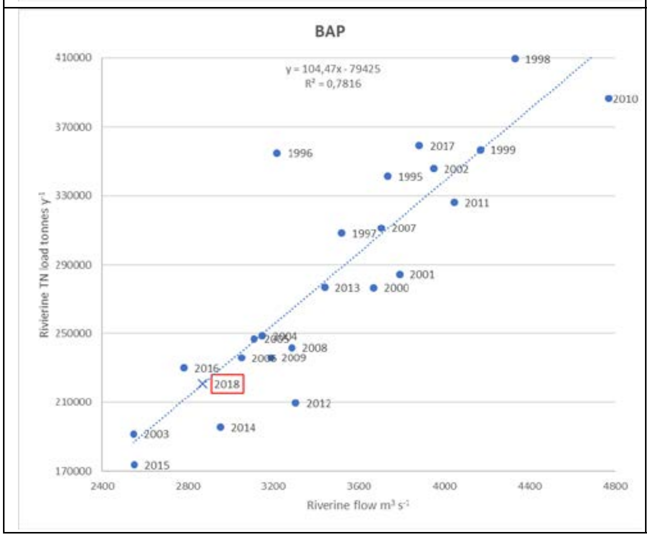


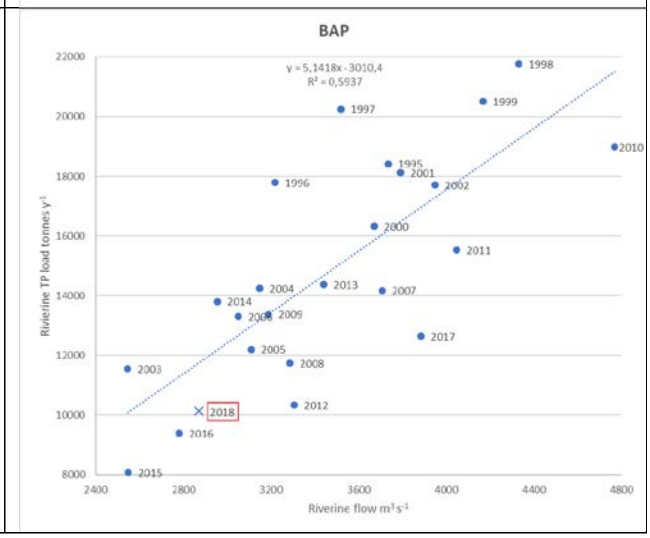

BOB
y = 17,303x - 11678
R^2 = 0,8537
Rivierine TN load tonnes y^{-1}
Riverine flow m^3 s^{-1}

