Waterborne nitrogen and phosphorus inputs and water flow to the Baltic Sea 1995-2020

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Key Message

Annual water flow in 2020 to the Baltic Sea was approximately 16,600 $m^3 s^{-1}$ which is about 6% higher than the average of 1995-2019, but this covers markedly lower flow than average to three subbasins and higher than average flows to four basins. Annual waterborne input (inputs via rivers and direct point sources discharging directly into the sea) of total nitrogen was approximately 572,000 tonnes in 2020 or 8% lower than the average of 2010-2019. The corresponding annual total phosphorus input amounted to approximately 22,700 tonnes, which is about 13% lower than the average of 2010-2019.

Inputs of nitrogen and phosphorus from direct point sources have decreased with approximately 57% and 83% since 1995, respectively. In 2020, inputs from direct point sources constituted 5% for both TN and TP 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 all sub-basin besides to the Kattegat since 1995. Both TN and TP concentrations decreased significantly for the total riverine inputs to the Baltic Sea.

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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 1995-2020. 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 2020a).

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 covering 1995-2019), 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.

Most of nutrient inputs originate from anthropogenic activities on land and at sea and enter 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 more than 90% of TP inputs in 2019 (HELCOM, 2022,a).

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, any significant data gaps are filled, and other validation 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. The assessment data with annual riverine and direct point source TN and TP and total flow during 1995-2020 are included include in tables 2-7 by Baltic Sea sub-basin and for the Baltic Sea.

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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.

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 95% of both TN and TP waterborne inputs to the Baltic Sea in 2020. In the evaluation of progress towards MAI and CART/NIC as published in HELCOM (2020) (MAI) and Svendsen et al. (2020) (NIC), 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, 2021).

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 2020. Flows are compared with the long-term average (1995-2019), but as there have been marked reductions in TN and TP input in the early part of the timeseries, TN and TP inputs in 2020 are compared with the corresponding latest ten years average (2010-19). Table 1 also includes the catchment and sea surface areas of the sub-basins 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 2020 was about 6% higher than the 1995-2020 average. The flow was higher to Bothnian Bay (23%), Bothnian Sea (20%), Gulf of Finland (15%) and Kattegat (12%), but lower to Baltic Proper (25%), Gulf of Riga (14%), and to the Danish Straits (10%) as compared with the average. Waterborne TN inputs in 2020 were 572,200 tons or 8% lower than average of TN inputs during 2010-19. The corresponding TP inputs were 22,750 tons or 13% lower than average of 2010-19. Higher than average flow usually implies higher waterborne TN and TP inputs; but it can be explained with lower than average flow to Baltic Proper, Gulf of Riga and Danish Straits that during 2010-2019 constitutes about 60 % of TN and TP input to the Baltic Sea, and by taking into account there have been some reduction in inputs since 2010 to some basins. The pattern is however complex since both interannual flow variations and long-term trends in nutrient inputs varies across sub-basins. TN inputs in 2020 were 26% (Bothnian Bay), 16% (Gulf of Finland), 15% (Bothnian Sea) and 2% (Kattegat), respectively, higher than average. For 3 basins it was lower than average: Baltic Proper (27%), Gulf of Riga (10%) and Danish Straits (11%). TP inputs in 2020 were 44% (Bothnian Sea), 21% (Bothnian Bay), 17% (Kattegat) and 2% (Gulf of Finland) higher than average. For 3 basins it was lower than average: Baltic Proper (34%), Gulf of Riga (23%) and Danish Straits (20%). For phosphorus there have been some reductions in inputs since 2010 to some of the basins. In 2020 the north and north-eastern part of the catchment area had high precipitation while the southern part of the catchment had rather dry conditions, and closer to average in the western part of the catchment area.

Annual flow-weighted riverine concentration (calculated by dividing annual riverine nutrient input with the corresponding water flow[3]) in 2020 to the Baltic Sea was 1.15 mg N l^{-1} or 3% lower than the average TN concentration during 2010-19, and for TP it was 0.040 mg P l^{-1} or 17% lower than average (2010-19. Flow-weighted TN concentrations were lower than average for two sub-basins, Baltic Proper (5%), and Kattegat (11%), and higher to two basins: Bothnian Bay (10%) and Gulf of Finland (9%). For the remaining three basins the flow weighted nitrogen concentration was close to the average. The lower than average concentration to Kattegat is a result of higher than average flow from the Swedish part of the catchment. It seems that high flow in 2020 to Bothnian Bay also have resulted in higher than average flow weighted concentration, indicating that some processes in the catchment have resulted in rather high inputs of TN. Flow-weighted TP was lower than average to three basins: Baltic Proper (13%), Gulf of Riga (12%) and Danish Straits (5%). TP flow weighted concentrations was very high to Bothnian Sea (31 % higher than average 2010-19) and higher to Gulf of Finland (6%) than the average, and close to average for the remaining basins. The very high flow weighted TP concentration in 2020 Bothnian Sea

[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.

is related to the much higher than average flow, that can result in flooding and high degree of erosion supplying with a lot of TP to inland surface waters.[4]

Area specific waterborne catchment inputs in 2020 were highest to the Danish Straits (1,150 kg N km^{-2}, 35 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 240 kg N km^{-2} and 12 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. Average for the Baltic Sea is approx. 330 kg N km^{-2} and 13 kg P km^{-2}. On the other hand, specific waterborne inputs per sea area are highest to the Gulf of Finland (3,900 kg N km^{-2}, 151 kg P km^{-2}) and Gulf of Riga (3,610 kg N km^{-2} and 88 kg P km^{-2}) but lowest to the Bothnian Sea (681 kg N km^{-2}, 36 kg P km^{-2}). Average for the Baltic Sea is approx. 1,400 kg N km^{-2} and 54 kg P km^{-2}).

[4] Catchment to Bothnian Bay received a lot more precipitation than normal in 2020. On the Finnish side of the Bothnian Bay peat soils dominate and high precipitation and a mild winter resulted in higher than normal nitrogen leaching but had less impact on phosphorus leaching.
The winter 2020 was exceptionally mild and rainy especially in the south-western Finland and the northern part of Swedish catchment to Bothnian Sea and the whole Bothnian Bay. A lot of suspended solids and total phosphorus was leached and washed into the watercourses from cultivated fields (clay soils were not frozen) in e.g. Finnish catchment. In January-February 2020 more than annual average total Finnish phosphorus was exported into the Bothnian Sea including Archipelago Sea.

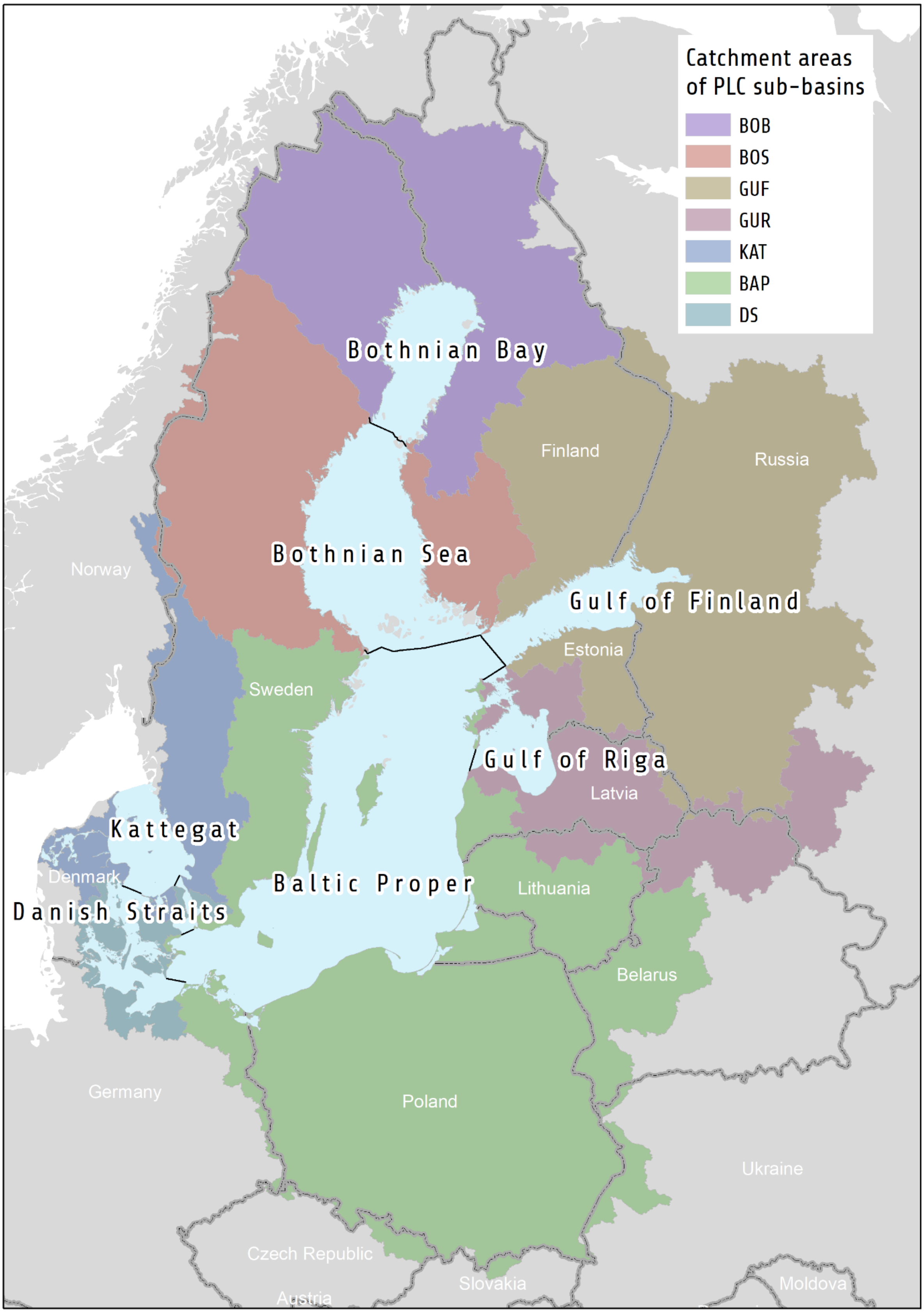
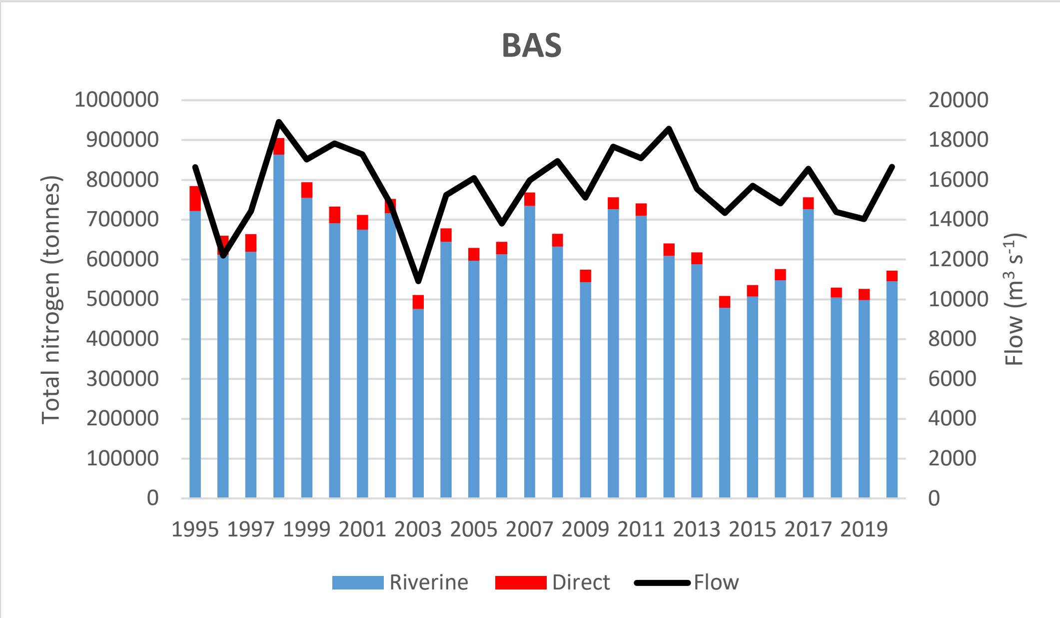


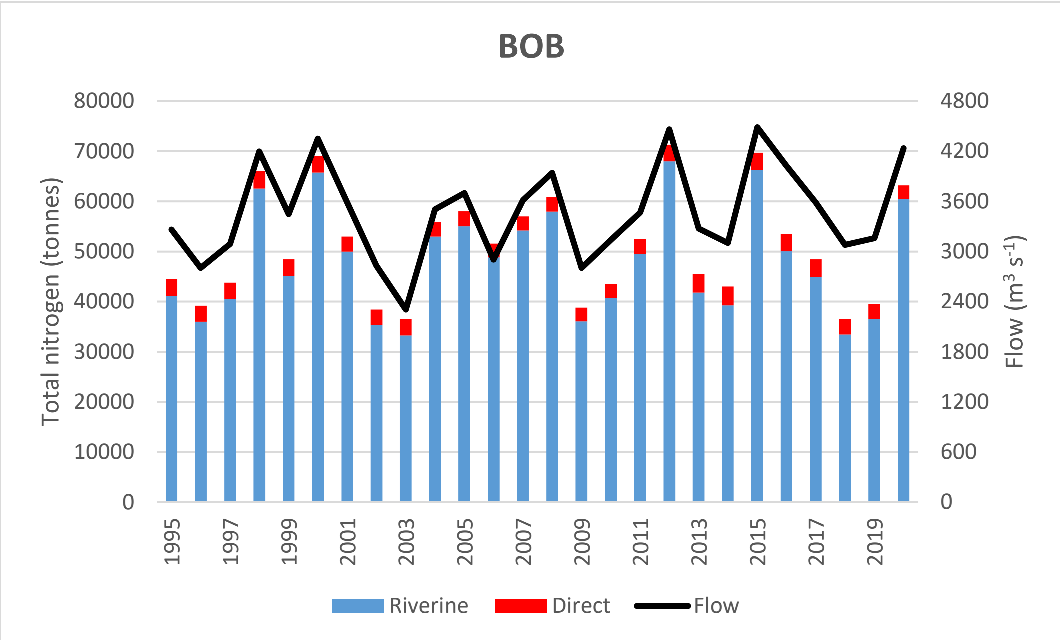
Figure 1. The catchment of the Baltic Sea is shared by nine HELCOM Contracting Parties - Denmark (DK), Estonia (EE), Finland (FI), Germany (DE), Latvia (LV), Lithuania (LT), Poland (PL), Russia (RU) and Sweden (SE) and 5 transboundary countries (Belarus, Czech Republic, Slovakia, Norway and Ukraine). 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).

