Waterborne nitrogen and phosphorus inputs and water flow to the Baltic Sea 1995-2017

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Key Message

Annual water flow in 2017 to the Baltic Sea was with approx. 16,600 m^3 s^{-1} about 5% higher than the average of 1995-2017. The annual waterborne inputs (inputs via rivers and via point sources discharging directly into the sea) of total nitrogen was in 2017 approx. 756,000 tonnes or 12% higher than the average of 1995-2017 while the corresponding annual total phosphorus inputs in 2017 amounted to approx. 27,900 tonnes, 14% lower than the average.

Inputs from point sources along the coasts discharging total nitrogen and phosphorus directly to the sea have decreased with approximately 50% and 75% since 1995, respectively. In 2017, the direct inputs of nitrogen and phosphorus constituted 4% and 5% of total waterborne inputs of these nutrients to the Baltic Sea. In 1995 the proportion of the direct inputs was 8% and 15%, respectively.

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

Results and Assessment

Relevance of the BSEFS 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 Baltic Sea sub-basins during 1995-2017. The inputs are the actual (not weather-normalized) annual inputs. A separate BSEFS on atmospheric nitrogen inputs is annually 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 2018).

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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. Waterborne inputs enter the sea via riverine inputs and direct 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.

Time series with information on annual nutrient inputs is needed 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.

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

Policy relevance and policy references[3]

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.

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

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[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.

[3] 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).

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) to fulfil, and the CART are converted to nutrient input ceilings country per Baltic Sea sub-basins.

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

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.

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.

Assessment

Based on the reported annual riverine and direct water flows, total nitrogen (TN) and phosphorus (TP) inputs by Contracting Parties, Baltic Nest Institute (BNI), Stockholm University and Danish Centre for Environment and Energy (DCE), Aarhus University establish an assessment dataset with inputs country per sub-basin and per sub-basin to the Baltic Sea, -after checking for outliers, filling in data gaps and other validations procedures. 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 amounts entering to the seven main Baltic Sea sub-basins (Figure 1) to allow for direct evaluation against environmental indicators in the sea. We focus mainly on riverine inputs as they in 2017 constituted 96% of TN and 95% of TP waterborne 2017 inputs to the Baltic Sea, respectively. In the evaluation of progress towards MAI and CART as publish in HELCOM (2018) (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.

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 2017 as compared with the average 1995-2017. Further, the catchment to the sub-basins and the area of the sub-basins are provided allowing for calculation of TN and TP inputs per catchment area and per sea area. Flow to the Baltic Sea in 2017 was about 5% higher than the 1995-2017 average. The flow was particularly higher to GUR (37%), BAP (13%) and DS (13%) compared with the average, while it was lower to KAT (17%) and BOS (10%). Higher flow usually will indicate higher waterborne TN and TP inputs, even though when comparing the 2017 waterborne input with the corresponding average 1995-2017 changes in waterborne inputs should be taken into account. Waterborne TN inputs in 2017 was 755,886 tons 12% higher, while corresponding TP inputs with 27,942 tons was 14% lower than the 1995-2017 average indicating overall reduction in TP inputs since 1995. For only GUR (39%) and BAP (26%) waterborne TN inputs was higher than the average of the time series, otherwise, it was equal (GUF) or lower. For waterborne TP the 2017 input was only higher to GUR (37%), equal to the 1995-2017 average for DS, but lower for the remaining sub-basins.

Annual flow-weighted riverine concentration (calculated by dividing annual riverine nutrient input with the corresponding water flow[4]) in 2017 to BAS was 8% higher than the corresponding average of 1995-2017 for TN, but 13% lower for TP. Annual TN flow-weighted riverine concentration was particularly higher to BAP (14%), but markedly lower to BOS (13%), BOB (10%) and DS (9%) than the average of 1995-2017. Correspondingly, TP annual flow-weighted riverine concentration in 2017 was higher to KAT (11%), but markedly lower particularly to BAP (23%) and GUF (22%) compared with the 1995-2017 average.

DS has the highest specific waterborne catchment inputs in 2017 (1,468 kg N km^{-2}, 58 kg P km^{-2}), reflecting high population density and high agricultural land-use. The corresponding lowest specific inputs are for BOB, BOS and GUR (approx. 185 N km^{-2} and 5.3-9.2 kg P km^{-2}), catchments that have overall rather low population densities and with 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 GUR (5,582 kg N km^{-2}, 159 kg P km^{-}2) and BAP (3,622 kg N km^{-2}, 158 kg P km^{-2}), and lowest to BOS (529 kg N km^{-2}, 25 kg P km^{-2}).

[4] The preferred option would be the use of the measured nutrient concentrations per river. Back-calculating nutrient concentrations from nutrient inputs using the river flow leads to different results, but is currently, based on data availability in PLC, the only possible option. Calculated nutrient concentrations therefore can only provide an indication and should be treated with care.