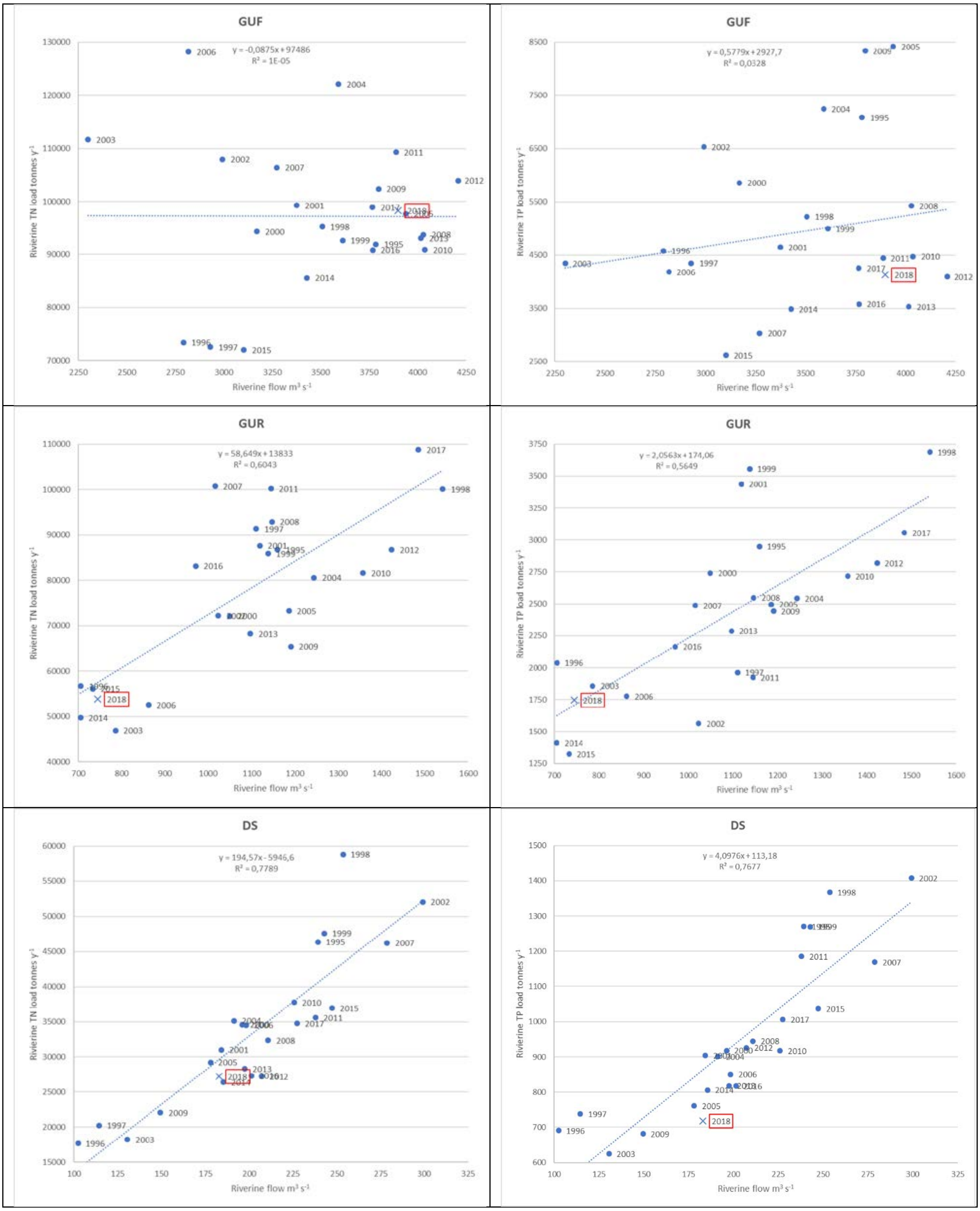

BOB
y = 0,8337x - 486,62
R^2 = 0,8035
Rivierine TP load tonnes y^{-1}
Riverine flow m^3 s^{-1}


BOS
y = 18,037x - 4893,6
R^2 = 0,7293
Rivierine TN load tonnes y^{-1}
Riverine flow m^3 s^{-1}


BOS
y = 0,887x - 587,43
R^2 = 0,6196
Rivierine TP load tonnes y^{-1}
Riverine flow m^3 s^{-1}


BAP
y = 104,47x - 79425
R^2 = 0,7816
Rivierine TN load tonnes y^{-1}
Riverine flow m^3 s^{-1}


BAP
y = 5,1418x - 3010,4
R^2 = 0,5937
Rivierine TP load tonnes y^{-1}
Riverine flow m^3 s^{-1}


GUF
y = -0,0875x + 97486
R² = 1E-05
Riverine TN load tonnes y⁻¹
Riverine flow m³ s⁻¹
GUF
y = 0,5779x + 2927,7
R² = 0,0328
Riverine TP load tonnes y⁻¹
Riverine flow m³ s⁻¹
GUR
y = 58,649x + 13833
R² = 0,6043
Riverine TN load tonnes y⁻¹
Riverine flow m³ s⁻¹
GUR
y = 2,0563x + 174,06
R² = 0,5649
Riverine TP load tonnes y⁻¹
Riverine flow m³ s⁻¹
DS
y = 194,57x - 5946,6
R² = 0,7789
Riverine TN load tonnes y⁻¹
Riverine flow m³ s⁻¹
DS
y = 4,0976x + 113,18
R² = 0,7677
Riverine TP load tonnes y⁻¹
Riverine flow m³ s⁻¹