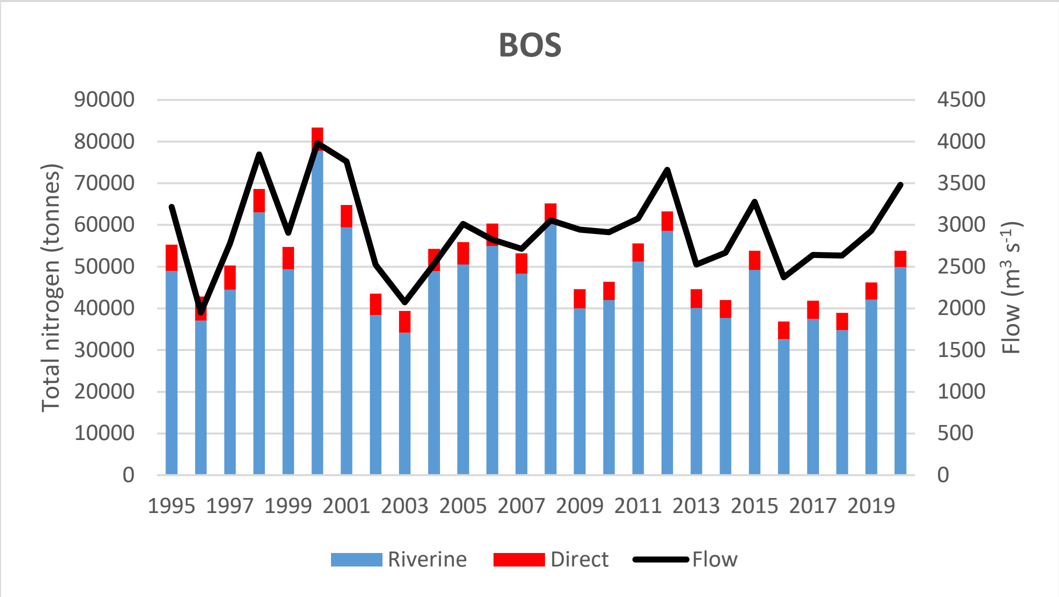
Table 1. Catchment area to and sea area of the seven sub-basins of the Baltic Sea (km^2). Annual waterborne flow (m^3 s^{-1}), area specific flow (l s^{-1} km^{-2}), waterborne total nitrogen (TN) and phosphorus inputs TP (tonnes) in 2020 and on average of 1995-2019 for flow and 2011-2019 for TN and TP. Flow weighted TN and TP concentrations (mg l^{-1}) of annual riverine inputs in 2020 and on average of 2010-2019. Further, waterborne inputs of TN and TP are 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.

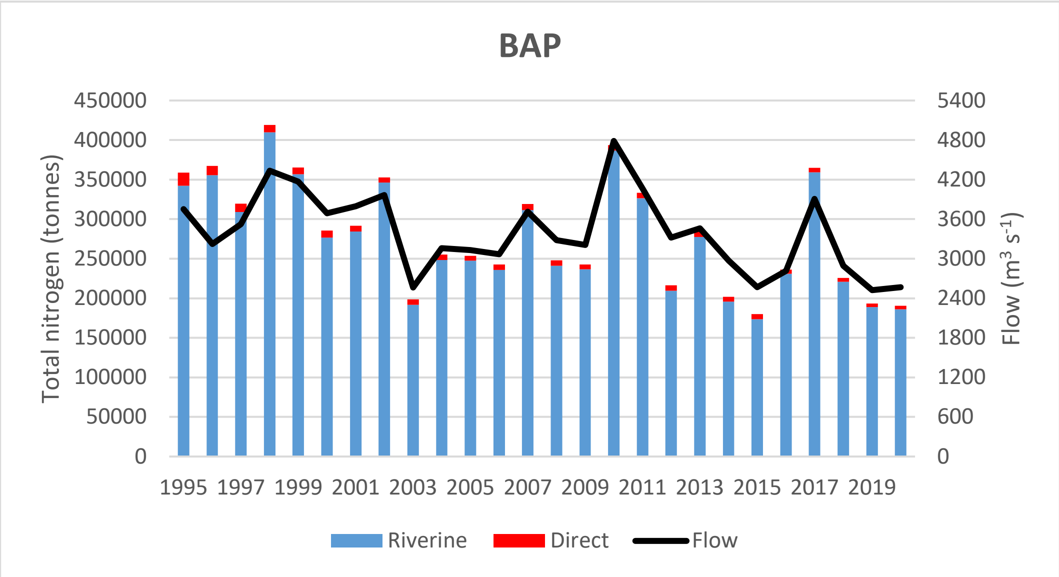
	Catchm. area	**Sub-basin sea area**	**Flow**	**Flow**	**Flow**	**Flow**	**TN water-borne**	**TN water-borne**	**TN flow-weight. river conc.**	**TN flow-weight. River conc.**	**TN water-borne /catch. area**	**TN water-borne /sea area**	**TP water-borne**	**TP water-borne**	**TP flow-weight. river conc.**	**TP flow-weight. River conc.**	**TP water-borne /catch. area**	**TP water-borne /sea area**
			2020	**1995-2019**	**2020**	**1995-2019**	**2020**	**2010-2019**	**2020**	**2010-2019**	**2020**	**2020**	**2020**	**20105-2019**	**2020**	**2010-2019**	**2020**	**2020**
	km^{-2}	**km^{-2}**	**m^3 s^{-1}**	**m^3 s^{-1}**	**l s^{-1}km^{-2}**	**l s^{-1}km^{-2}**	**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	263,000	36,000	4,237	3,444	16.1	13.1	63,213	50,369	0.45	0.41	240	1,756	2,999	2,479	0.022	0.021	11	83
BOS	228,000	79,000	3480	2,913	15.3	12.8	53.,826	46,945	0.48	0.47	236	681	2,835	1,968	0.025	0.019	12	36
BAP	576,000	209,000	2,569	3,436	4.5	6.0	190,761	262,877	2.31	2.43	331	913	8,164	12,409	0.099	0.114	14	39
GUF	423,000	30,000	4,051	3,519	9.6	8.3	116,120	100,313	0.84	0.77	275	3,871	4,523	4,451	0.034	0.032	10	151
GUR	138,000	19,000	922	1,071	6.7	7.8	68,625	75,838	2.35	2.30	497	3,612	1,669	2,166	0.056	0.064	12	88
DS	27,000	21,000	196	217	7.3	8.0	31,016	34,644	4.81	4.82	1,149	1,477	948	1,180	0.129	0.136	35	45
KAT	87,000	24,000	1,207	1,077	13.9	12.4	48,620	47,823	1.24	1.38	559	2,026	1,612	1,372	0.040	0.038	19	67
BAS	**1,742,000**	**418,000**	**16,661**	**15,676**	**9.6**	**9.0**	**572,181**	**618,808**	**1.15**	**1.18**	**328**	**1,369**	**22,749**	**26,024**	**0.040**	**0.049**	**13**	**54**

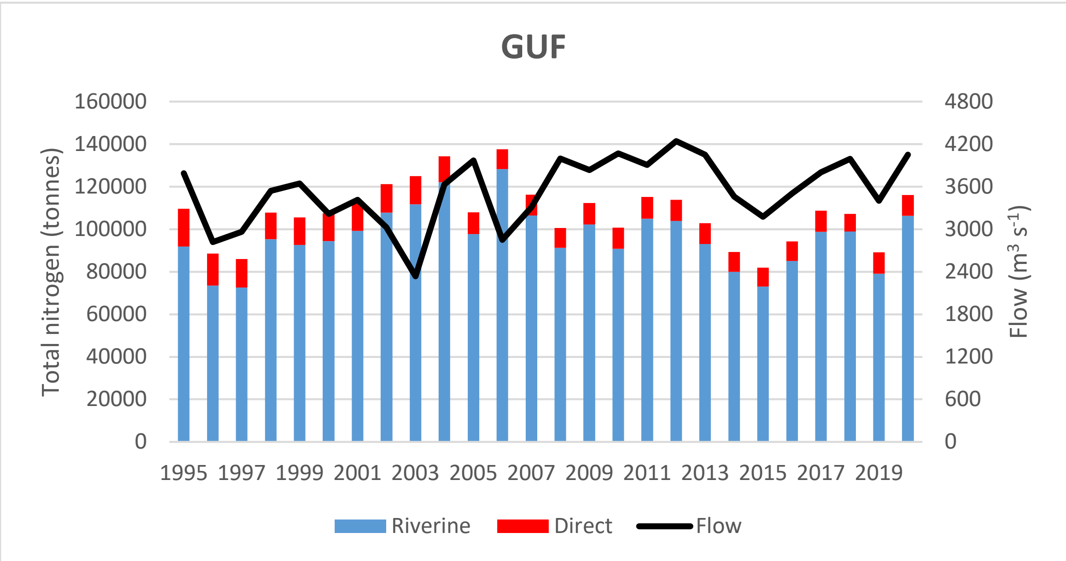
The annual water flow, direct inputs of TN and TP and riverine TN and TP inputs during 1995-2020 to the sub-basins and to the Baltic Sea are shown in Figure 2a and b as well as in Tables 2-8 in the "Data" section. There are significant reductions in total direct nitrogen inputs from 1995 to 2020 to the Baltic Sea (57%). Significant 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 (76%), Baltic Proper (72%) and to Gulf of Riga (70%). There are significant reductions of direct TP inputs to all sub-basins, the highest to Gulf of Finland (90%), Gulf of Riga (90%) and Baltic proper (88%), resulting in a total reduction of 83% in the Baltic Sea, although data on direct inputs are more uncertain in the beginning of the time series. Even though 2020 direct inputs to the Baltic Sea constitute only a minor share of the waterborne TN and TP waterborne inputs (both 5%), they provide large proportions of the nutrient inputs to some sub-basins e.g. the Danish Straits (10%) for TN, and the Danish Straits (21%) and Bothnian Sea (7%) for TP in 2020.

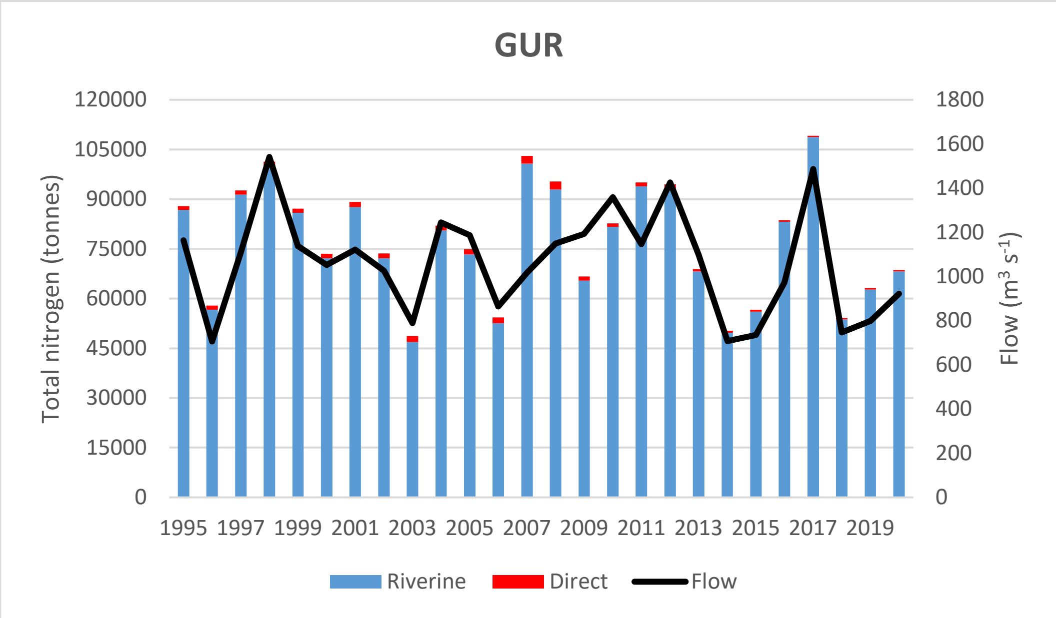


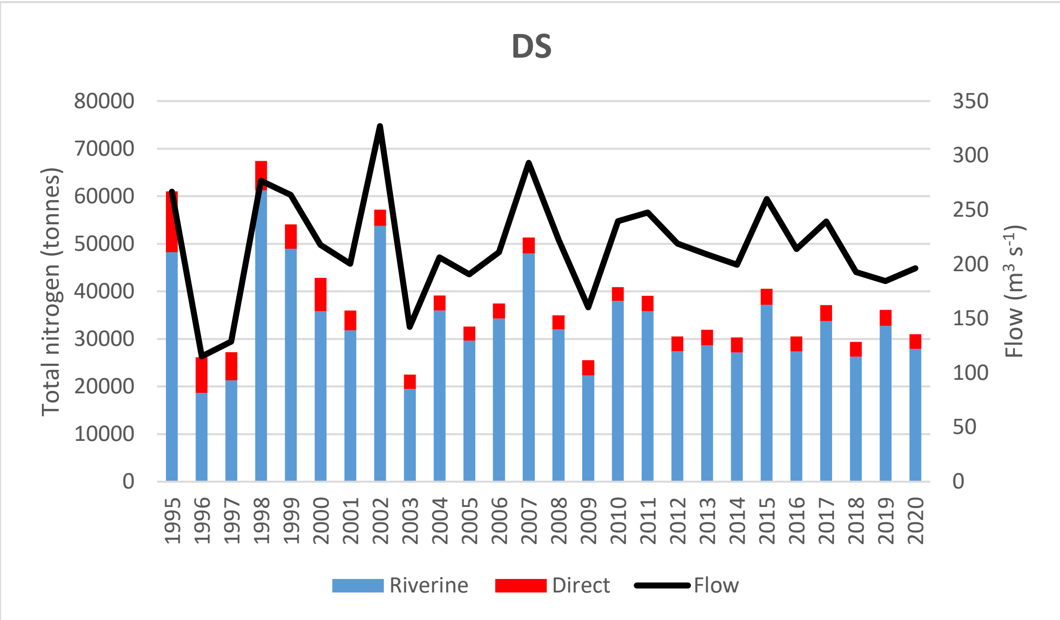



BOS
Total nitrogen (tonnes)
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Flow (m3 s-1)
1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017 2019
Riverine
Direct
Flow