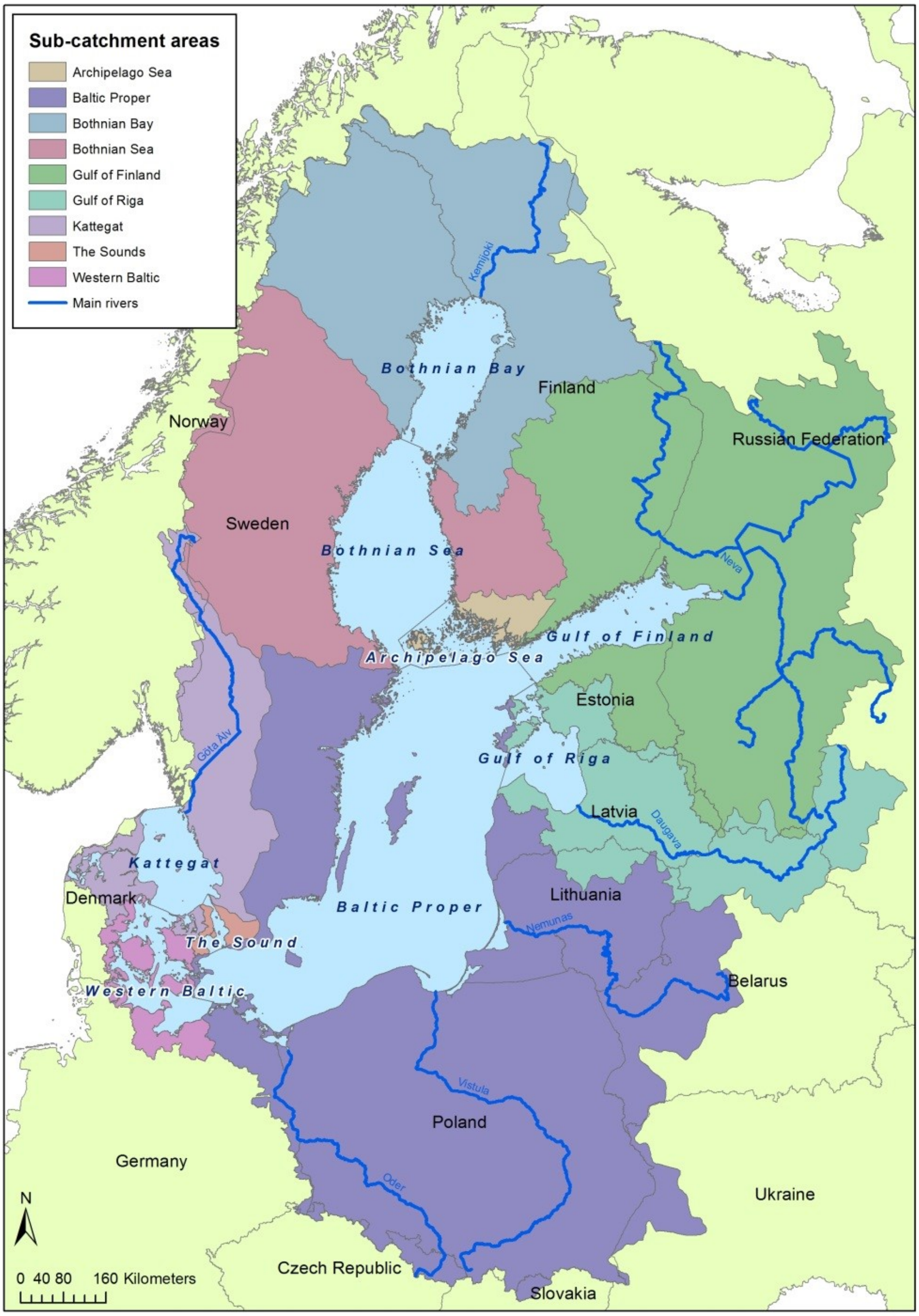
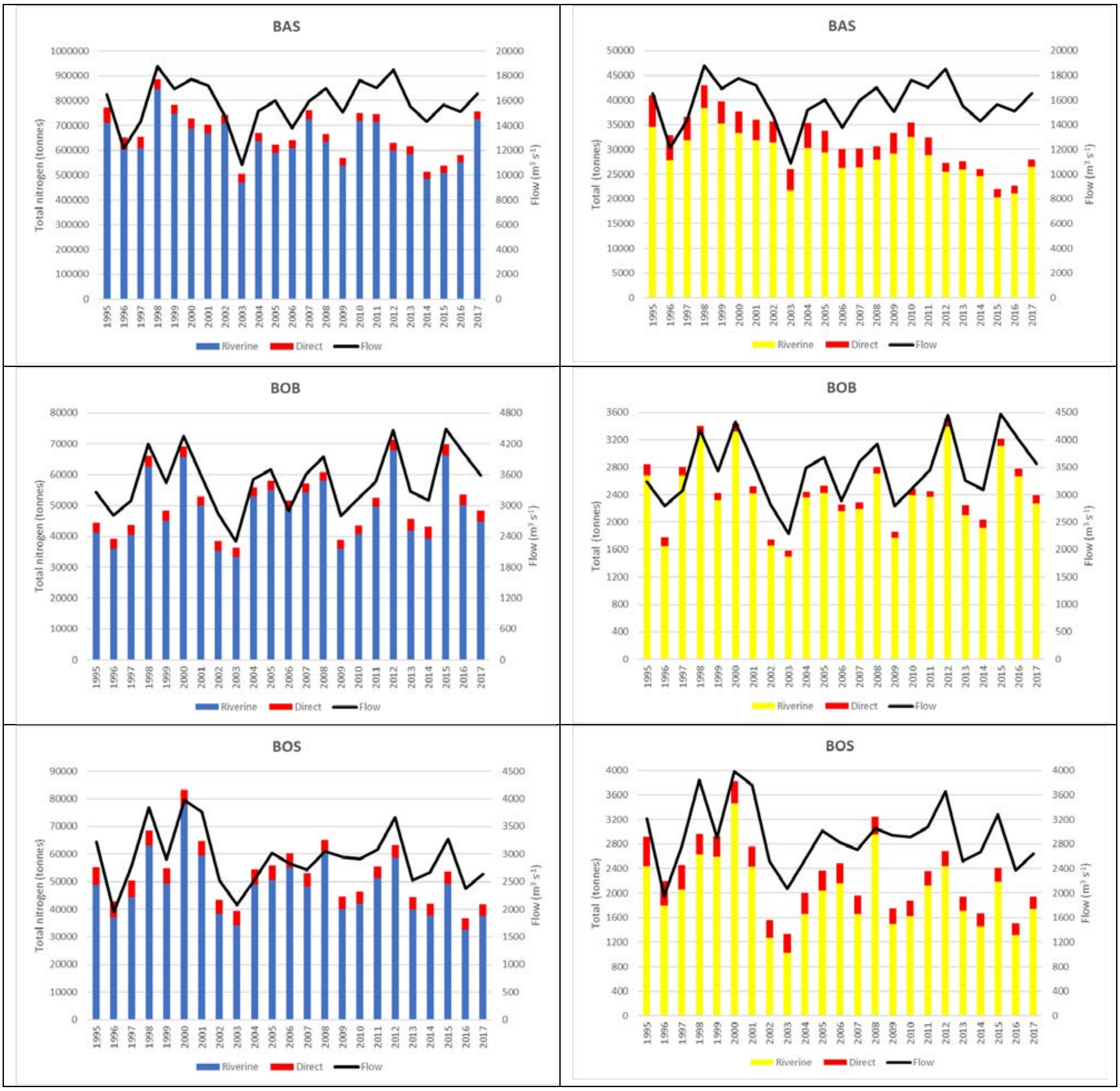


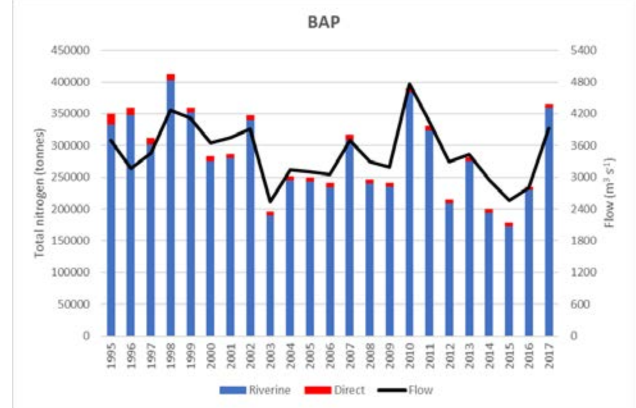
Figure 1. The catchment of the Baltic Sea is divided by 9 HELCOM member countries Denmark (DK), Estonia (EE), Finland (FI), Germany (DE), Latvia (LV), Lithuania (LT), Poland (PL), Russia (RU) and Sweden (SE) and 5 transboundary countries (Belarus, Czech Republic, Slovakia, Norway and Ukraine). The Baltic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