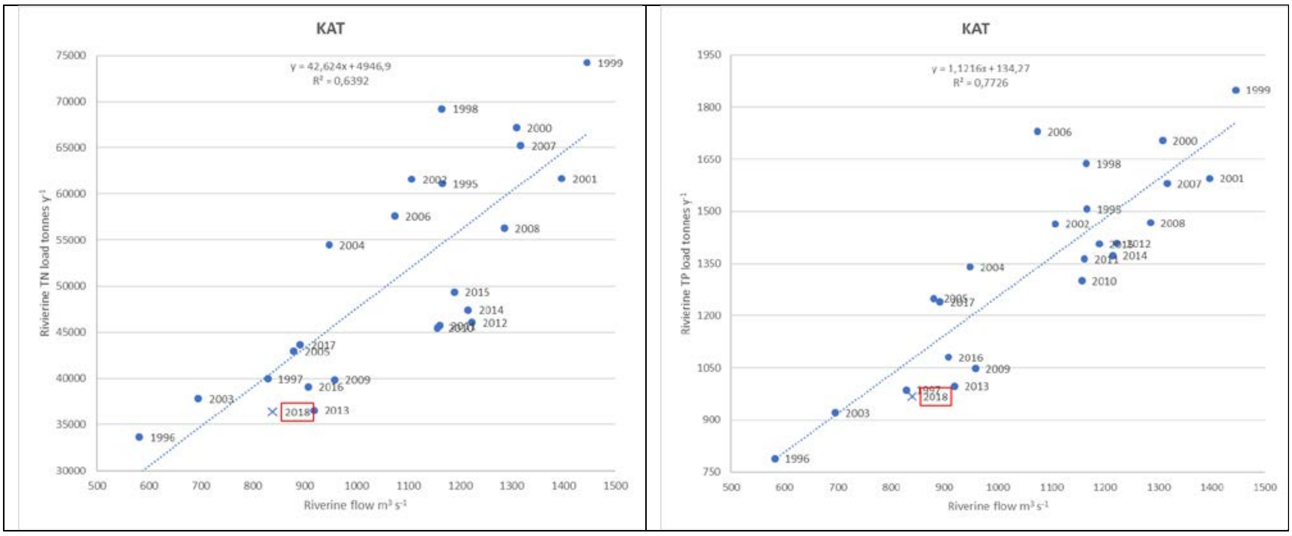


Figure 3. Linear regression plots of annual riverine flows (m^3 s^{-1}) against annual riverine total nitrogen inputs - TN - (left column) and total phosphorus inputs – TP – (right column) to the seven Baltic Sea sub-basins and to the Baltic Sea. 2018 is marked with "X" and 2018 in a red box. The linear regression is indicated as y = a·X + b, Y = riverine input (TN, TP), a = slope, b = intercept Y-axis, R^2 indicates how much of the variation is explained by the regression, e.g. R^2 =0.8667 say that nearly 87 % of the variation is explained (good correlation) by the regression. The statistical test calculates an F-value and analyses if the linear relation is significant (95 % confidence). All relations besides TN and TP for the GUF are significant. For an explanation of abbreviations, see the caption to Figure 1.

Flow weighted annual concentrations are used as a rough evaluation of any trends in nutrient inputs combined with a simple linear regression analysis. In Figure 4 the discharge weighted riverine TN and TP annual concentrations during 1995-2018 are shown. A statistical test on the linear regressions (test explained in the caption to Figure 3) indicates that the discharged weighted TN riverine concentrations decreased significantly (95% significance) to the Bothnian Sea, the Baltic Proper, the Danish Straits, the Kattegat and the Baltic Sea. The discharged weighted TP riverine concentrations decreased significantly to the Bothnian Sea, the Baltic Proper, the Gulf of Finland, the Gulf of Riga, the Danish Straits and the Baltic Sea.

Figure 4 have been sub-divided because flow-weighted TN and TP concentrations to the Baltic Proper, the Danish Straits and the Gulf of Riga are higher than for the four remaining sub-basins. Particularly flow-weighted TN and TP concentrations to the Bothnian Bay and the Bothnian Sea are an order of magnitude lower than the Danish Straits concentrations. This is the result of both, scarce population and low agricultural pressures combined together with high area specific flow to these sub-basins: BOB, BOS and Kattegat have area specific flow of about 12 l s^{-1} km^{-2} on average for 1995-2018, see Table 1. On average, the area specific flow to the Baltic Sea is 9 l s^{-1} km^{-2}, with only 6 to 8 l s^{-1} km^{-2} to the Baltic Proper, the Gulf of Finland and the Gulf of Riga during 1995-2018.