BAP
Total nitrogen (tonnes)
450000
400000
350000
300000
250000
200000
150000
100000
50000
0
5400
4800
4200
3600
3000
2400
1800
1200
600
0
Flow (m3 s-1)
1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017 2019
Riverine
Direct
Flow


GUF
Total nitrogen (tonnes)
160000
140000
120000
100000
80000
60000
40000
20000
0
4800
4200
3600
3000
2400
1800
1200
600
0
Flow (m3 s-1)
1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017 2019
Riverine
Direct
Flow


GUR
Total nitrogen (tonnes)
Flow (m3 s-1)
Riverine
Direct
Flow


DS
Total nitrogen (tonnes)
Flow (m3 s-1)
Riverine
Direct
Flow

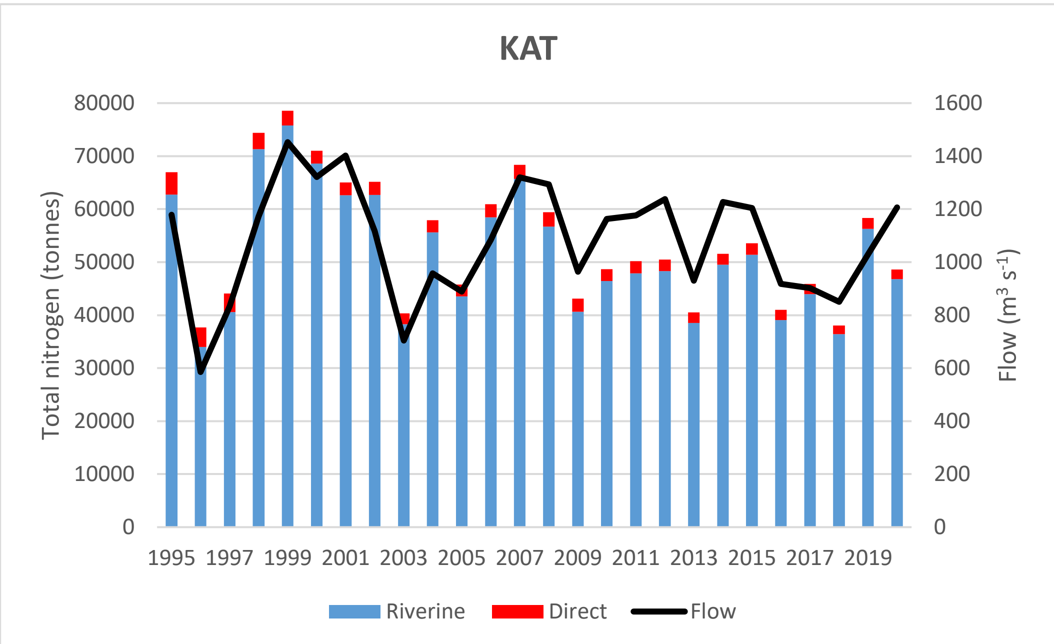
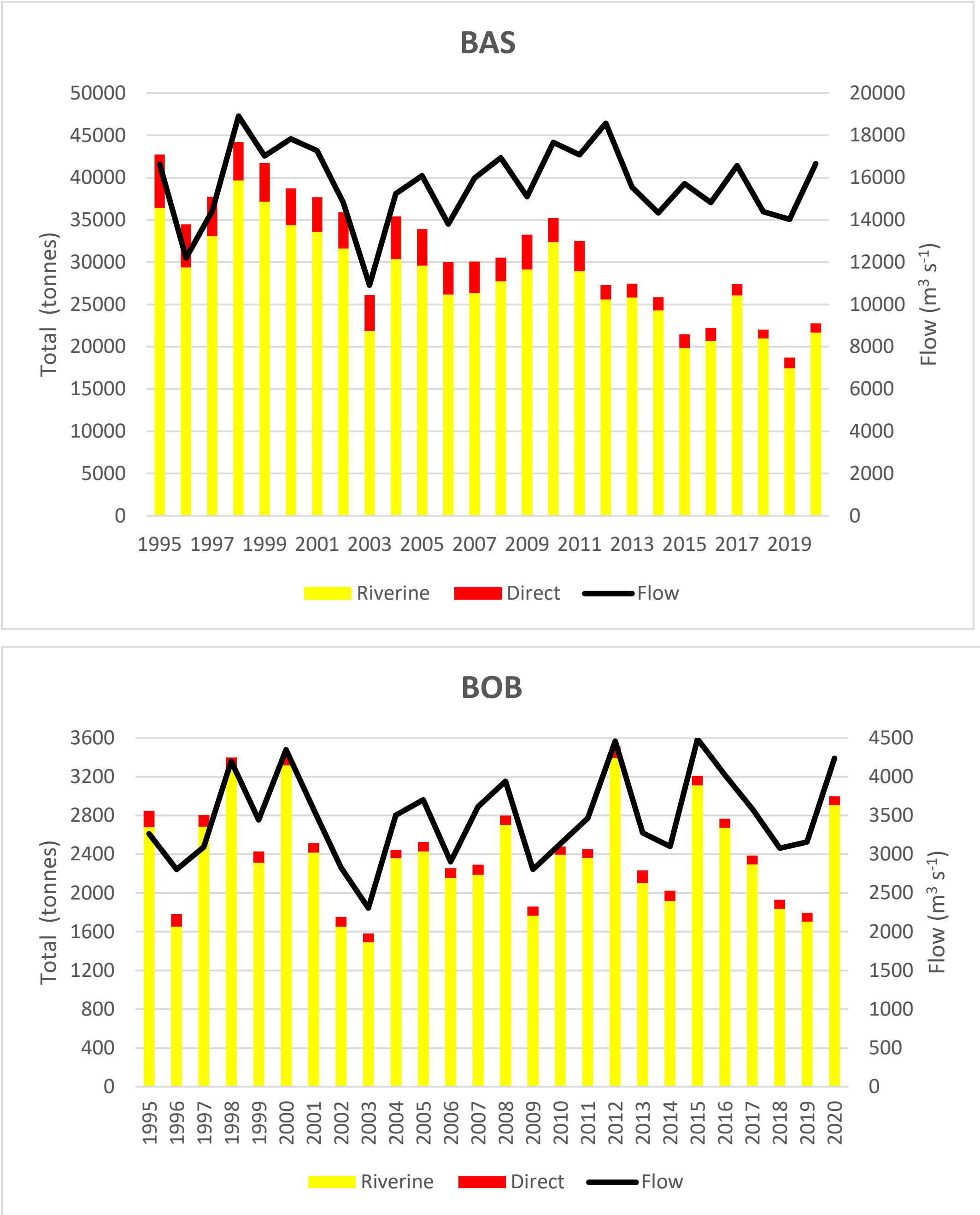
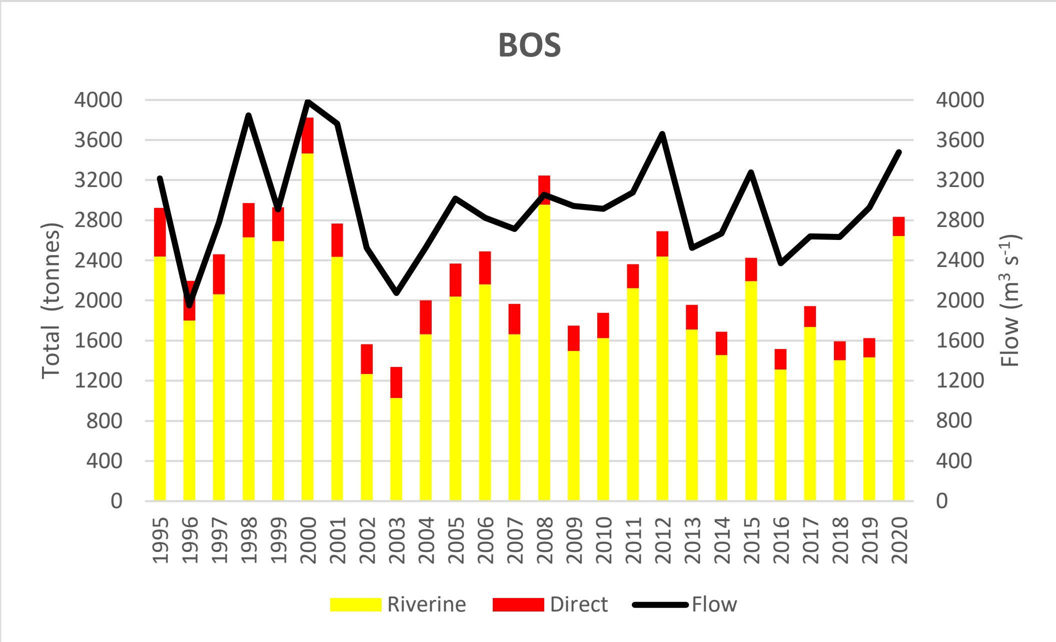
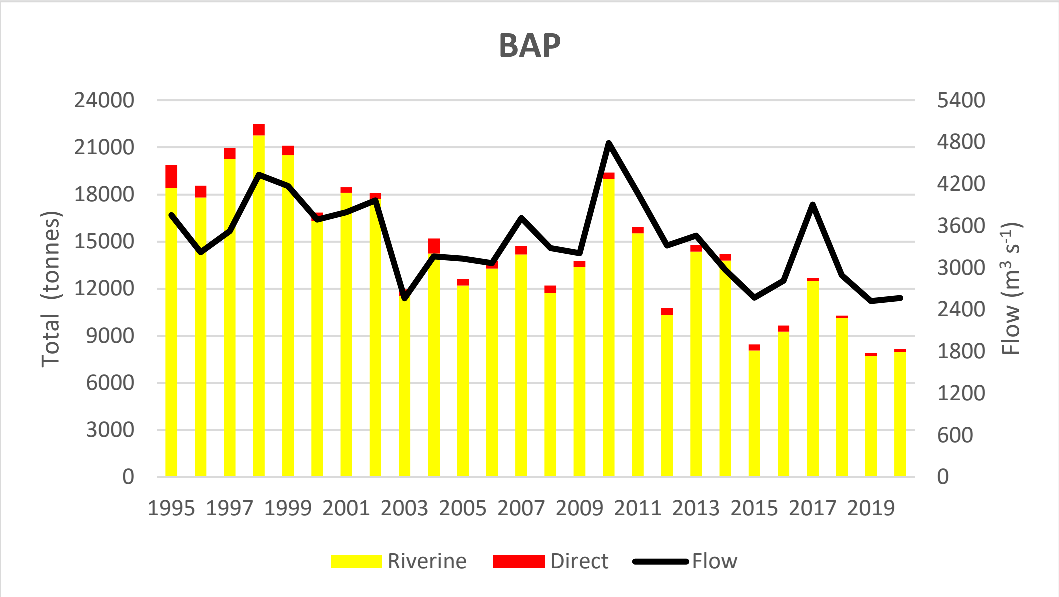
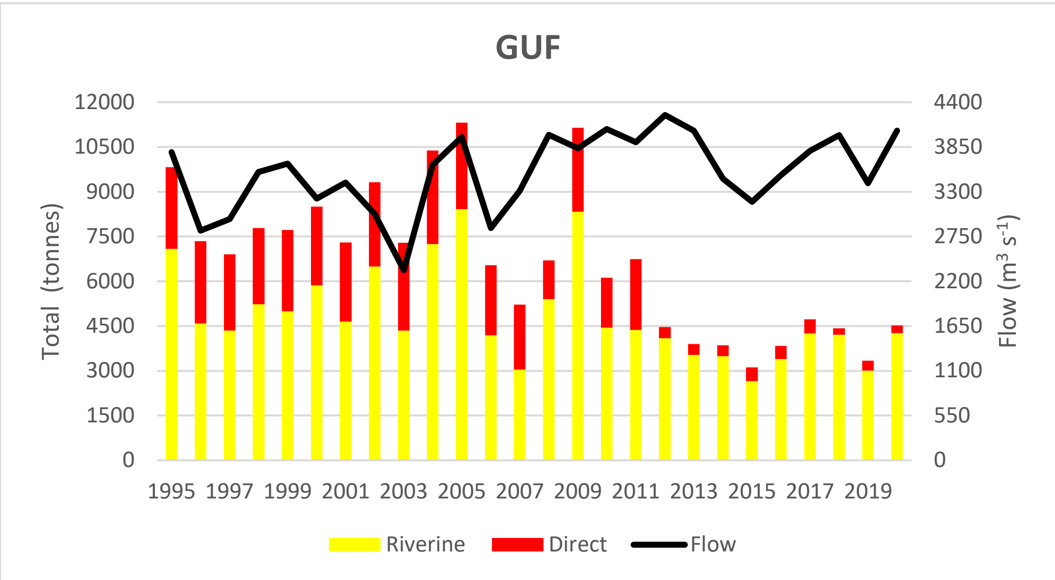