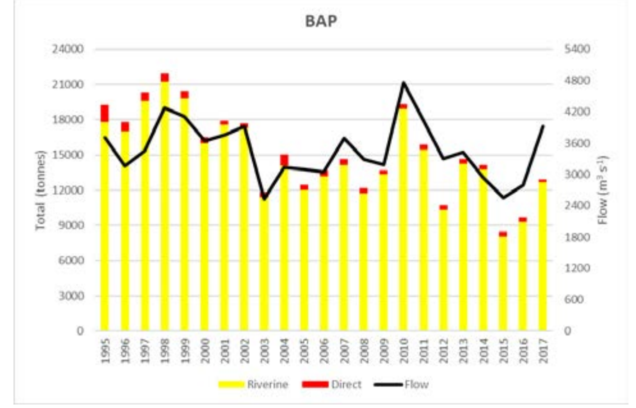
Table 1. Catchment area to and sea area of the seven sub-basins of the Baltic Sea (km^2). Annual waterborne flow (m^3 s^{-1}), waterborne total nitrogen and phosphorus inputs (tonnes) in 2017 and in average for 1995-2017. Flow weighted TN and TP concentrations (mg l^{-1}) of annual riverine inputs in 2017 and in average for 1995-2017. Further, waterborne inputs of TN and TP is 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.

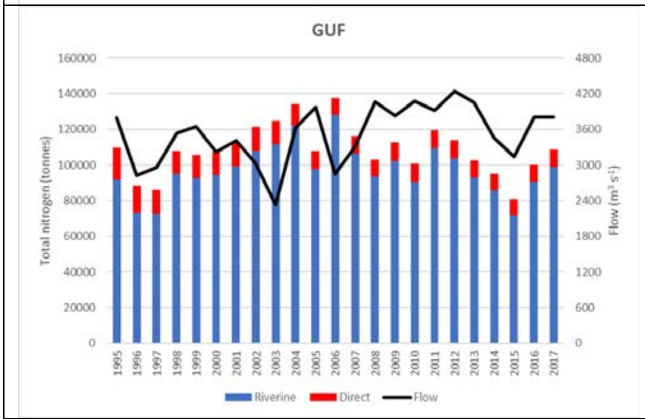
	Catchment area	**Sub-basin sea area**	**Flow 2017**	**Flow 1995-2017**	**TN water-borne 2017**	**TN water-borne 1995-2017**	**TN flow-weighted river conc. 2017**	**TN flow-weighted river conc. 1995-2017**	**TN water-borne /catchment area 2017**	**TN water-borne /sea area 2017**	**TP water-borne 2017**	**TP water-borne 1995-2017**	**TP flow-weighted river conc. 2017**	**TP flow-weighted river conc. 1995-2017**	**TP water-borne /catchment area 2017**	**TP water-borne /sea area 2017**
	km^{-2}	**km^{-2}**	**m^3 s^{-1}**	**m^3 s^{-1}**	**tonnes**	**tonnes**	**mg l^{-1}**	**mg l^{-1}**	**kg km^{-2}**	**kg km^{-2}**	**tonnes**	**tonnes**	**mg l^{-1}**	**mg l^{-1}**	**kg km^{-2}**	**kg km^{-2}**
BOB	261000	36000	3584	3473	48444	51689	0,398	0,442	186	1346	2390	2515	0,020	0,022	9,2	66
BOS	230000	79000	2639	2924	41774	53029	0,452	0,521	182	529	1940	2311	0,021	0,022	8,4	25
BAP	423000	209000	3921	3469	364809	289028	2,922	2,562	862	1745	12920	15269	0,103	0,135	31	62
GUF	130000	30000	3803	3517	108672	108571	0,832	0,904	836	3622	4727	6971	0,036	0,046	36	158
GUR	572000	19000	1453	1061	106061	76425	2,308	2,264	185	5582	3022	2212	0,065	0,062	5,3	159
DS	27000	21000	256	227	39639	39944	4,744	5,223	1468	1888	1564	1528	0,171	0,176	58	74
KAT	87000	24000	900	1086	46457	54655	1,586	1,543	534	1936	1378	1512	0,045	0,041	16	57
BAS	**1730000**	**418000**	**16557**	**15756**	**755856**	**673342**	**1,401**	**1,295**	**437**	**1808**	**27942**	**32318**	**0,051**	**0,059**	**16**	**67**

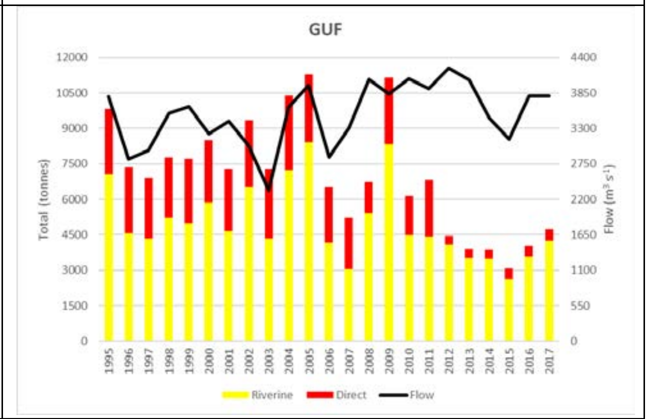
The annual water flow, direct inputs of TN and TP, riverine TN and TP inputs and waterborne TN and TP inputs during 1995-2017 to the sub-basins and to the Baltic Sea are shown in figure 2 as well as in tables 2-7 in the "Data" section. There are significant reductions in inputs from direct inputs from 1995 to 2017 to all sub-basins except BOB, for TN e.g. to DS (74%), BAP (67%) and GUR (63%), and for TP e.g. to GUR (87%), BAP (84%), GUF (87%) and DS (72%), although data on direct inputs are more uncertain in the beginning of the times series. Even though 2017 direct inputs to BAS constitute only 4% of the waterborne TN and 5% of waterborne TP inputs, their importance is significantly higher to e.g. BOS (10%) for TN and DS (16%) for TP.