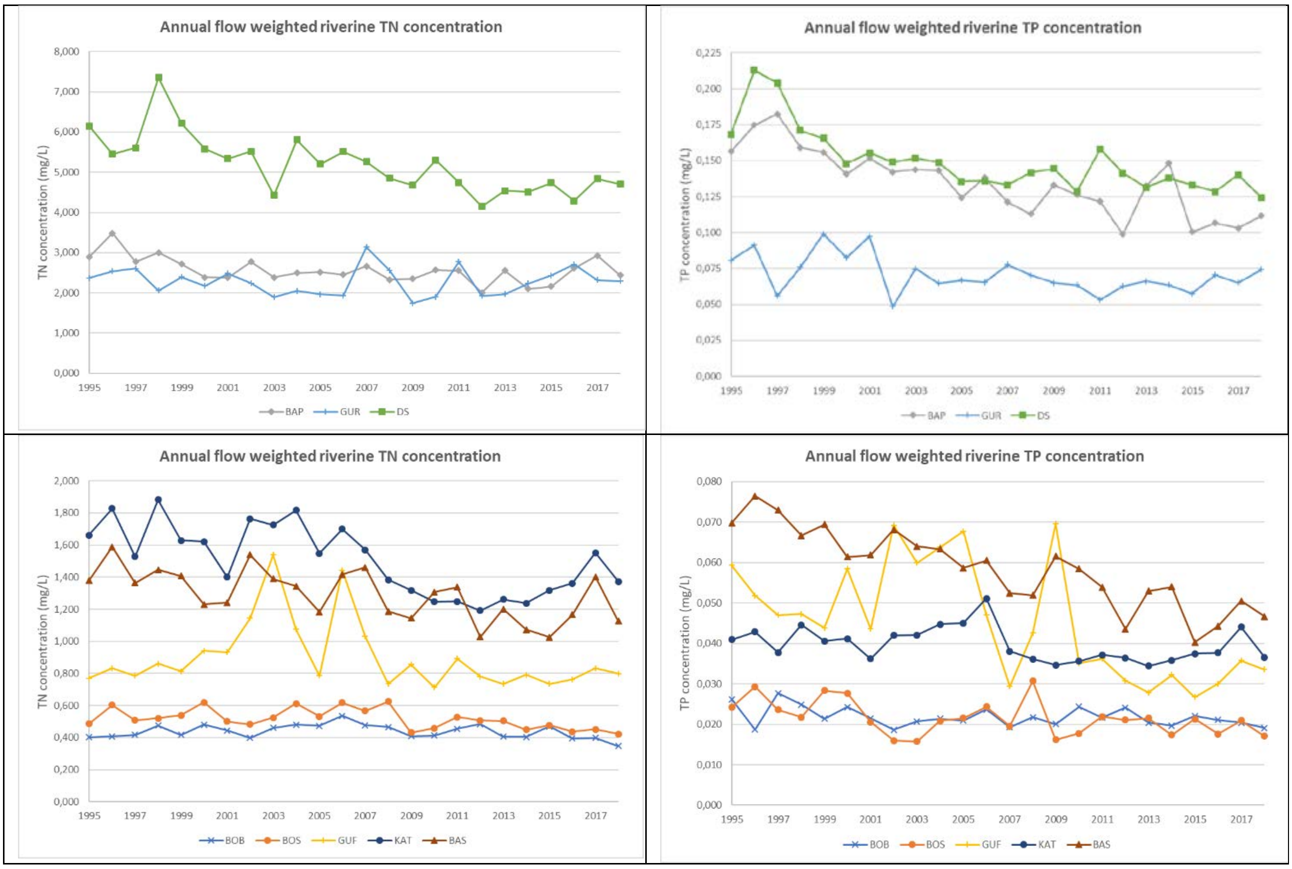


Figure 4. Annual average flow weighted riverine TN (left column) and TP (right column) concentrations for the seven Baltic Sea sub-basins and the Baltic Sea (calculated as total annual riverine inputs divided with the corresponding flow). Baltic Proper, Gulf of Riga and Danish Straits are in separate figures (upper row) due to higher flow-weighted concentrations than to the remaining sub-basins (low row). For an explanation of abbreviations, see the caption to Figure 1.

Policy relevance and policy references[4]

Since the establishment of the Convention for the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention) in 1974, the Commission for the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Commission or HELCOM for short) has been working to reduce the inputs of nutrients to the sea.

In Article 3 and Article 16 of the Convention on the Protection of the Marine Environment of the Baltic Sea Area, 1992 (Helsinki Convention), the Contracting Parties agreed to undertake measures to prevent and eliminate pollution of the marine environment of the Baltic Sea and to provide pollution load data, as far as available. Through coordinated monitoring, since the mid-1980s HELCOM has been compiling information about the magnitude and sources of nutrient inputs into the Baltic Sea. By regularly compiling and reporting data on pollution inputs, HELCOM follows the progress towards reaching politically agreed nutrient reduction input targets.

[4] Regarding atmospheric inputs the relevant policies are: The Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone under UNECE Convention on Long-range Transboundary Air pollution (CLRTAP); EU NEC Directive (2016/2284/EU); IMO designation of the Baltic Sea as a ”special area” for passenger ships under MARPOL (International Convention for the Prevention of Pollution from Ships) Annex IV (on sewage from ships); EC Directive 2000/59/EC on port reception facilities; and the Application of the Baltic Sea NOx emission control area (NECA).

The HELCOM Baltic Sea Action Plan (BSAP) was adopted in 2007 by the Baltic Sea coastal countries and the European Union (HELCOM 2007). The BSAP sets the overall objective of reaching good environmental status in the Baltic Sea by 2021, by addressing eutrophication, hazardous substances, biodiversity and maritime activities. As an innovative feature, the BSAP included a scientific based nutrient input reduction scheme identifying Maximum Allowable Inputs (MAI) of nutrients to achieve good status in terms of eutrophication. The plan also adopted provisional country-wise allocation of reduction targets (CARTs), and the CARTs are converted to nutrient input ceilings for each country and Baltic Sea sub-basin.

The 2013 HELCOM Copenhagen Ministerial Declaration (HELCOM 2013a, 2013b and 2013c) revised maximum allowable inputs of nutrients and reduction targets using the best available scientific data and models. Further, national nutrient input ceilings (NIC) were calculated for each country and each Baltic Sea sub-basin.

The HELCOM Brussels Ministerial Declaration 2018 committed HELCOM member states to act further to achieve national reduction requirements based on Maximum Allowable Inputs of nutrients to the Baltic Sea sub-basins.

Reducing the effects of human-induced eutrophication is the stated goal of Descriptor 5 in the EU Marine Strategy Framework Directive (MSFD). Inputs of nutrients to the Baltic Sea marine environment have an effect on the nutrient levels under criterion D5C1 of the MSFD.

The information provided in this BSEFS also supports the follow-up of the implementation of the targets and measures under the following policies addressing reduction of nutrient inputs: EU Maritime Strategy Framework Directive (MSFD); EU Water Framework Directive (WFD); EU Nitrates Directive; EU Urban Waste-Water Treatment Directive; EU Industrial Emissions Directive (IED); Water Code of Russian Federation; Federal Act on the internal maritime waters, territorial sea and contiguous zone of the Russian Federation.

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Data

Table 2. Annual waterborne flow (sum of riverine flow and direct flow (flow for point sources discharging direct into the Baltic Sea)) to the seven Baltic Sea sub-basins and the Baltic Sea (in $m^3 s^{-1}$). For an explanation of abbreviations, see the caption to Figure 1.