KAT
Total nitrogen (tonnes)
Flow (m3 s-1)
Riverine
Direct
Flow

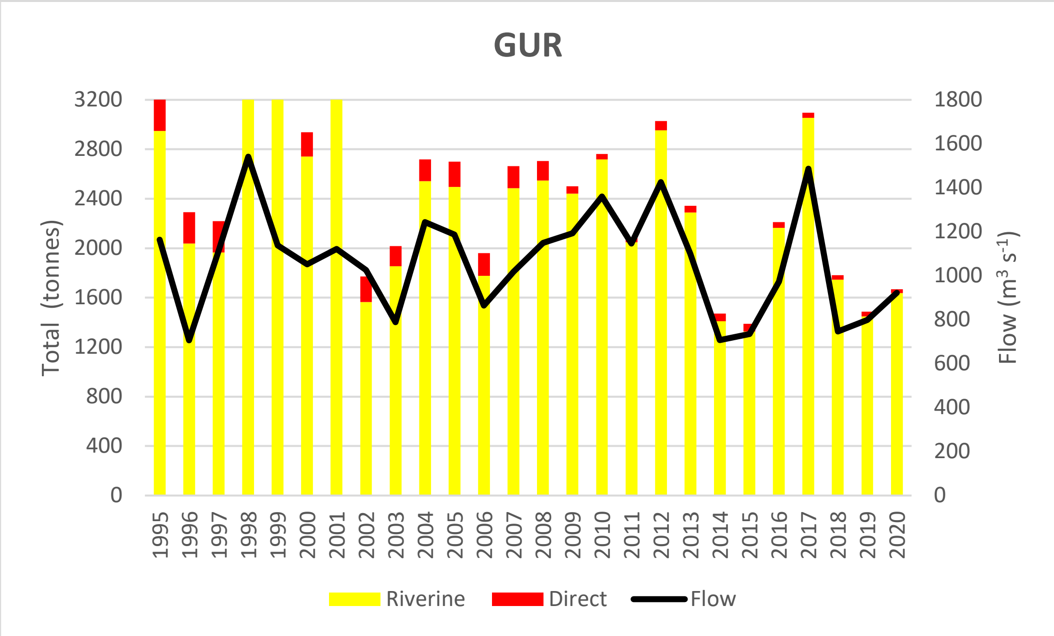
Figure 2A: Annual riverine and direct inputs of total nitrogen in tonnes and annual waterborne flow (m^{-3} s^{-1}) to the seven Baltic Sea sub-basin and to the Baltic Sea in 1995-2020. Data behind the figures are shown in Tables 2-5. For an explanation of the basin abbreviations, see the caption to Figure 1.

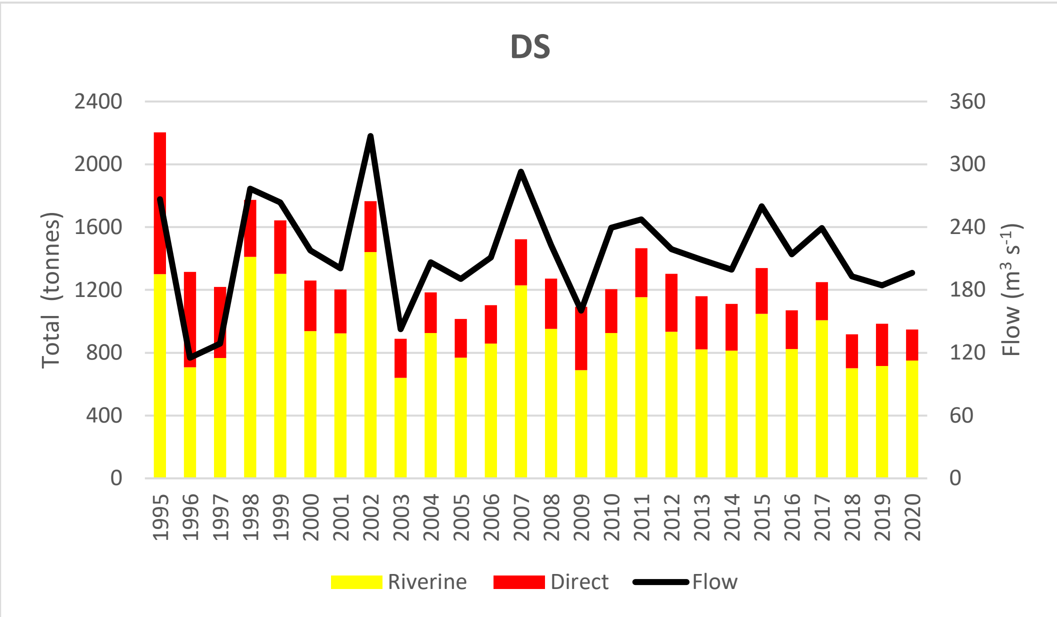



BOS
Total (tonnes)
Flow (m3 s-1)
Riverine
Direct
Flow


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


GUF
Total (tonnes)
Flow (m3 s-1)
Riverine
Direct
Flow


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


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

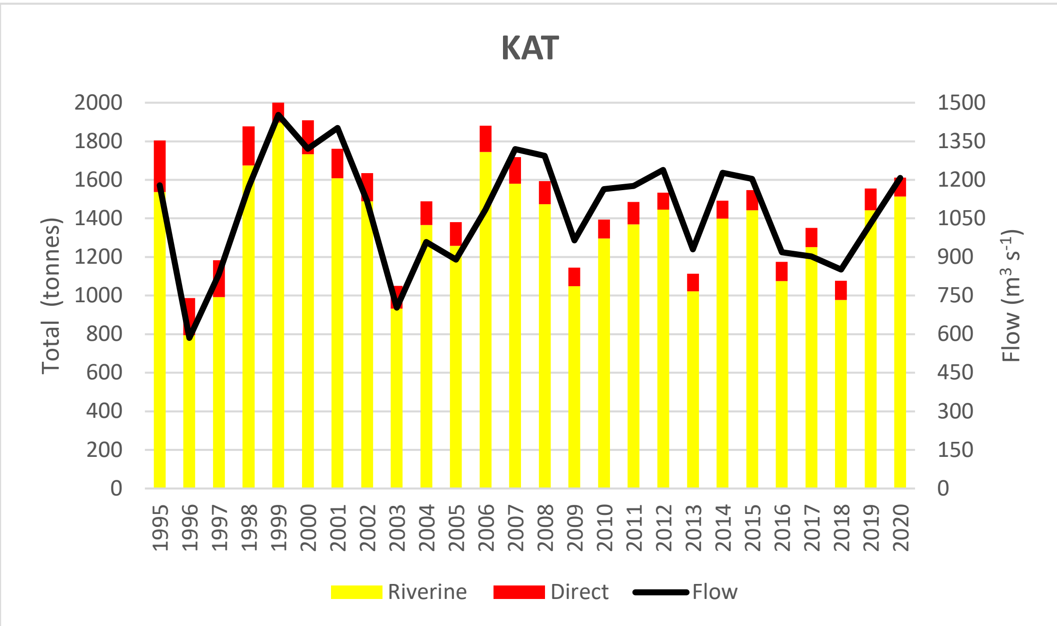
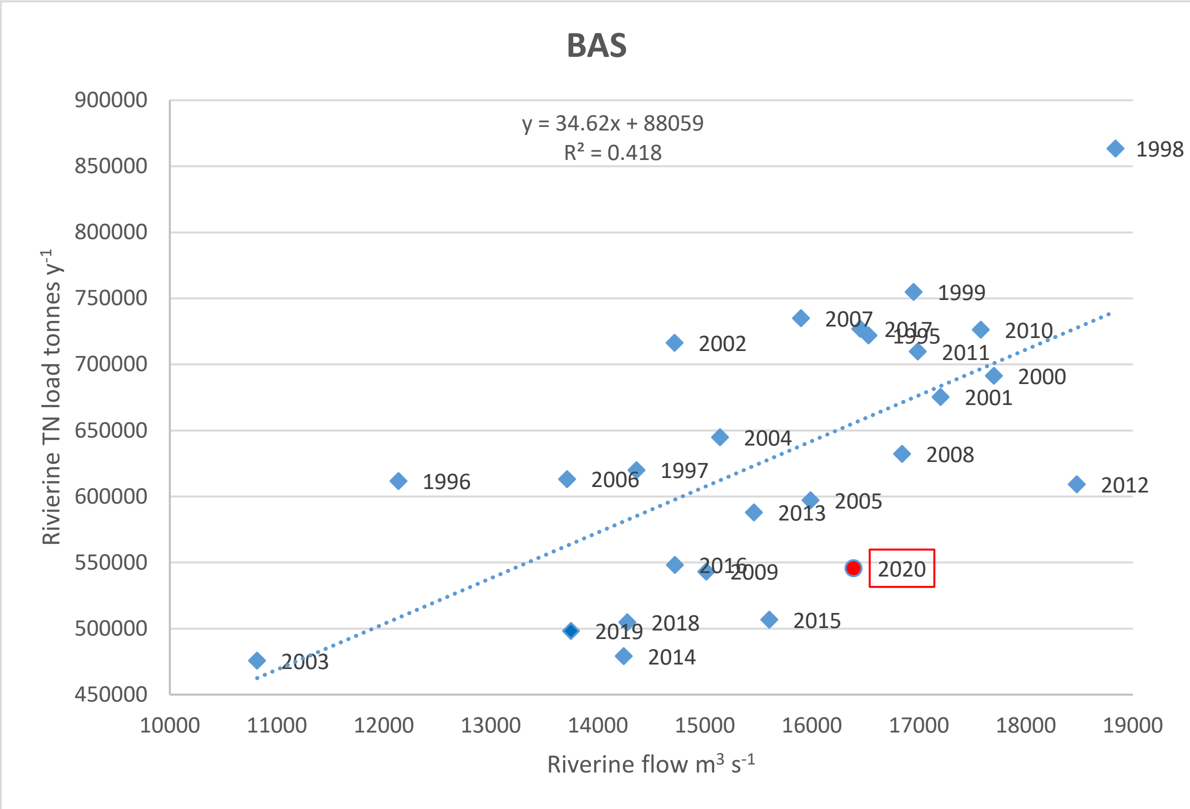

KAT
Total (tonnes)
Flow (m³ s⁻¹)
Riverine
Direct
Flow

Figure 2B: Annual riverine and direct inputs of total phosphorus in tonnes and annual waterborne flow ($m^{-3}\ s^{-1}$) to the seven Baltic Sea sub-basin and to the Baltic Sea in 1995-2020. Data behind the figures are shown in Tables 2 and 6-8. For an explanation of the basin 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 significance of the linear regression is tested statistically (see caption to Figure 3). The plots allow for characterization and evaluation of the TN and TP riverine inputs 1995-2020 specifically the inputs in 2020. The linear relation between riverine inputs and flow is significant for both TN and TP for all sub-basins and for the Baltic Sea except for the Gulf of Finland. Lack of significant correlation indicates some main challenges estimating input data to the GUF for some unmonitored areas and the nutrient load in some rivers particularly in the 1990s and up to around 2005.

Riverine TN and TP inputs in 2020 were under or markedly under what the regressions line indicates for the magnitude of flow during 1995-2020 to Baltic Sea, except for TN to Gulf of Riga (nearly on the regression line), and TP to Bothnian Sea where it was markedly over the regression line (and we don't evaluate on Gulf of Finland). For TP to Bothnian Sea the 20% higher flow than average (1995-2019) has resulted in 44% higher TP inputs than average (2010-19), and higher inputs that can be explained from a linear relation between flow and load, indicating that some extreme events have caused big supply of phosphorus via erosion. Overall, the Figures 3A and B indicate a rather 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 2020 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 3A and 3B. It will also give a lower regression coefficient R^2 compared with time series with low share of inputs from point sources.