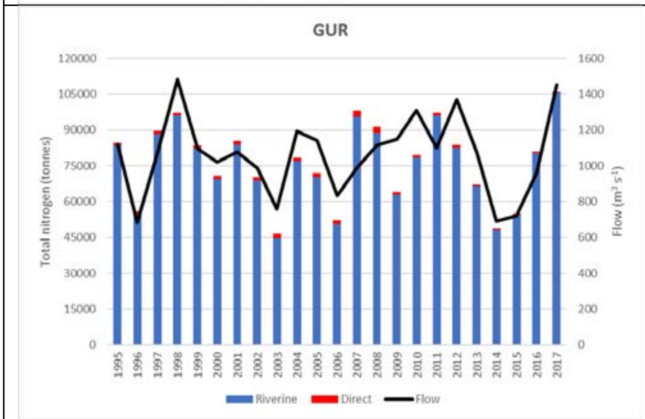


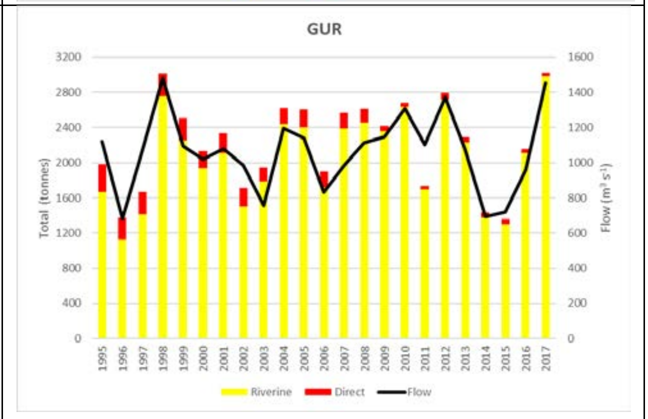

BAP
Total nitrogen (tonnes)
Flow (m³ s⁻¹)
Riverine
Direct
Flow

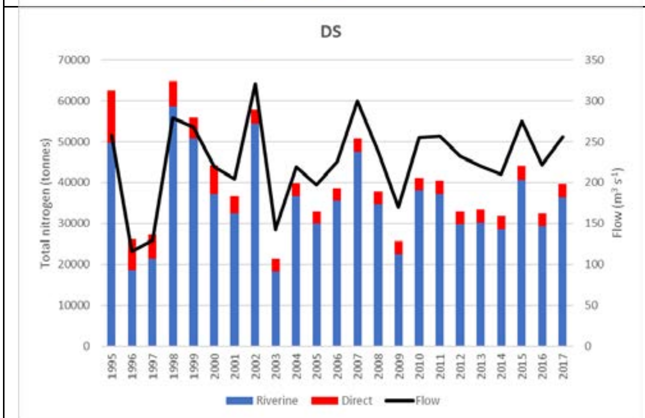

BAP
Total (tonnes)
Flow (m³ s⁻¹)
Riverine
Direct
Flow

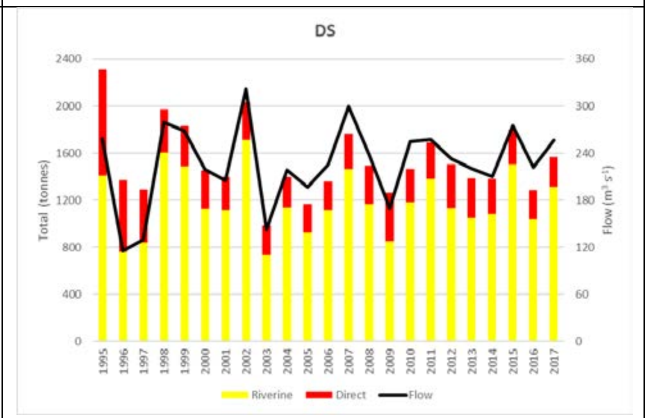

GUF
Total nitrogen (tonnes)
Flow (m³ s⁻¹)
Riverine
Direct
Flow


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

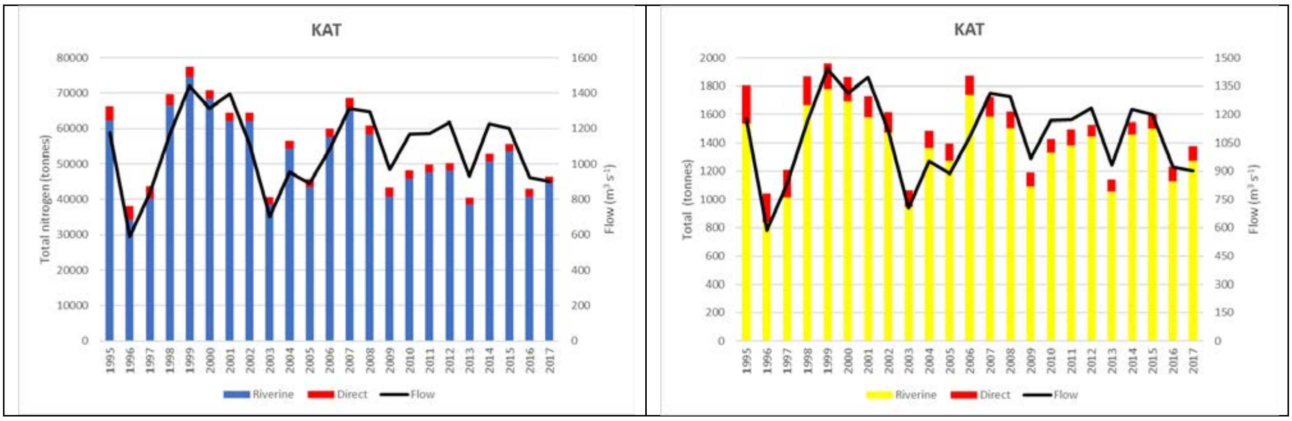
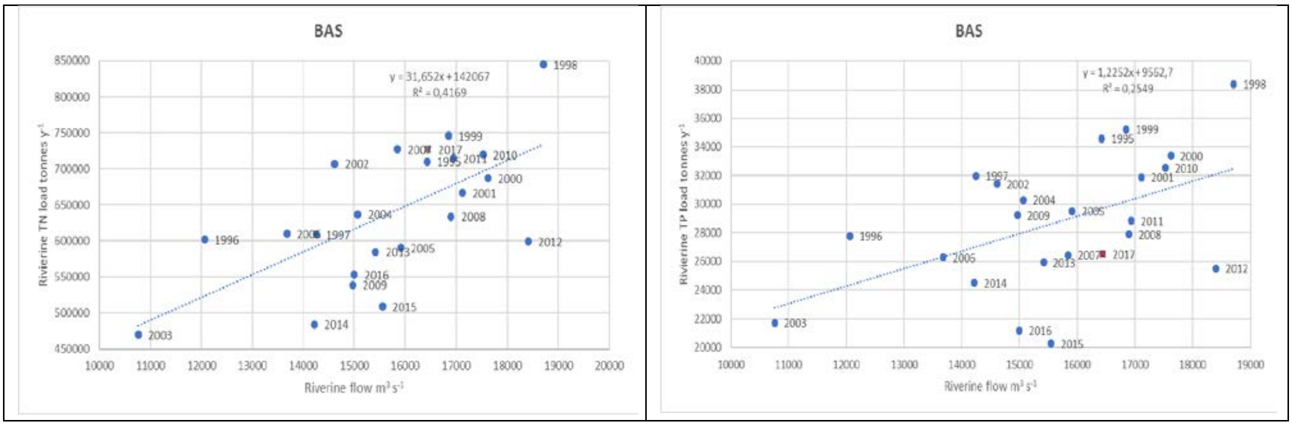