Flow ($m^3 s^{-1}$) River	BOB	BOS	BAP	GUF	GUR	DS	KAT	BAS
1995	3241	3196	3735	3784	1160	239	1166	16521
1996	2791	1943	3218	2792	706	103	582	12134
1997	3076	2770	3520	2931	1111	115	829	14352
1998	4182	3840	4332	3508	1541	254	1166	18822
1999	3428	2900	4169	3613	1138	243	1445	16937
2000	4328	3966	3671	3172	1050	196	1309	17692
2001	3570	3755	3793	3376	1119	184	1396	17195
2002	2811	2516	3950	2994	1023	299	1107	14701
2003	2288	2067	2547	2300	786	131	695	10815
2004	3488	2525	3149	3592	1244	191	948	15137
2005	3683	3007	3111	3939	1187	178	880	15985
2006	2889	2818	3052	2819	862	198	1074	13713
2007	3602	2701	3707	3273	1016	279	1317	15895
2008	3929	3044	3287	4030	1147	211	1286	16932
2009	2792	2937	3189	3799	1191	150	959	15016
2010	3123	2907	4769	4039	1358	226	1157	17580
2011	3453	3070	4048	3889	1145	238	1162	17004
2012	4446	3656	3307	4209	1424	207	1222	18472
2013	3262	2521	3441	4017	1097	198	918	15455
2014	3088	2662	2955	3429	705	186	1215	14240
2015	4470	3266	2550	3104	733	247	1189	15560
2016	4012	2361	2782	3769	971	201	907	15004
2017	3568	2628	3885	3768	1485	228	892	16454
2018	3058	2614	2872	3901	745	183	839	14213

Table 3. Annual total nitrogen (TN) direct inputs to the seven Baltic Sea sub-basins and the Baltic Sea (in tonnes). For an explanation of abbreviations, see the caption to Figure 1.

TN (tonnes) **Direct**	**BOB**	**BOS**	**BAP**	**GUF**	**GUR**	**DS**	**KAT**	**BAS**
1995	3421	6319	16671	17730	1164	12786	4245	62336
1996	3193	5707	11774	15051	1224	7449	3700	48098
1997	3270	5825	10314	13421	1250	5907	3527	43514
1998	3524	5565	9128	12598	1247	6216	3063	41342
1999	3397	5381	8167	12958	1251	5082	2773	39009
2000	3305	5613	8720	13129	1400	7007	2447	41622
2001	3047	5392	6953	13285	1521	4167	2438	36804
2002	3047	5169	6829	13318	1430	3430	2506	35729
2003	3246	5199	6693	13258	1815	3036	2086	35332
2004	2911	5364	6555	12130	1442	3157	2280	33839
2005	3013	5336	6409	10229	1573	2958	2219	31737
2006	2729	5377	6783	9328	1768	3100	2475	31561
2007	2788	4916	7717	9750	2379	3357	2635	33542
2008	2900	4965	6822	9266	2460	3018	2700	32132
2009	2712	4659	6339	10164	1277	3272	2466	30889
2010	2823	4422	6799	9890	1121	2875	2233	30162
2011	2996	4348	6968	10242	1143	3244	2306	31247
2012	3311	4697	6480	9898	1107	3117	2198	30807
2013	3676	4514	6472	9731	696	3251	2009	30349
2014	3733	4272	5973	9406	516	3160	2044	29103
2015	3452	4574	6271	8968	543	3384	2164	29356
2016	3426	4254	5276	9278	518	3171	1950	27873
2017	3591	4390	5505	9822	432	3399	1918	29056
2018	3094	4111	4759	8201	402	2661	1682	24910

Table 4. Annual total nitrogen (TN) riverine inputs to the seven Baltic Sea sub-basins and the Baltic Sea (in tonnes). For an explanation of abbreviations, see the caption to Figure 1.

TN (tonnes)								
River	**BOB**	**BOS**	**BAP**	**GUF**	**GUR**	**DS**	**KAT**	**BAS**
1995	41102	48951	341571	91913	86782	46361	61087	717766
1996	36029	37116	354784	73450	56695	17688	33642	609402
1997	40513	44464	308227	72569	91385	20262	39940	617358
1998	62564	63056	409485	95253	100132	58844	69228	858562
1999	45064	49395	356762	92635	85896	47605	74224	751581
2000	65728	77735	276611	94340	72176	34583	67140	688312
2001	49948	59393	284300	99232	87660	31004	61636	673175
2002	35367	38357	345951	107992	72212	52064	61566	713509
2003	33239	34195	191846	111697	46935	18233	37840	473985
2004	52949	48918	248599	122129	80593	35113	54446	642746
2005	55010	50530	247058	97663	73307	29219	42967	595754
2006	48822	54970	235749	128229	52558	34502	57620	612449
2007	54194	48310	311370	106440	100741	46239	65229	732522
2008	57971	60223	241824	93737	92898	32356	56291	635299
2009	36075	39981	236093	102425	65424	22055	39846	541899
2010	40719	41986	386530	90839	81637	37784	45490	724985
2011	49542	51197	326072	109315	100218	35577	45731	717652
2012	67999	58595	209528	103959	86744	27225	46072	600123
2013	41812	40073	276895	93048	68255	28294	36546	584924
2014	39284	37698	195686	85578	49743	26371	47415	481776
2015	66246	49209	173646	71974	56117	36935	49399	503527
2016	50058	32636	230030	90795	83156	27314	39087	553075
2017	44874	37468	359012	98850	108734	34737	43657	727334
2018	33469	34781	220810	98257	53782	27193	36356	504647

Table 5. Annual total nitrogen (TN) waterborne (riverine + direct) inputs to the seven Baltic Sea sub-basins and the Baltic Sea (in tonnes). For an explanation of abbreviations, see the caption to Figure 1.