BAS
y = 34.62x + 88059
R² = 0.418
Rivierine TN load tonnes y-1
Riverine flow m3 s-1
900000
850000
800000
750000
700000
650000
600000
550000
500000
450000
10000
11000
12000
13000
14000
15000
16000
17000
18000
19000
1998
1999
2007
2010
2011
2002
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2004
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1996
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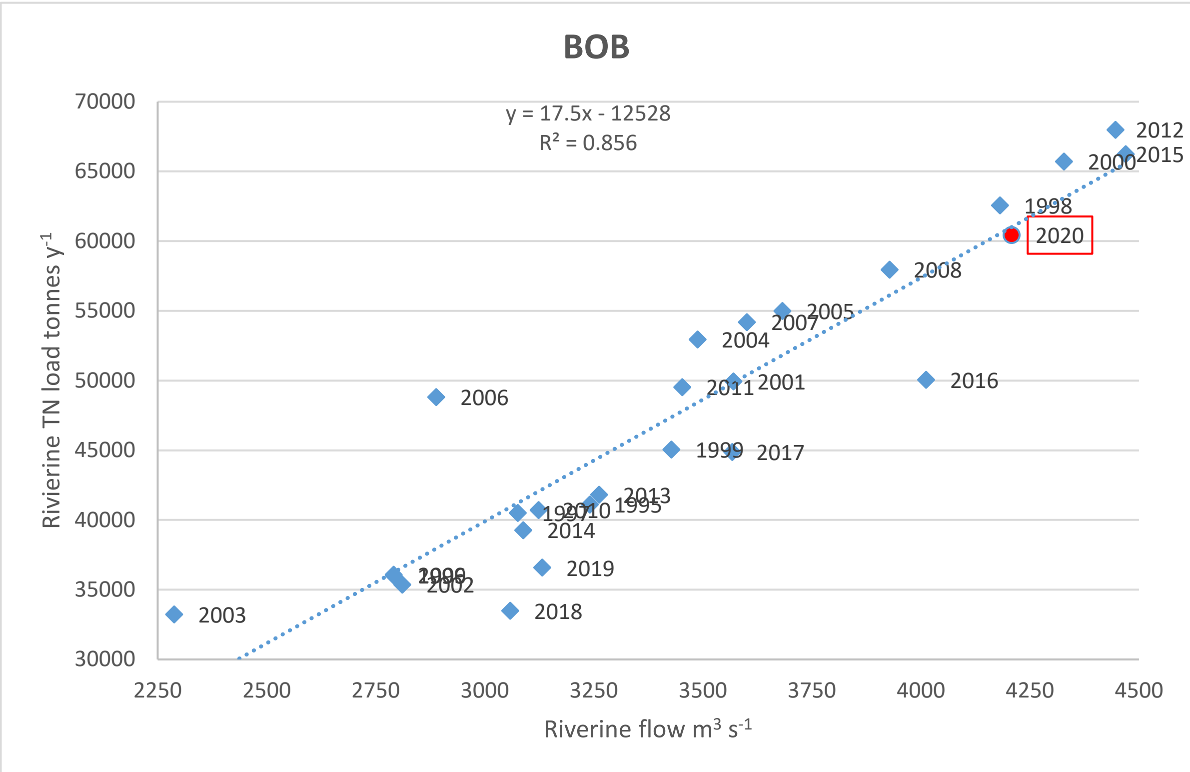
2020
2019
2018
2015
2003
2014


BOB
y = 17.5x - 12528
R² = 0.856
Rivierine TN load tonnes y-1
Riverine flow m3 s-1
70000
65000
60000
55000
50000
45000
40000
35000
30000
2250
2500
2750
3000
3250
3500
3750
4000
4250
4500
2012
2000
2015
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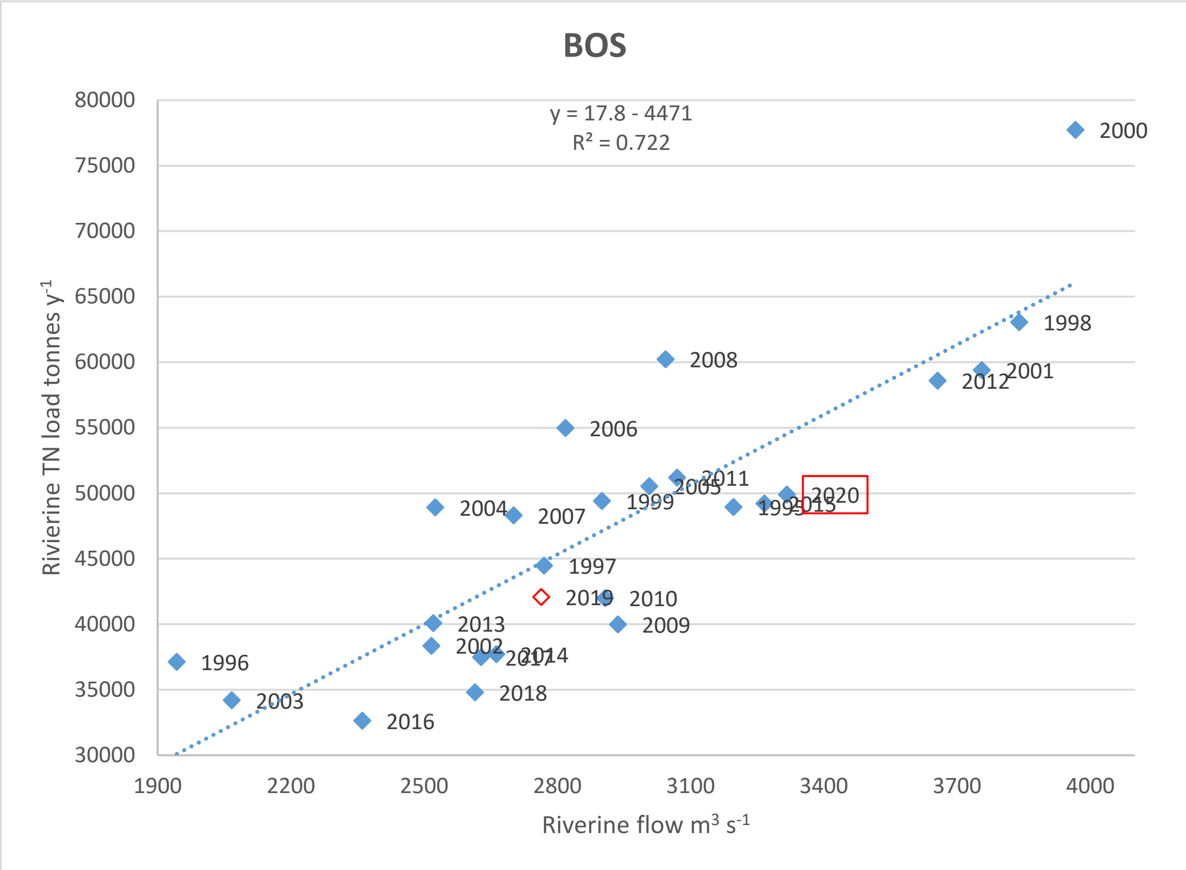
2014
2019
2002
2018
2003


BOS
y = 17.8 - 4471
R² = 0.722
Rivierine TN load tonnes y-1
Riverine flow m3 s-1
80000
75000
70000
65000
60000
55000
50000
45000
40000
35000
30000
1900
2200
2500
2800
3100
3400
3700
4000
2000
1998
2008
2012
2001
2006
2011
2005
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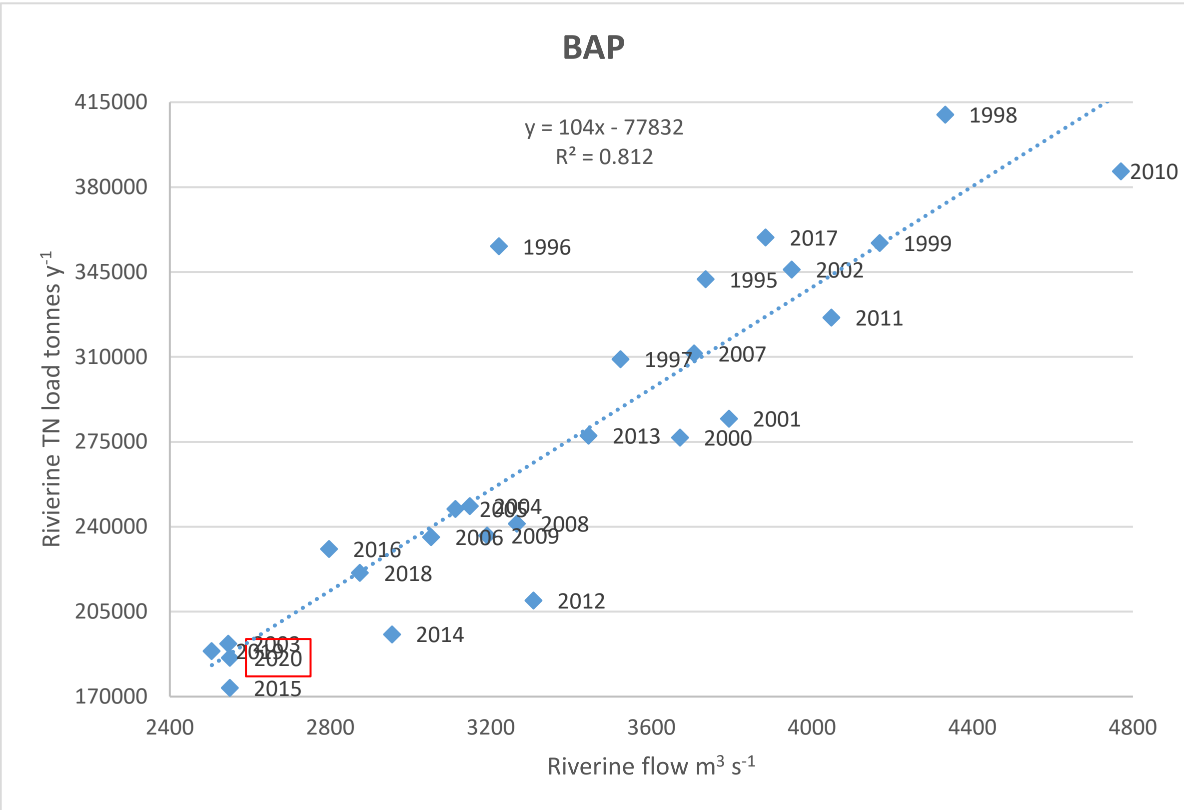
2014
2003
2018
2016