Figure 2: Annual riverine and direct inputs of total nitrogen (figures in the left column) and total phosphorus (figures in the right column) in tonnes and annual waterborne flow (m^{-3} s^{-1}) to the seven Baltic Sea sub-basin and to the Baltic Sea. Data behind the figures are in tables 2-7. For an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

Annual riverine TN and TP inputs are plotted against the corresponding water flow together with the linear regressions between inputs and flow in Figure 3. Together with a statistical test (see caption to figure 3) it is used to allow for characterization and evaluation of the TN and TP riverine 1995-2017 inputs and these inputs specifically in 2017. For both TN and TP the relation between riverine inputs and flow is significant for all sub-basins and for BAS except GUF. Lack of significant correlation indicates some main challenges with the input data to GUF that is in large parts estimated both for unmonitored areas and for some rivers.

Even though riverine TN and TP input in 2017 was higher than corresponding average inputs during 1995-2017 to many basins, and very high in GUR they are within the expected range based on the relation shown in figure 3.

As a rule of thumb, a decrease in riverine TN and/or TP inputs during 1995 to 2017 is significant if most of the inputs in the latest 12-13 years falls below the dotted lines in figure 3. This can be seen for many sub-basin.



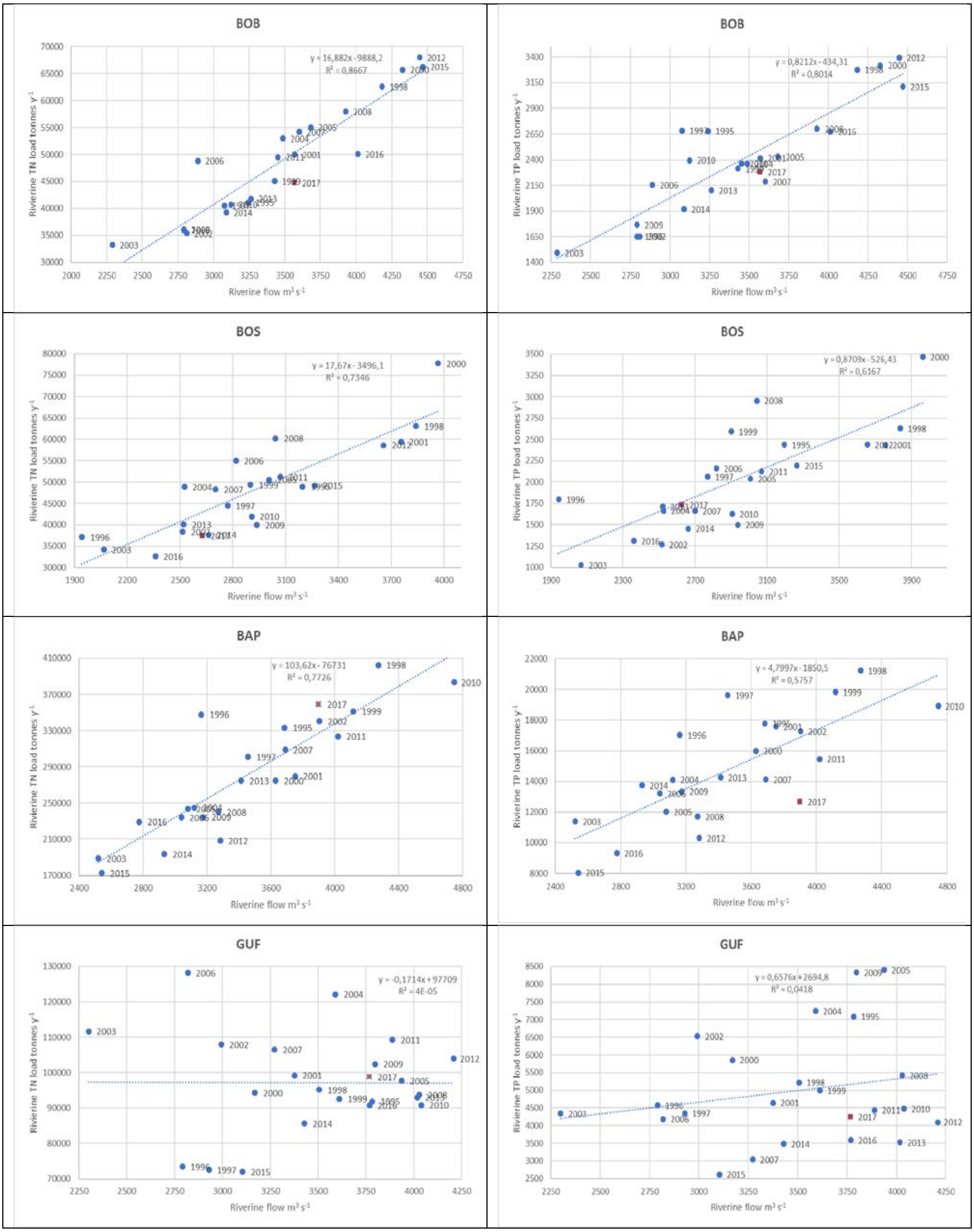
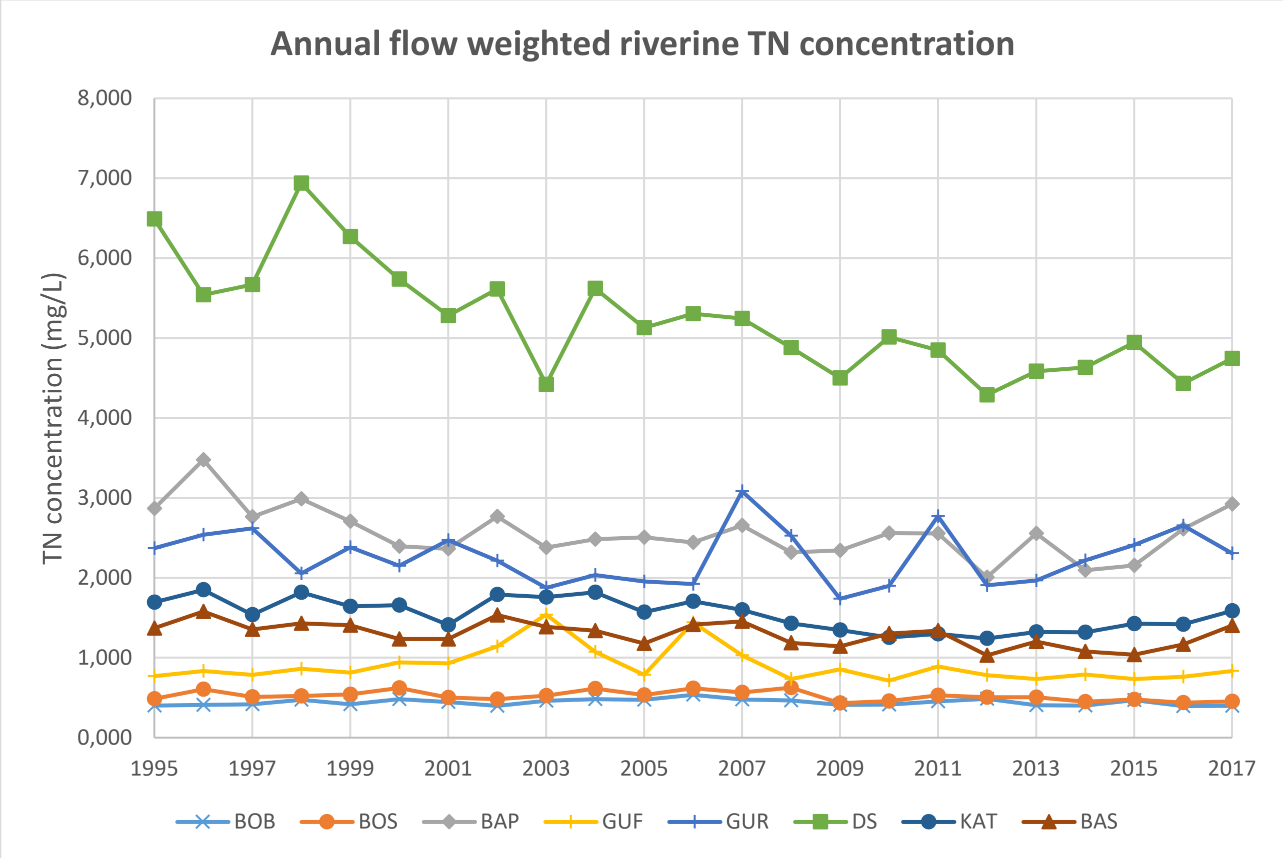