TN (tonnes) **Sum**	**BOB**	**BOS**	**BAP**	**GUF**	**GUR**	**DS**	**KAT**	**BAS**
1995	44523	55270	358241	109642	87946	59147	65332	780102
1996	39222	42823	366557	88500	57919	25137	37342	657500
1997	43783	50288	318541	85990	92635	26169	43467	660873
1998	66088	68621	418614	107851	101379	65060	72291	899904
1999	48461	54776	364928	105594	87146	52686	76998	790590
2000	69033	83348	285331	107469	73576	41589	69588	729934
2001	52995	64785	291254	112518	89182	35171	64074	709978
2002	38414	43526	352780	121310	73642	55494	64072	749238
2003	36484	39395	198539	124955	48749	21269	39926	509317
2004	55860	54282	255154	134258	82034	38270	56726	676585
2005	58022	55866	253467	107892	74880	32178	45186	627491
2006	51551	60347	242532	137558	54326	37602	60095	644010
2007	56982	53226	319087	116190	103120	49596	67864	766064
2008	60870	65188	248647	103003	95357	35374	58991	667431
2009	38787	44640	242432	112589	66701	25327	42312	572788
2010	43541	46409	393329	100729	82758	40658	47723	755147
2011	52539	55545	333040	119557	101361	38821	48037	748900
2012	71309	63292	216008	113857	87851	30342	48270	630930
2013	45488	44587	283368	102779	68951	31546	38555	615273
2014	43017	41970	201659	94984	50258	29531	49459	510879
2015	69698	53783	179917	80942	56660	40319	51563	532883
2016	53484	36890	235306	100073	83674	30485	41037	580948
2017	48465	41859	364517	108672	109166	38136	45575	756390
2018	36563	38892	225568	106457	54184	29854	38038	529557

Table 6. Annual total phosphorus (TP) direct inputs to the seven Baltic Sea sub-basins and the Baltic Sea (in tonnes). For an explanation of abbreviations, see the caption to Figure 1.

TP (tonnes) **Direct**	**BOB**	**BOS**	**BAP**	**GUF**	**GUR**	**DS**	**KAT**	**BAS**
1995	171	485	1463	2738	314	902	267	6339
1996	126	398	755	2760	253	606	192	5090
1997	124	400	691	2553	255	452	191	4666
1998	124	341	735	2561	253	363	204	4582
1999	115	337	596	2724	254	340	181	4549
2000	108	355	523	2649	197	322	176	4331
2001	100	332	341	2656	230	281	153	4093
2002	100	296	387	2817	208	323	146	4277
2003	90	310	416	2941	163	248	117	4284
2004	85	336	961	3141	175	258	123	5079
2005	97	329	413	2898	203	246	123	4309
2006	100	330	493	2356	184	242	136	3840
2007	103	303	529	2181	179	292	137	3725
2008	100	293	468	1303	157	319	120	2759
2009	93	252	394	2811	59	404	97	4109
2010	87	254	408	1667	46	276	98	2836
2011	90	239	416	2370	38	312	116	3579
2012	116	250	415	371	76	368	88	1685
2013	130	245	404	366	55	339	91	1630
2014	107	233	409	371	61	297	93	1570
2015	99	234	400	462	64	292	105	1654
2016	94	204	385	444	46	246	100	1519
2017	90	207	197	477	42	244	99	1356
2018	94	187	178	221	36	204	99	1018

Table 7. Annual total phosphorus (TP) riverine inputs to the seven Baltic Sea sub-basins and the Baltic Sea (in tonnes). For an explanation of abbreviations, see the caption to Figure 1.

TP (tons) **River**	**BOB**	**BOS**	**BAP**	**GUF**	**GUR**	**DS**	**KAT**	**BAS**
1995	2678	2440	18422	7084	2949	1270	1506	36349
1996	1653	1799	17794	4579	2038	691	789	29342
1997	2683	2061	20252	4349	1964	738	986	33034
1998	3277	2630	21760	5223	3689	1367	1637	39583
1999	2314	2593	20507	4994	3556	1269	1849	37082
2000	3318	3467	16326	5858	2741	918	1704	34332
2001	2415	2435	18119	4645	3437	904	1595	33551
2002	1654	1268	17714	6529	1564	1407	1464	31600
2003	1493	1027	11553	4345	1856	625	921	21820
2004	2359	1664	14252	7244	2542	901	1340	30302
2005	2428	2039	12200	8414	2496	761	1249	29587
2006	2155	2160	13296	4183	1777	850	1730	26152
2007	2188	1662	14179	3035	2486	1169	1580	26299
2008	2702	2954	11737	5423	2548	945	1468	27777
2009	1766	1498	13375	8334	2442	682	1048	29143
2010	2394	1625	18980	4472	2717	917	1300	32405
2011	2363	2122	15523	4440	1925	1186	1363	28921
2012	3392	2440	10336	4095	2818	926	1409	25416
2013	2103	1712	14367	3529	2288	818	997	25815
2014	1918	1455	13805	3484	1411	806	1373	24252
2015	3111	2193	8074	2618	1326	1037	1406	19766
2016	2672	1312	9386	3581	2164	818	1080	21014
2017	2296	1736	12638	4250	3054	1006	1239	26218
2018	1837	1405	10115	4129	1745	718	968	20916