BAP
y = 104x - 77832
R² = 0.812
Rivierine TN load tonnes y-1
Riverine flow m3 s-1
415000
380000
345000
310000
275000
240000
205000
170000
2400
2800
3200
3600
4000
4400
4800
1998
2010
1996
2017
1999
1995
2002
2011
1997
2007
2001
2013
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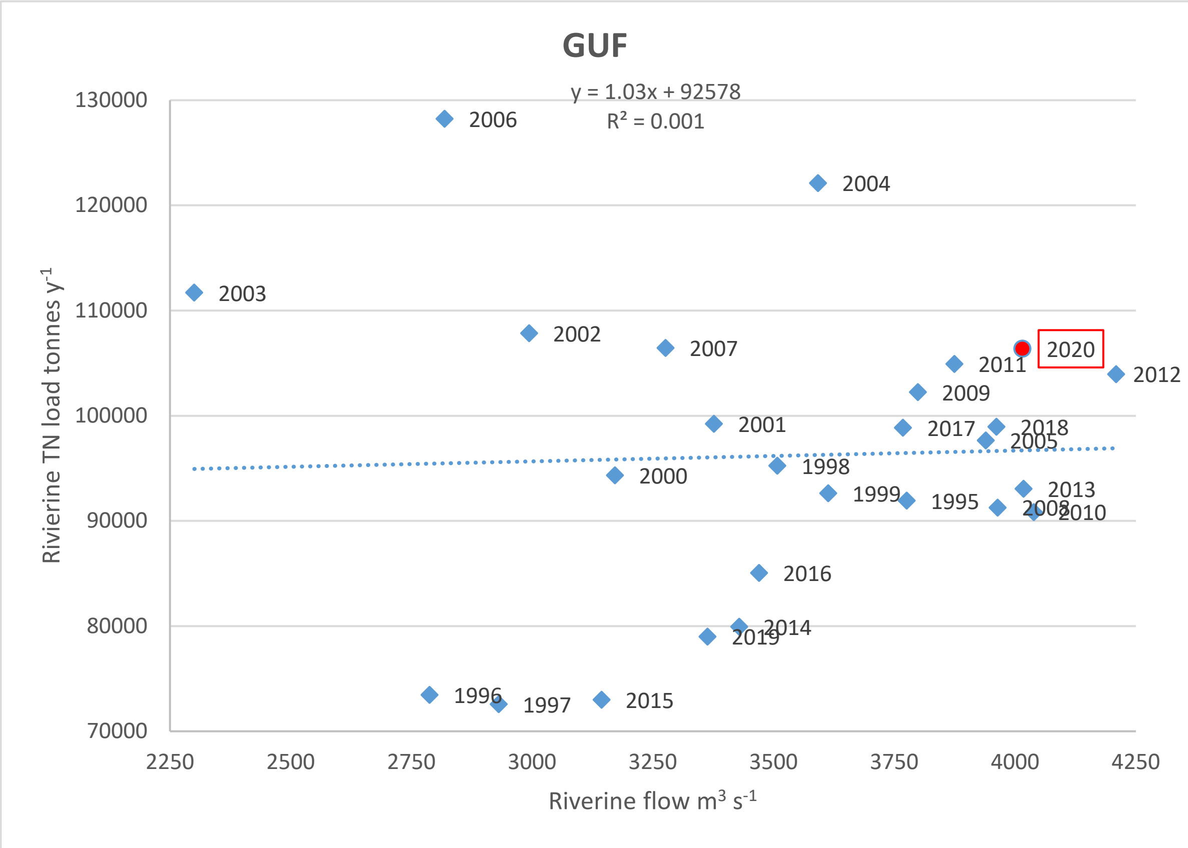
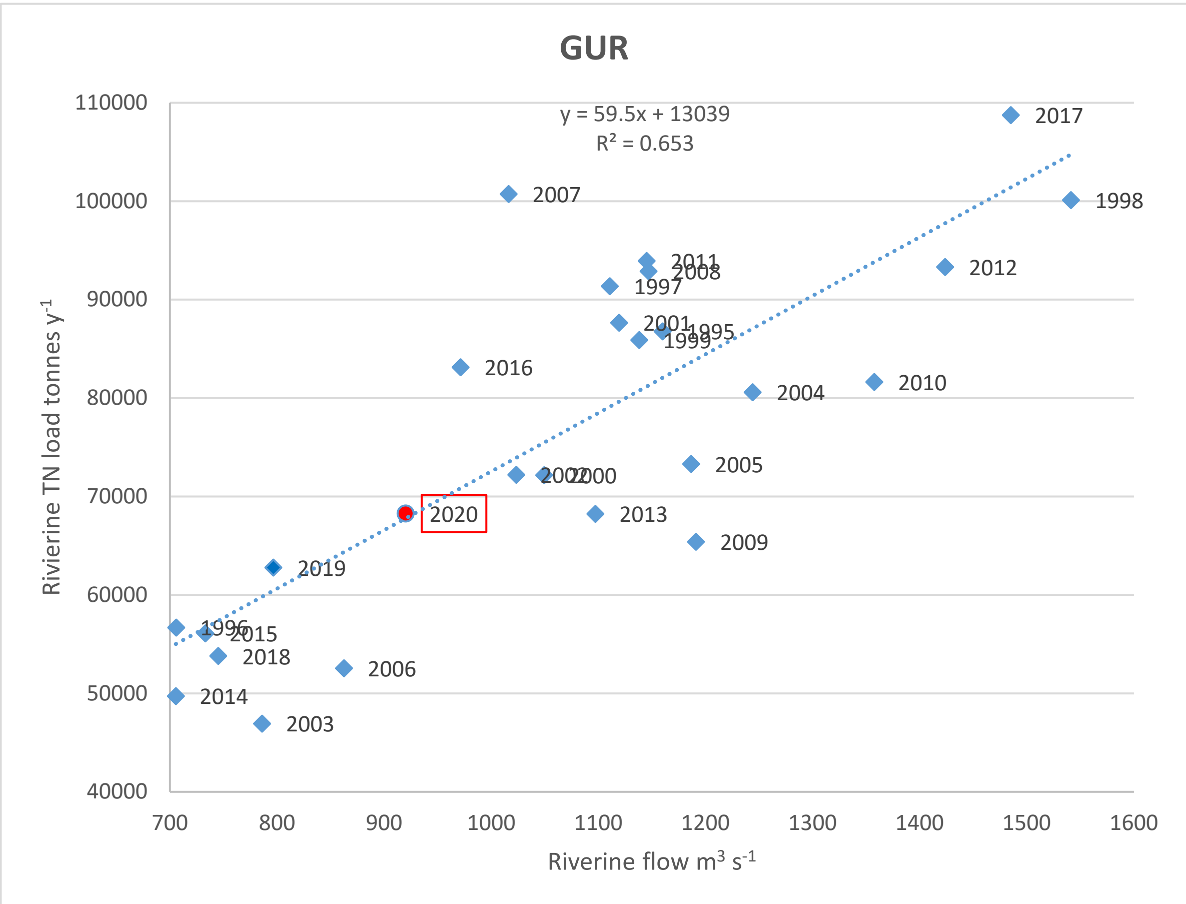
2004
2006
2009
2008
2016
2018
2012
2014
2003
2019
2020
2015


GUF
y = 1.03x + 92578
R² = 0.001
Rivierine TN load tonnes y-1
Riverine flow m3 s-1
2006
2004
2003
2002
2007
2020
2011
2012
2009
2001
2017
2018
2005
2000
1998
1999
1995
2013
2008
2010
2016
2019
2014
1996
1997
2015


GUR
y = 59.5x + 13039
R² = 0.653
Rivierine TN load tonnes y-1
Riverine flow m3 s-1
2017
2007
1998
2011
2008
1997
2012
2001
1995
1999
2016
2004
2010
2002
2000
2005
2020
2013
2009
2019
1996
2015
2018
2006
2014
2003

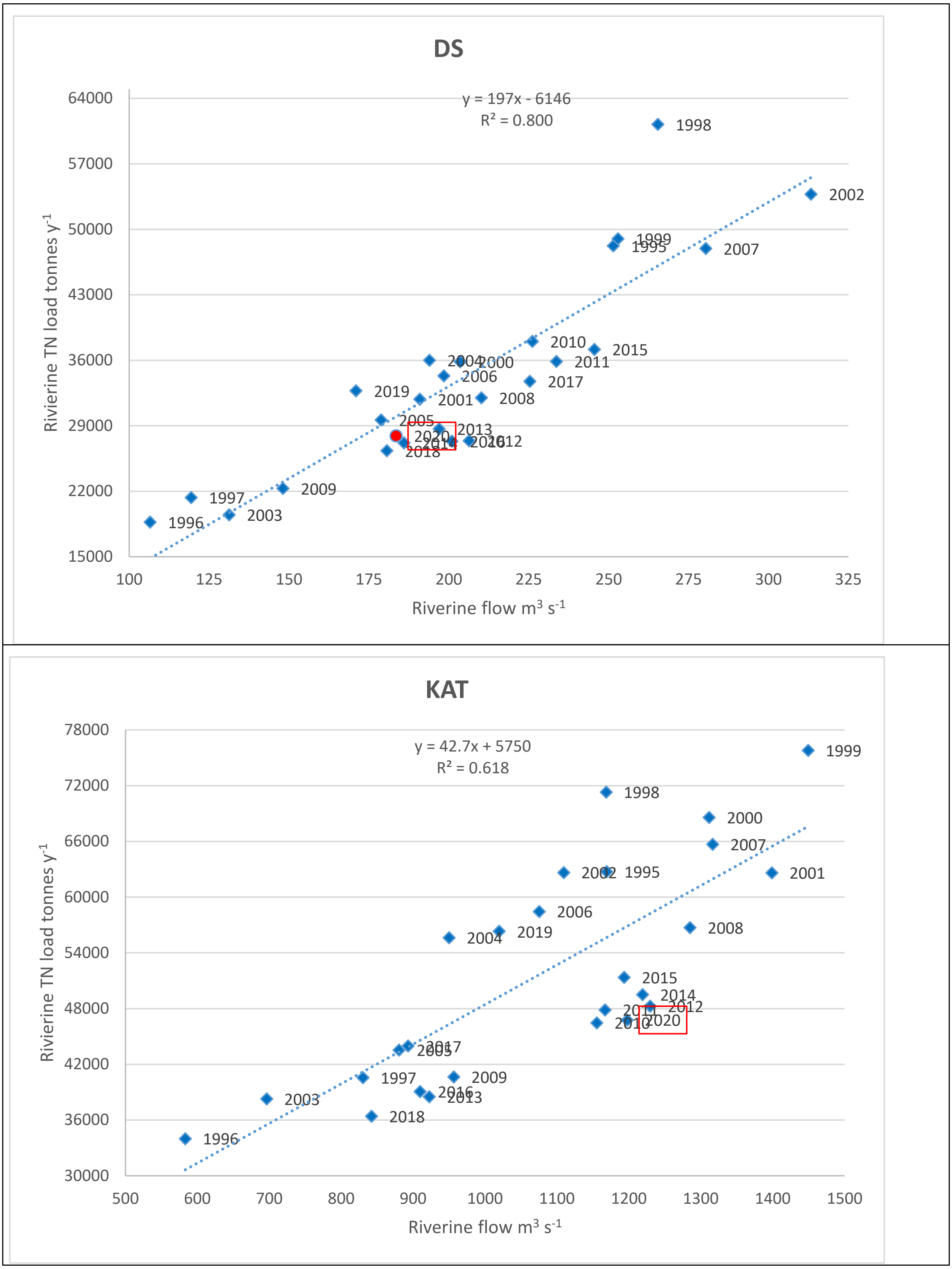
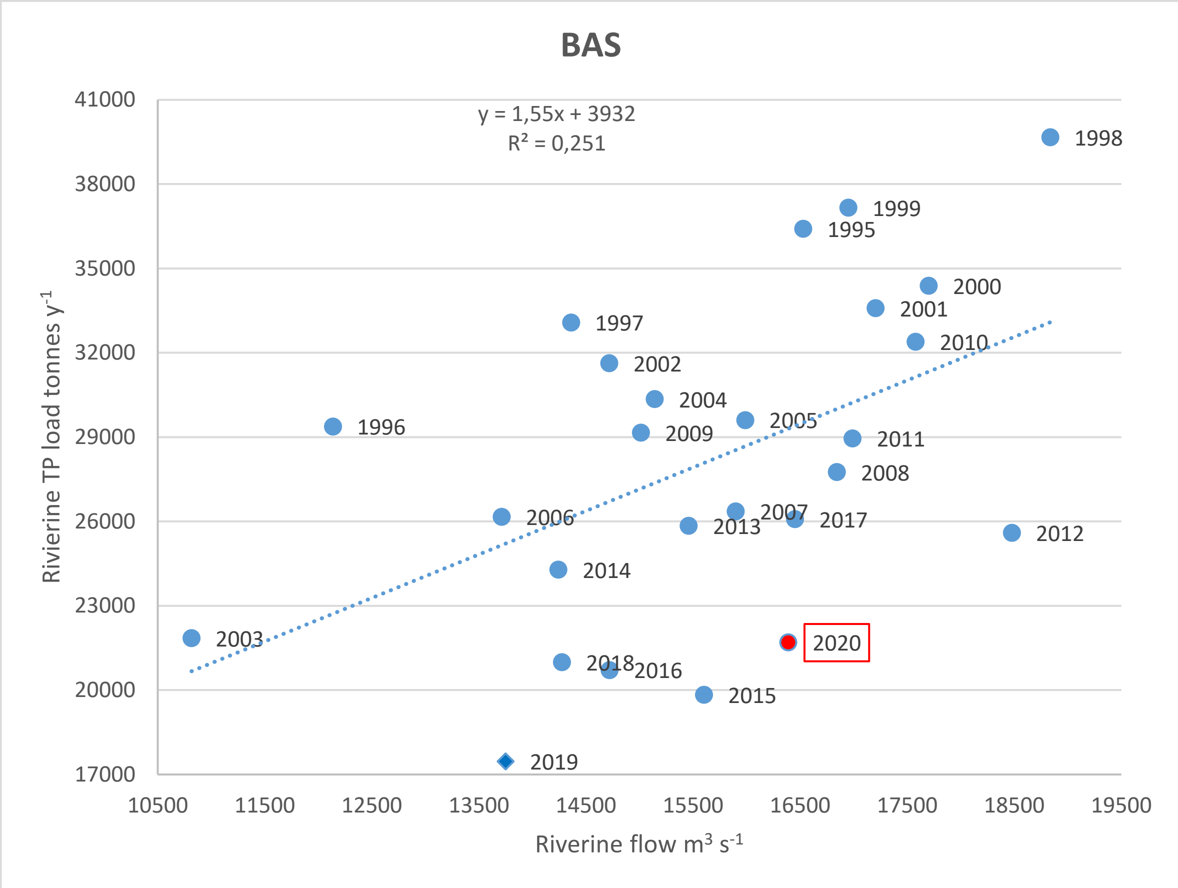


Figure 3A. Linear regression plots of annual riverine flows ($m^3\ s^{-1}$) against annual riverine total nitrogen inputs - TN to the seven Baltic Sea sub-basins and to the Baltic Sea during 1995-2020. Most recent year (2020) is marked with a dot "2020" surrounded by a red box. The linear regression is indicated as y = a·X + b, where 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 =0.867 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 to GUF are significant. For an explanation of abbreviations, see the caption to Figure 1.