BOB
y = 16,882x - 9888,2
R² = 0,8667
Riverine TN load tonnes y⁻¹
Riverine flow m³ s⁻¹
BOB
y = 0,8212x - 434,31
R² = 0,8014
Riverine TP load tonnes y⁻¹
Riverine flow m³ s⁻¹
BOS
y = 17,67x - 3496,1
R² = 0,7346
Riverine TN load tonnes y⁻¹
Riverine flow m³ s⁻¹
BOS
y = 0,8709x - 526,43
R² = 0,6167
Riverine TP load tonnes y⁻¹
Riverine flow m³ s⁻¹
BAP
y = 103,62x - 76731
R² = 0,7726
Riverine TN load tonnes y⁻¹
Riverine flow m³ s⁻¹
BAP
y = 4,7997x - 1850,5
R² = 0,5757
Riverine TP load tonnes y⁻¹
Riverine flow m³ s⁻¹
GUF
y = -0,1714x + 97709
R² = 4E-05
Riverine TN load tonnes y⁻¹
Riverine flow m³ s⁻¹
GUF
y = 0,6576x + 2694,8
R² = 0,0418
Riverine TP load tonnes y⁻¹
Riverine flow m³ s⁻¹

Figure 3. Linear regression plot of annual riverine flow (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. 2017 is marked in red. The linear regression is indicated as y = a·X + b, Y = waterborne 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 variation explained (good correlation). From the statistical test, an F-value is calculated, and it is tested if the linear relation is significant (95 % confidence). All relations besides TN and TP for GUF are significant. For an explanation of abbreviations see the caption to figure 1.

Flow weighted annual concentrations is 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 1995-2017 are shown. A statistical test on the linear regressions (test explained in the caption to figure 3) indicates that the discharged weighted TN riverine concentration has decreased significantly to BOS, BAP, DS, KAT and BAS. For TP there is a significant decrease to BOS, BAP, GUF, DS and BAS and a significant increase to GUR.



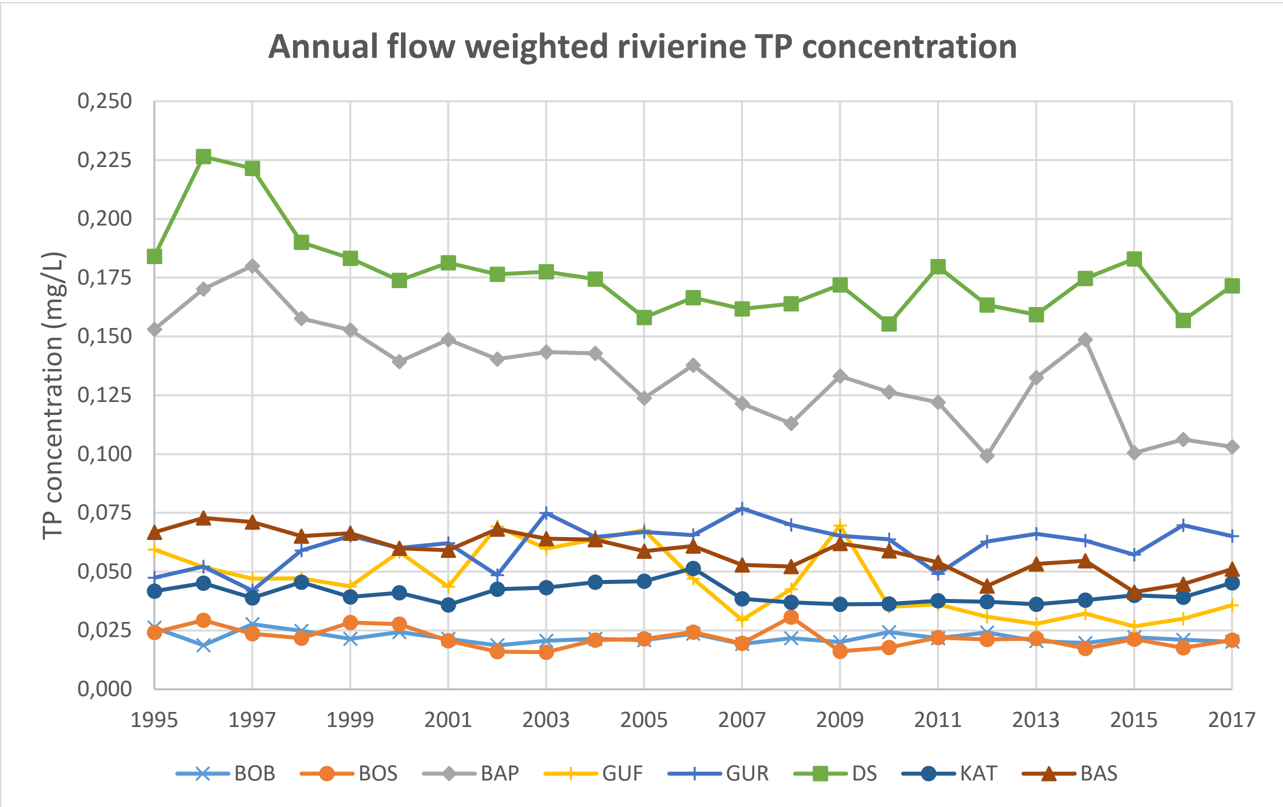


Figure 4. Annual average flow weighted riverine TN (upper figure) and TP (lower figure) concentration for the seven Baltic Sea sub-basins and the Baltic Sea (calculated as total annual riverine inputs divided with corresponding flow). For an explanation of abbreviations see the caption to figure 1.