Table 8. Annual total phosphorus (TN) waterborne (riverine + direct) inputs to the seven Baltic Sea sub-basins and the Baltic Sea (in tonnes). For an explanation of abbreviations, see the caption to Figure 1.

TP (tons) Sum	BOB	BOS	BAP	GUF	GUR	DS	KAT	BAS
1995	2848	2925	19885	9821	3263	2172	1773	42688
1996	1779	2197	18549	7339	2291	1297	981	34433
1997	2807	2461	20943	6901	2219	1190	1177	37700
1998	3401	2972	22495	7784	3942	1730	1841	44165
1999	2429	2931	21103	7719	3810	1609	2030	41631
2000	3426	3823	16849	8507	2938	1240	1879	38663
2001	2516	2767	18460	7302	3667	1185	1748	37643
2002	1754	1564	18101	9346	1773	1730	1611	35878
2003	1583	1337	11969	7286	2018	873	1039	26104
2004	2444	2000	15213	10385	2718	1159	1463	35382
2005	2525	2368	12613	11312	2699	1007	1372	33896
2006	2255	2490	13789	6539	1962	1092	1866	29993
2007	2291	1965	14708	5216	2665	1461	1717	30024
2008	2802	3247	12206	6726	2704	1264	1587	30536
2009	1858	1749	13769	11145	2501	1086	1145	33252
2010	2481	1879	19388	6139	2763	1193	1398	35241
2011	2452	2361	15939	6809	1962	1497	1479	32500
2012	3509	2690	10751	4466	2894	1294	1496	27101
2013	2233	1957	14771	3896	2343	1157	1088	27444
2014	2024	1688	14214	3855	1471	1103	1467	25822
2015	3209	2427	8474	3080	1390	1329	1510	21420
2016	2766	1515	9772	4025	2211	1064	1180	22533
2017	2385	1943	12835	4727	3096	1250	1338	27574
2018	1930	1592	10293	4350	1781	922	1067	21934

Metadata

Technical information

1. Source:

The HELCOM Contracting Parties annually report annual water flow, inputs of total nitrogen and total phosphorus from rivers (riverine inputs) and annual inputs from direct point sources (direct inputs) to the Baltic Sea sub-basins to the HELCOM PLC database (PLUS) according to HELCOM Recommendation 37-38-1 "Waterborne pollution input assessment (PLC-Water) (HELCOM, 2016a). Further, data on atmospheric emissions and monitored atmospheric deposition are submitted by countries to the Co-operative programme for monitoring and evaluation of the long-range transmission of air pollutants in Europe (EMEP) according to HELCOM Recommendation 37-38-2 "Monitoring of airborne pollution input" (HELCOM 2016c). EMEP subsequently compiles and reports this information to HELCOM including a BSEF on nutrient emissions and deposition (e.g. Gauss and Bartnicki, 2018 and Gauss et al., 2018).

Total nutrient inputs (air- + waterborne inputs) to the Baltic Sea and its sub-basins are assessed annually in a HELCOM core indicator report on water and airborne inputs (e.g. HELCOM, 2019a) and periodically in HELCOM PLC reports (e.g. HELCOM, 2012, HELCOM, 2013d and HELCOM, 2015) and when assessing progress towards national nutrient ceilings (e.g. Svendsen et al., 2018).

2. Description of data:

Annual water flow together with load of nitrogen and phosphorus are reported from more than 300 monitoring stations in rivers covering the monitored part of the Baltic Sea catchment area. Direct inputs from point sources discharging directly into the Baltic Sea are reported from approximately 500 municipal waste water treatment plants, 220 industries and 170 marine fish farms. Further the nine HELCOM member countries model or estimate inputs for the unmonitored parts of the catchments to the seven sub-basins shown in Figure 1.

3. Geographical coverage:

Flow, nitrogen and phosphorus inputs from the entire catchment area to the Baltic Sea (approximately 1.73 mio. km^2) are covered by monitoring (monitored part of the catchment which constitutes 83% of the catchment area) or modelling/estimates (unmonitored part of the catchment constituting 17% of the catchment area). It includes catchments in the nine HELCOM member countries and catchments in five transboundary countries (see Figure 1). Further, annual flow and nutrient inputs from point sources discharging directly into the Baltic Sea are included in the compilation of total waterborne inputs to the Baltic Sea.