BAS
y = 1,55x + 3932
R² = 0,251
Rivierine TP load tonnes y-1
Riverine flow m3 s-1
41000
38000
35000
32000
29000
26000
23000
20000
17000
10500
11500
12500
13500
14500
15500
16500
17500
18500
19500
1998
1999
1995
2000
2001
2010
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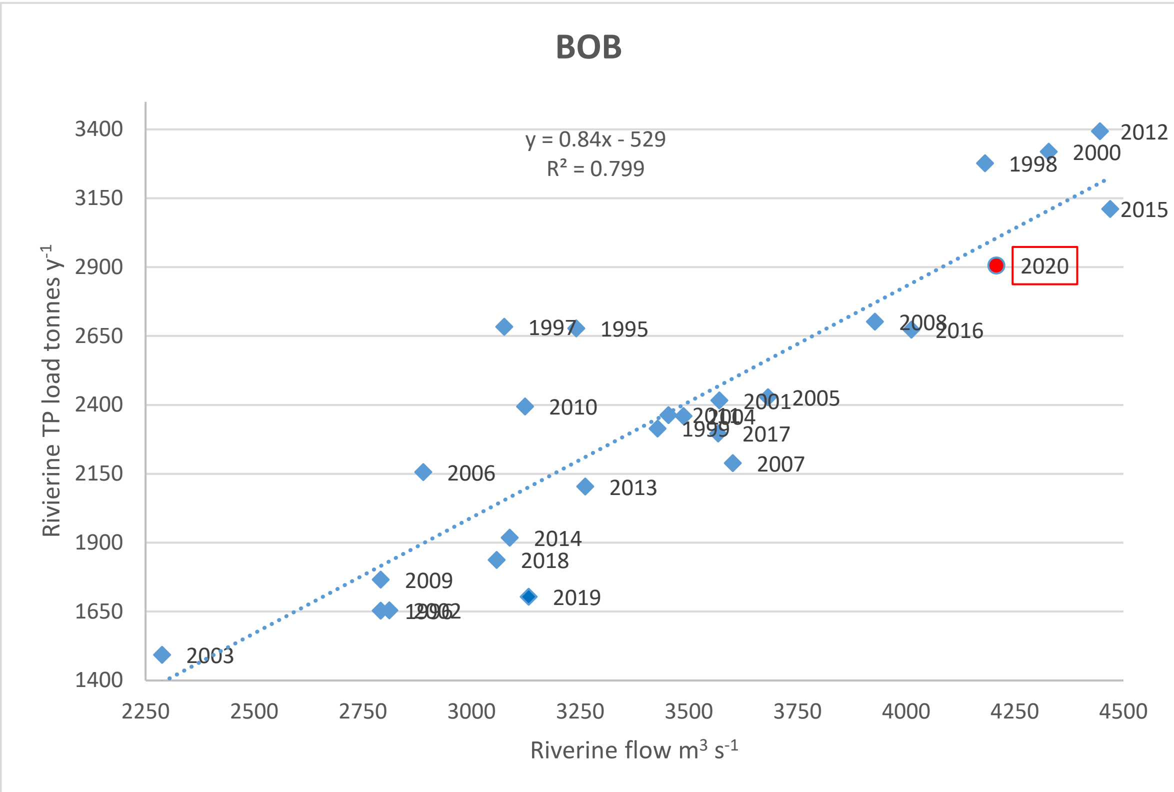
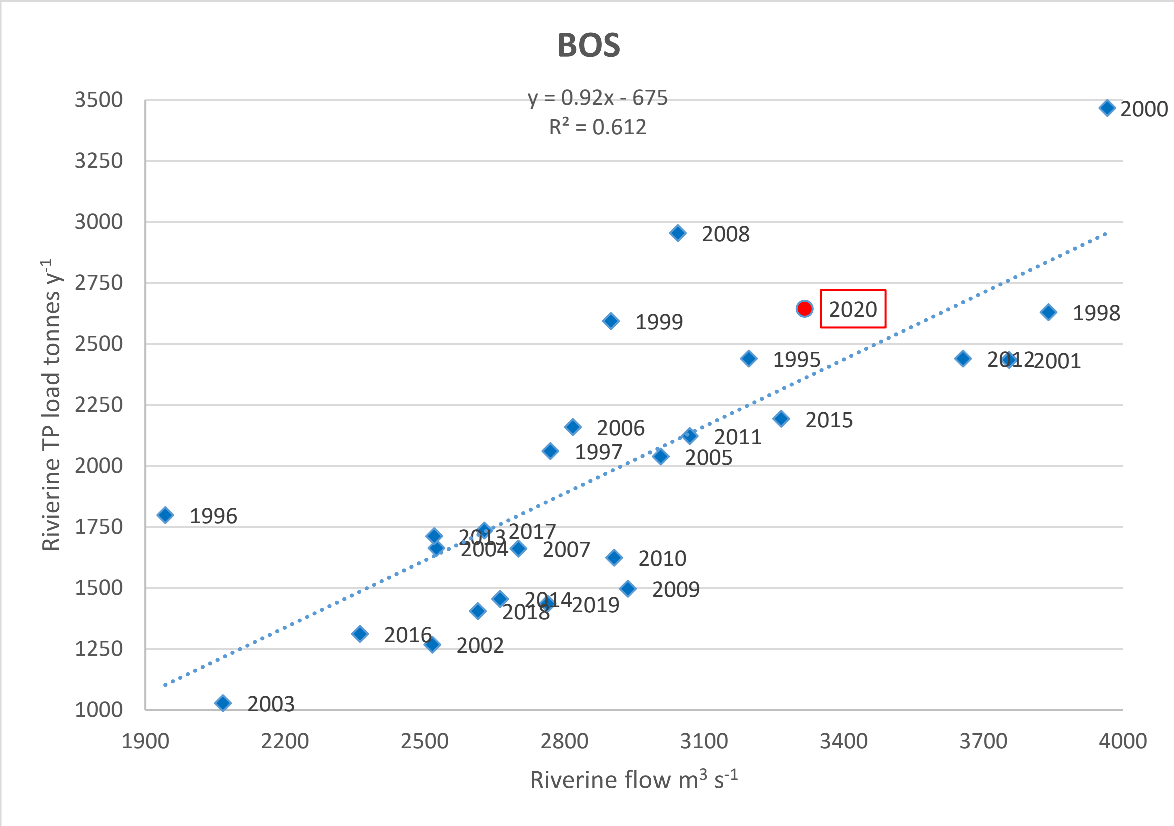
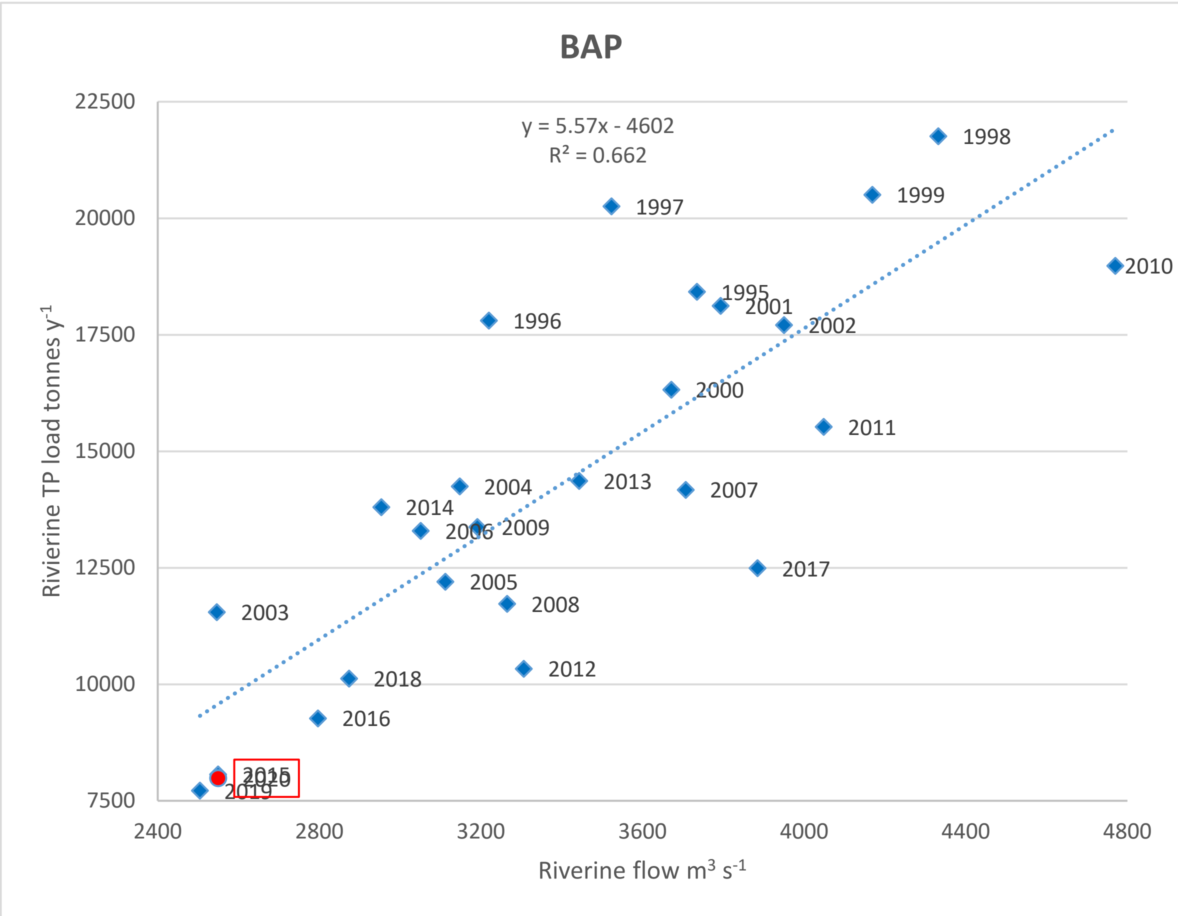
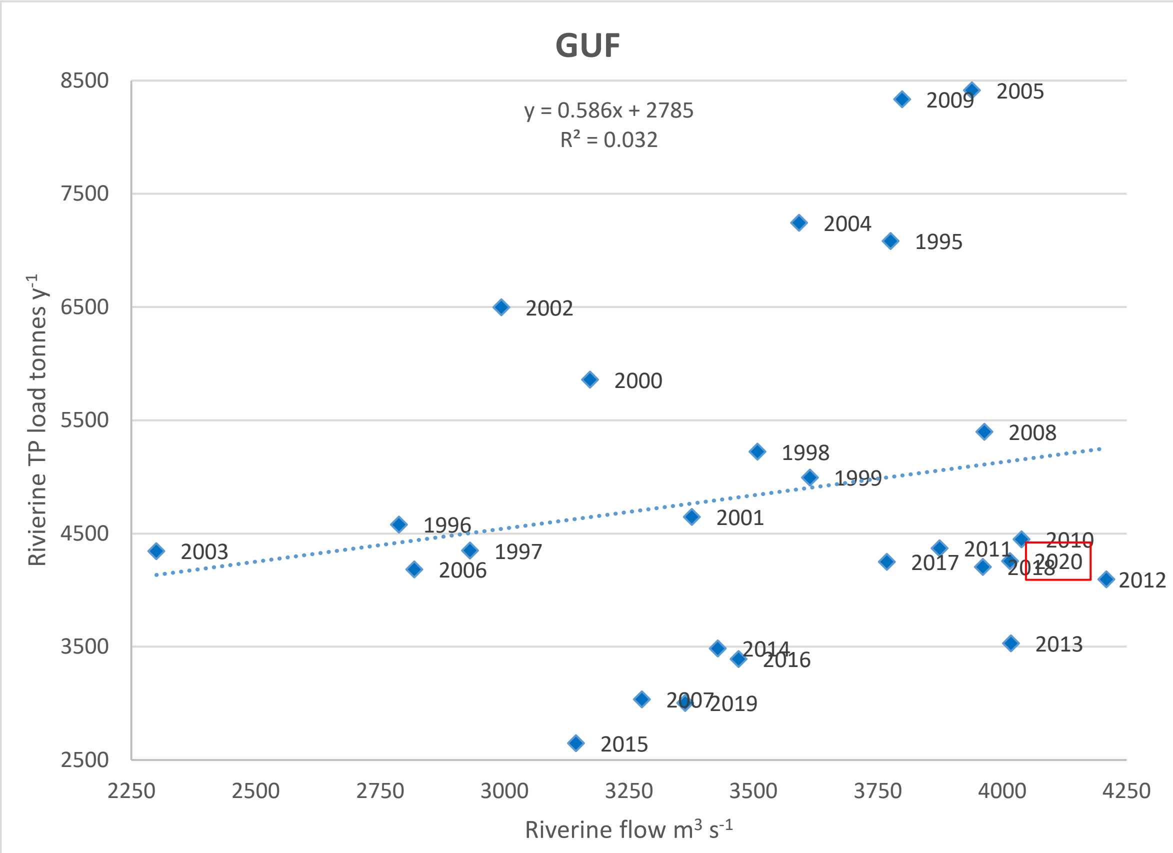
2014
2003
2020
2018
2016
2015
2019


BOB
y = 0.84x - 529
R² = 0.799
Rivierine TP load tonnes y-1
Riverine flow m3 s-1
3400
3150
2900
2650
2400
2150
1900
1650
1400
2250
2500
2750
3000
3250
3500
3750
4000
4250
4500
2012
2000
1998
2015
2020
1997
1995
2008
2016
2010
2001
2005
2004
1999
2017
2007
2006
2013
2014
2018
2009
2019
2003


BOS
y = 0.92x - 675
R² = 0.612
Rivierine TP load tonnes y⁻¹
Riverine flow m³ s⁻¹
3500
3250
3000
2750
2500
2250
2000
1750
1500
1250
1000
1900
2200
2500
2800
3100
3400
3700
4000
2000
2008
2020
1999
1998
1995
2012
2001
2006
2011
2015
1997
2005
1996
2013
2017
2004
2007
2010
2014
2019
2018
2009
2016
2002
2003


BAP
y = 5.57x - 4602
R² = 0.662
Rivierine TP load tonnes y⁻¹
Riverine flow m³ s⁻¹
22500
20000
17500
15000
12500
10000
7500
2400
2800
3200
3600
4000
4400
4800
1998
1999
1997
2010
1995
2001
1996
2002
2000
2011
2004
2013
2007
2014
2006
2009
2005
2017
2003
2008
2012
2018
2016
2015
2020
2019