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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})								
Sum	**BOB**	**BOS**	**BAP**	**GUF**	**GUR**	**DS**	**KAT**	**BAS**
1995	3263	3216	3703	3795	1119	258	1174	16528
1996	2805	1951	3166	2823	682	115	588	12131
1997	3092	2779	3458	2963	1070	130	832	14323
1998	4198	3846	4273	3541	1482	279	1164	18784
1999	3445	2907	4118	3645	1094	268	1442	16919
2000	4349	3981	3649	3215	1021	219	1313	17747
2001	3585	3762	3755	3413	1078	205	1396	17194
2002	2829	2523	3918	3028	987	321	1107	14714
2003	2305	2074	2535	2336	758	143	703	10855
2004	3505	2531	3135	3629	1195	219	952	15166
2005	3701	3015	3099	3970	1140	197	888	16009
2006	2902	2825	3055	2852	834	226	1079	13773
2007	3613	2713	3696	3307	986	300	1313	15929
2008	3941	3054	3289	4064	1115	238	1296	16996
2009	2802	2943	3192	3832	1149	170	967	15055
2010	3135	2914	4763	4070	1310	255	1169	17616
2011	3466	3077	4038	3921	1101	257	1172	17033
2012	4460	3661	3297	4242	1371	233	1234	18498
2013	3276	2526	3430	4051	1074	220	931	15508
2014	3101	2667	2950	3461	692	210	1227	14309
2015	4486	3277	2561	3137	720	275	1201	15658
2016	4023	2371	2796	3801	959	222	922	15094
2017	3584	2639	3921	3803	1453	256	900	16557

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 seethe caption to figure 1.

TN (tonnes)								
Direct	**BOB**	**BOS**	**BAP**	**GUF**	**GUR**	**DS**	**KAT**	**BAS**
1995	3421	6289	16673	17760	1164	12793	4251	62350
1996	3193	5692	11779	15066	1224	7428	3742	48124
1997	3270	5786	10312	13460	1250	5887	3517	43483
1998	3524	5544	9127	12620	1247	6235	3052	41348
1999	3397	5355	8152	12984	1251	5120	2762	39021
2000	3305	5565	8709	13178	1400	7040	2437	41634
2001	3047	5324	6942	13354	1521	4202	2425	36815
2002	3047	5132	6819	13355	1430	3460	2495	35739
2003	3246	5165	6702	13292	1815	3045	2080	35344
2004	2911	5364	6547	12130	1442	3173	2272	33839
2005	3013	5336	6401	10229	1573	2959	2211	31723
2006	2729	5333	6775	9373	1768	3091	2469	31538
2007	2788	4884	7708	9783	2379	3381	2631	33553
2008	2900	4879	6813	9353	2460	3070	2696	32170
2009	2712	4597	6330	10227	1277	3323	2454	30920
2010	2823	4364	6792	9949	1121	2934	2218	30200
2011	2996	4308	6965	10282	1143	3255	2244	31195
2012	3311	4660	6476	9934	1107	3127	2191	30807
2013	3723	4438	6471	9759	696	3258	2003	30348
2014	3796	4209	5975	9406	516	3166	2038	29105
2015	3529	4497	6279	8968	543	3397	2152	29366
2016	3498	4182	5271	9278	518	3162	1954	27865
2017	3676	4306	5499	9822	432	3319	1928	28981

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	333086	91883	83376	49665	62157	710220
1996	36029	37116	347950	73429	54753	18689	34249	602215
1997	40513	44464	301306	72544	88328	21462	40191	608807
1998	62564	63056	402549	95194	96007	58576	66616	844562
1999	45064	49395	351515	92594	82236	50868	74567	746239
2000	65728	77735	274823	94317	69351	37198	68350	687502
2001	49948	59393	279741	99197	83876	32487	61971	666613
2002	35367	38357	340461	107960	68722	54452	62032	707350
2003	33239	34196	189007	111674	44682	18324	38539	469661
2004	52949	48918	244984	122107	76916	36681	54247	636801
2005	55010	50530	243699	97617	70219	29924	43517	590516
2006	48822	54970	234120	128220	50436	35605	57562	609734
2007	54194	48310	308977	106430	95694	47486	65996	727086
2008	57971	60223	239992	93722	88829	34749	58258	633744
2009	36075	39981	234636	102406	62857	22349	40762	539066
2010	40719	41986	383300	90816	78260	38208	45974	719263
2011	49542	51197	323818	109277	96058	37190	47581	714661
2012	67999	58595	208389	103949	82506	29830	48048	599315
2013	41812	40073	274854	93048	66456	30096	38518	584857
2014	39284	37698	193840	85578	48284	28736	50713	484134
2015	66246	49209	172598	71974	54603	40689	53559	508879
2016	50058	32636	229181	90795	80432	29297	40899	553297
2017	44768	37468	359310	98850	105629	36320	44529	726875

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)**							
Waterborne	**BOB**	**BOS**	**BAP**	**GUF**	**GUR**	**DS**	**KAT**	**BAS**
1995	44523	55241	349759	109642	84540	62458	66408	772570
1996	39222	42808	359729	88495	55977	26118	37991	650339
1997	43783	50250	311618	86004	89578	27349	43707	652290
1998	66088	68600	411676	107814	97254	64811	69667	885910
1999	48461	54750	359667	105579	83487	55988	77328	785260
2000	69033	83300	283533	107494	70751	44238	70787	729136
2001	52995	64717	286683	112551	85397	36689	64396	703427
2002	38414	43489	347280	121315	70152	57912	64527	743089
2003	36484	39360	195709	124966	46497	21369	40619	505005
2004	55860	54282	251531	134236	78358	39854	56520	670641
2005	58022	55866	250101	107846	71792	32883	45728	622239
2006	51551	60303	240895	137592	52204	38696	60031	641271
2007	56982	53193	316685	116213	98073	50866	68627	760639
2008	60870	65102	246806	103075	91288	37819	60954	665914
2009	38787	44578	240967	112633	64134	25672	43215	569986
2010	43541	46350	390092	100764	79381	41142	48192	749463
2011	52539	55505	330783	119559	97201	40444	49825	745856
2012	71309	63255	214865	113884	83613	32957	50239	630122
2013	45535	44511	281325	102807	67152	33354	40521	615205
2014	43081	41907	199815	94984	48800	31902	52751	513239
2015	69776	53706	178877	80942	55146	44087	55711	538245
2016	53556	36818	234452	100073	80950	32460	42853	581161
2017	48444	41774	364809	108672	106061	39639	46457	755856