4. Temporal coverage:

Time series with annual water flow, total nitrogen and total phosphorus riverine and direct inputs summing up to total flow and waterborne inputs to the seven sub-basins covering the Baltic Sea are available for the period 1995 – 2018.

5. Methodology and frequency of data collection:

Monitored part of the catchment and direct inputs

For rivers with hydrological stations, the location of these stations, measurement equipment, frequency of water level and flow (velocity) measurement should at least follow the World Meteorological Organization (WMO) Guide to Hydrological Practices (WMO-No. 168, 2008) and national quality assurance (QA) standards.

Preferably, the discharge (or at least the water level) should be monitored continuously and close to where water samples for chemical analyses are taken. The flow should be monitored at least 12 times every year. If the discharges are not monitored continuously the measurements must cover low, mean and high river flow rates, i.e. they should as a minimum reflect the main annual river flow pattern. Further details are provided in the PLC-guidelines (HELCOM 2019b).

For riverine inputs, as a minimum 12 water samples for measuring nutrients concentrations should be taken each year at a frequency that appropriately reflects the expected river flow pattern. If more samples are taken (e.g. 18, 26 or more) and/or the flow pattern does not show major annual variations, the samples can be evenly distributed during the year (see PLC-guideline HELCOM 2019b). Overall, for substances transported in connection with suspended solids, lower bias and better precision is obtained with higher sampling frequency. National and EU regulation regulate the number of water samples from big point sources. For big point sources the sampling frequency is at least 24 each year, and often much higher.

The load in rivers is typically calculated by multiplying daily flow with a daily concentration of TN and TP, respectively. Daily flow for most rivers is obtain from a stage-discharge relationship and daily concentration by linear interpolation between days with chemical sampling (HELCOM, 2019b). For some rivers monthly average concentration are multiplied with the corresponding flow.

Unmonitored parts of the catchment

The nine HELCOM member countries estimate annual flow, load of total nitrogen and total phosphorus from the unmonitored catchment areas to the Baltic Sea by simple empirical or more advance physico-hydro-geochemical modelling, and/or extrapolation (see PLC-guidelines HELCOM, 2019b and HELCOM, 2019c). In average 17% of the catchment is unmonitored, ranging from 4% unmonitored catchment (Gulf of Finland) to 52% (Danish Straits).

Total waterborne inputs:

Riverine and direct inputs and water flow data are quality assured by the Contracting Parties reporters before reporting to the PLC-PLUS database with the reporting WEB application. The data are further verified and quality assured using the PLC-PLUS database verification tools and national expert quality assurance.

After the national expert quality assurance in the PLC-PLUS database, BNI and DCE under the auspices of HELCOM RedCore DG make a quality assessment of the data in the PLC-PLUS database. The experts amend the dataset filling in missing and correcting suspicious data to establish an assessment dataset, which is finally approved by the countries according to procedures described in HELCOM (2016b). The assessment dataset is used in the PLC assessments including this Baltic Sea Environmental Fact Sheet. A description of the methods used to fill data gaps is given in PLC guidelines (HELCOM 2019b) and HELCOM (2013d).

Quality information

6. Strengths and weaknesses:

Strength: The data set is the most comprehensive and consistent time series of annual riverine and direct inputs 1995-2018 of total nitrogen and phosphorus to the Baltic Sea and its seven sub-basins covering the entire Baltic Sea catchment area. Data has been checked with standardized quality assurance methods and some of them have been updated. For example, Denmark has re-reported all flow and input data (monitored, unmonitored and direct) for 1995-2017 together with reporting 2018 data.

Weakness: Data from some parts of the Baltic Sea catchment and some of the direct inputs in the beginning of the time series (1995-2018) are rather uncertain, and many estimates of missing data were required for the early years, particularly for direct inputs of nitrogen and phosphorus to some Baltic Sea sub-basins. Methods/models for estimating water flow and nutrient inputs from unmonitored areas are not completely comparable and consistent between countries.

Further, the monitoring frequency and strategy are probably not adequate in some rivers with high variation in water flow and/or nitrogen and phosphorus concentrations, and where a substantial part of the annual load occurs within some days/few weeks.

7. Uncertainty:

The uncertainty of total nitrogen and total phosphorus inputs has not been estimated systematically by contracting parties. The PLC-group has roughly estimated an uncertainty (precision and bias) of 15-25% for annual total waterborne nitrogen and 20-30% for total inputs to the Kattegat, the Danish Straits, the main part of the Baltic Proper, the Bothnian Sea and the Bothnian Bay. For the remaining part of the BAP, and for the Gulf of Finland and the Gulf of Riga the uncertainty might be higher and up to 50% for waterborne TP inputs (HELCOM, 2015).

8. Further work required:

Total nitrogen and phosphorus inputs from all unmonitored areas must be modelled/estimated with methods that provide consistent and comparable results. The sampling frequency and strategy in rivers should be adjusted to flow and concentrations regime and patterns in individual rivers, and at least 12 samples should be taken annually. Water flow or at least the water level should be monitored continuously in rivers and in outlets from big direct point sources. Further, laboratories should use methods that actually provide the total nitrogen and phosphorus and with methods providing reproducible and comparable results between the involved laboratories.