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	483	1463	2740	314	900	271	6342
1996	126	395	756	2762	253	606	205	5104
1997	124	396	691	2557	255	453	191	4666
1998	124	338	735	2564	253	365	202	4581
1999	115	335	596	2727	254	344	178	4548
2000	108	353	522	2652	197	325	173	4331
2001	100	330	340	2658	230	282	151	4092
2002	100	294	386	2819	208	321	145	4274
2003	90	308	416	2943	163	248	116	4284
2004	85	336	960	3141	175	259	121	5078
2005	97	329	412	2898	203	245	121	4305
2006	100	328	492	2358	184	241	135	3838
2007	103	301	528	2183	179	296	137	3727
2008	100	290	467	1305	157	325	119	2763
2009	93	250	393	2813	59	410	95	4112
2010	87	252	408	1668	46	282	96	2840
2011	90	236	416	2372	38	313	113	3577
2012	116	248	414	373	76	369	87	1685
2013	143	231	403	368	55	340	90	1630
2014	119	221	409	371	61	298	92	1570
2015	109	223	401	462	64	294	102	1655
2016	110	187	385	444	46	247	102	1521
2017	113	204	240	477	42	251	107	1434

Table 7. 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)							
River	**BOB**	**BOS**	**BAP**	**GUF**	**GUR**	**DS**	**KAT**	**BAS**
1995	2678	2440	17775	7081	1668	1408	1534	34584
1996	1653	1799	17028	4578	1124	764	837	27782
1997	2683	2061	19621	4347	1415	838	1017	31983
1998	3277	2630	21230	5220	2757	1604	1667	38385
1999	2314	2593	19825	4989	2250	1486	1780	35238
2000	3318	3467	15989	5856	1935	1127	1691	33383
2001	2415	2435	17593	4643	2108	1115	1577	31886
2002	1654	1268	17279	6526	1506	1711	1472	31415
2003	1493	1027	11393	4343	1787	736	946	21725
2004	2359	1664	14097	7242	2442	1138	1361	30303
2005	2428	2039	12025	8409	2405	922	1272	29500
2006	2155	2160	13202	4183	1719	1118	1737	26274
2007	2188	1662	14130	3035	2387	1464	1585	26450
2008	2702	2954	11697	5422	2456	1167	1504	27901
2009	1766	1498	13328	8333	2360	854	1092	29230
2010	2394	1625	18921	4471	2633	1184	1328	32555
2011	2363	2122	15466	4437	1701	1379	1379	28847
2012	3392	2440	10300	4094	2716	1136	1442	25520
2013	2103	1712	14257	3529	2233	1046	1052	25932
2014	1918	1455	13742	3484	1376	1084	1455	24513
2015	3111	2193	8052	2618	1297	1505	1499	20275
2016	2672	1312	9331	3581	2110	1037	1128	21172
2017	2278	1736	12680	4250	2981	1313	1272	26508

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	(tonnes)							
Waterborne	**BOB**	**BOS**	**BAP**	**GUF**	**GUR**	**DS**	**KAT**	**BAS**
1995	2848	2923	19238	9821	1982	2308	1805	40926
1996	1779	2194	17784	7340	1377	1370	1041	32886
1997	2807	2458	20312	6903	1670	1291	1208	36649
1998	3401	2969	21965	7784	3010	1969	1869	42966
1999	2429	2928	20420	7716	2505	1830	1958	39786
2000	3426	3820	16512	8508	2132	1452	1864	37714
2001	2516	2765	17933	7301	2337	1398	1728	35978
2002	1754	1562	17665	9344	1715	2032	1617	35689
2003	1583	1336	11810	7285	1949	984	1063	26009
2004	2444	2000	15057	10383	2618	1397	1482	35381
2005	2525	2368	12438	11307	2608	1167	1393	33805
2006	2255	2488	13694	6540	1903	1359	1872	30111
2007	2291	1963	14658	5218	2565	1761	1722	30178
2008	2802	3245	12164	6727	2613	1491	1623	30664
2009	1858	1747	13721	11146	2419	1264	1187	33342
2010	2481	1877	19329	6140	2679	1466	1424	35395
2011	2452	2359	15882	6809	1738	1692	1492	32424
2012	3509	2688	10714	4468	2792	1505	1529	27205
2013	2246	1943	14660	3897	2289	1386	1142	27561
2014	2036	1676	14151	3855	1436	1382	1547	26083
2015	3220	2416	8452	3080	1361	1799	1601	21930
2016	2783	1499	9716	4025	2156	1283	1230	22693
2017	2390	1940	12920	4727	3022	1564	1378	27942

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 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 2018) 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 part of the catchment areas 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 (approx. 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). It includes catchments in the nine HELCOM member countries and catchments in five transboundary countries (see table 1 and 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 together with the waterborne inputs to the seven sub-basins covering the Baltic Sea are available for the period 1995 – 2017.

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 2019).

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-guidelines HELCOM 2019). 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, and often much higher.

The load in rivers are 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, 2019). For some rivers monthly average concentration are? multiplied with 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-guideline HELCOM, 2019). 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 2019) and HELCOM, 2013.

Quality information

6. Strengths and weaknesses:

Strength: The data set is the most comprehensive and consistent time series of annual riverine and direct inputs 1995-2017 of total nitrogen and phosphorus to the Baltic Sea and its seven sub-basins covering the entire Baltic Sea catchment area. Data has been check with standardized quality assurance methods.

Weakness: Data from some part of the Baltic Sea catchment and some of the direct inputs in the beginning of the time series (1995-2017) are rather uncertain, and many estimates of missing data were required for the early years, particularly for direct inputs of nitrogen and phosphorus. Methods/models for estimating water flow and nutrient inputs from unmonitored areas are not completely comparable and consistent.

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 Kattegat, Danish Straits, the main part of Baltic Proper, Bothnian Sea and Bothnian Bay. For the remaining part of BAP, and for Gulf of Finland and Gulf of Riga the uncertainty might be higher and up to 50 % for waterborne TP inputs (Svendsen et al, 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 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.