GUF
y = 0.586x + 2785
R² = 0.032
Rivierine TP load tonnes y-1
Riverine flow m3 s-1
8500
7500
6500
5500
4500
3500
2500
2250
2500
2750
3000
3250
3500
3750
4000
4250
2009
2005
2004
1995
2002
2000
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1998
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2017
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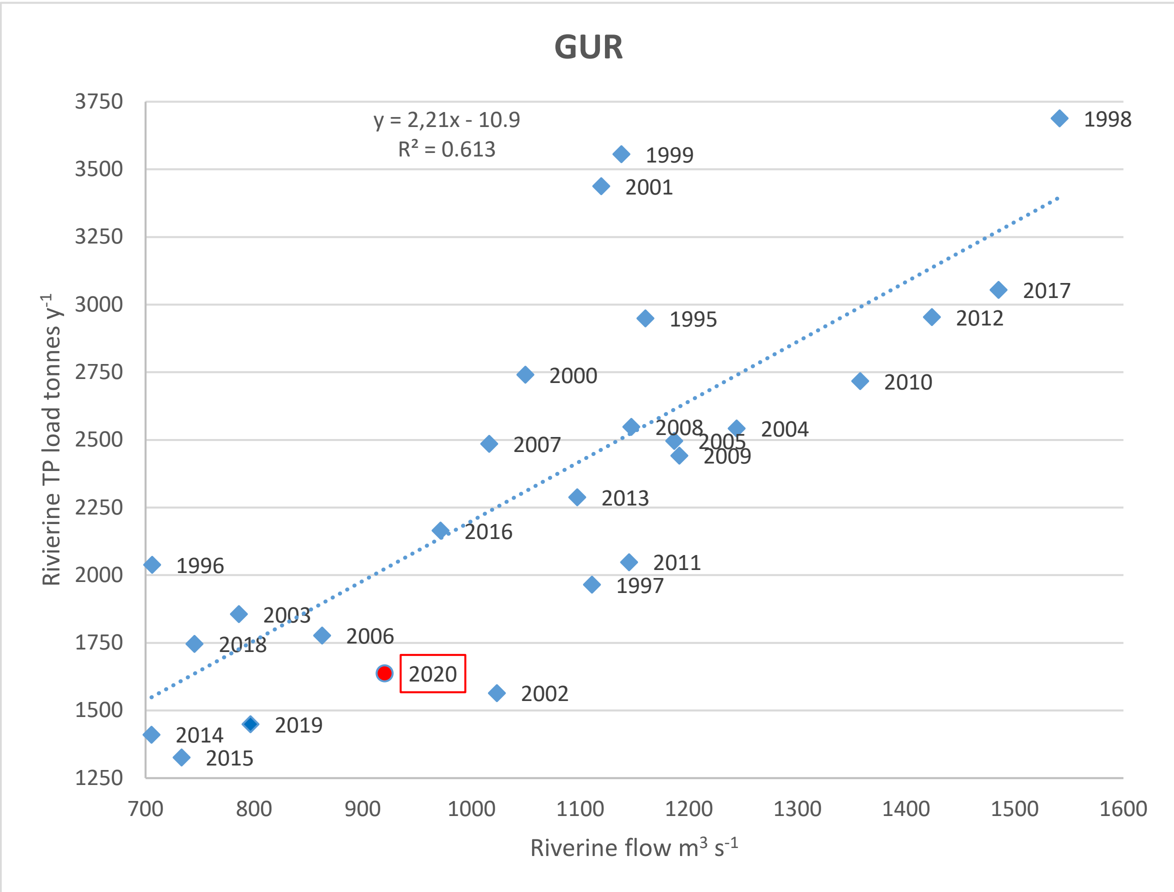
2020
2012
2014
2016
2013
2007
2019
2015


GUR
y = 2,21x - 10.9
R² = 0.613
Rivierine TP load tonnes y-1
Riverine flow m3 s-1
3750
3500
3250
3000
2750
2500
2250
2000
1750
1500
1250
700
800
900
1000
1100
1200
1300
1400
1500
1600
1998
1999
2001
2017
1995
2012
2000
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2003
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2006
2020
2002
2014
2019
2015

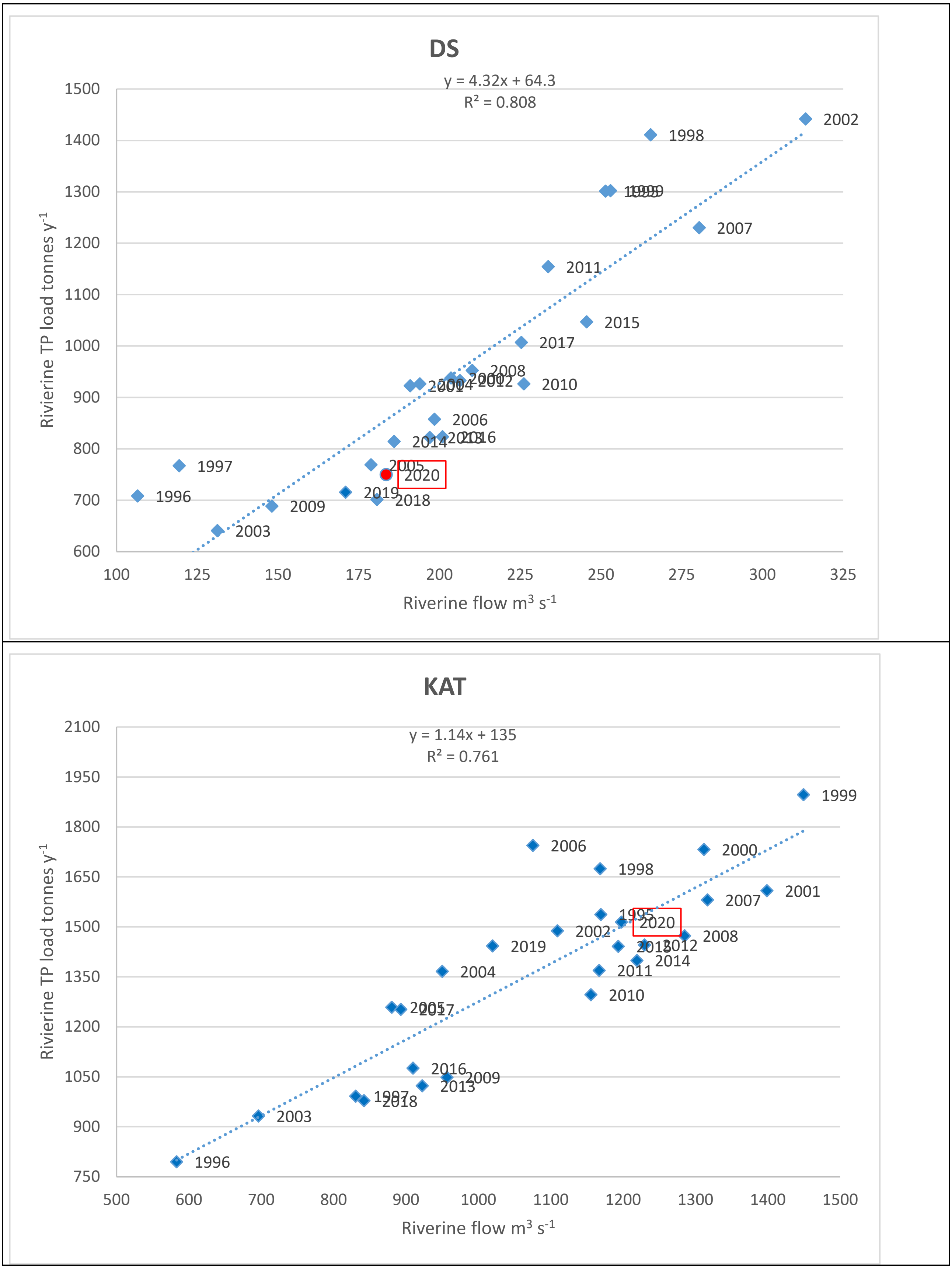
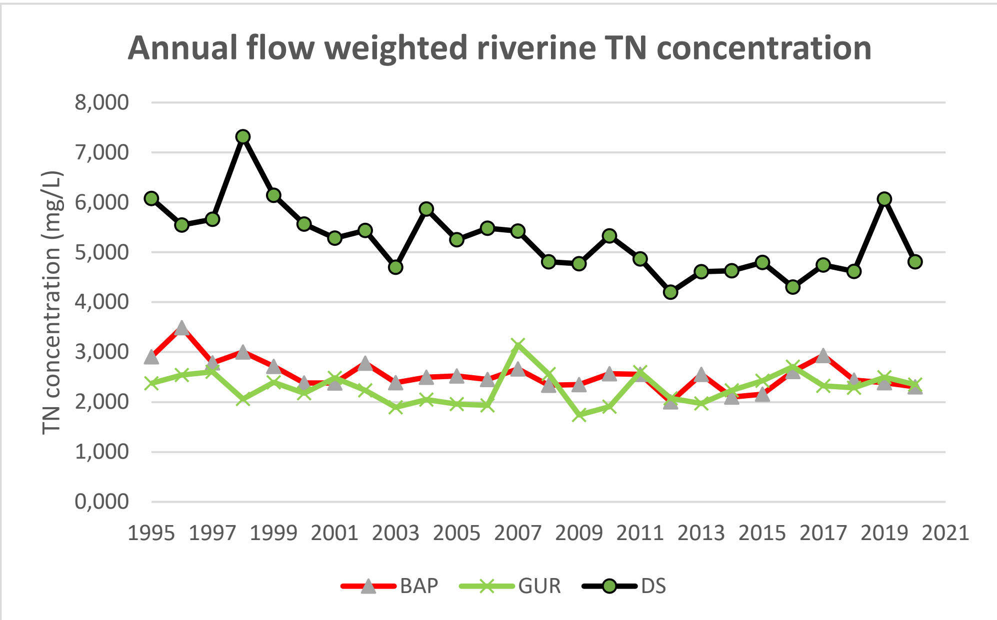
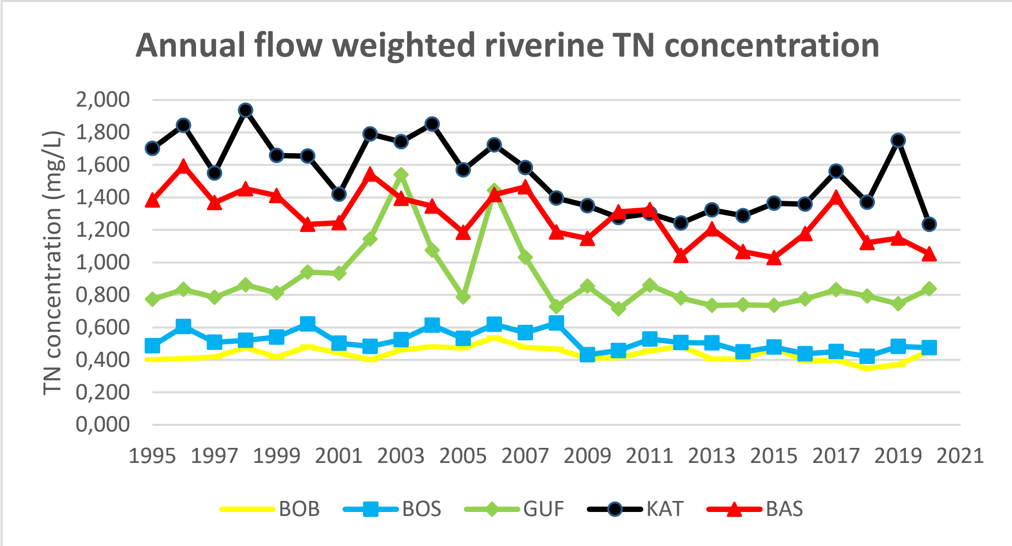


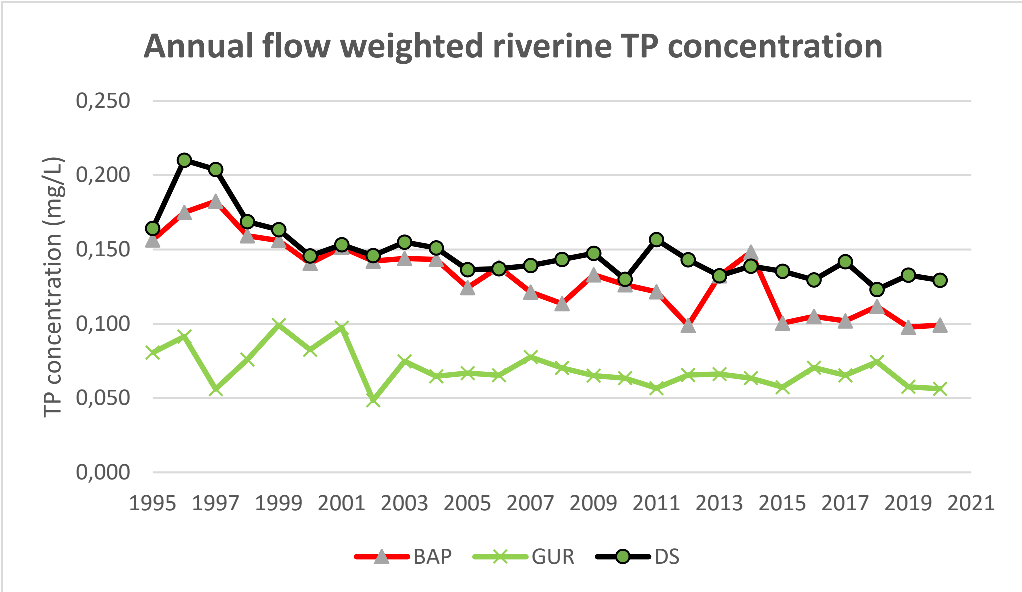
Figure 3B. As figure A but for total phosphorus. All relations besides TP to GUF are significant. For an explanation of abbreviations, see the caption to Figure 1.

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 flow weighted riverine TN and TP annual concentrations during 1995-2020 are shown for the Baltic Sea and its seven sub-basins. 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 all sub-basins and to the Baltic Sea besides to the Kattegat with a not significant decrease.

Figure 4 has been sub-divided as the 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 of an order of magnitude lower than for the inputs to 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 12-13 l s^{-1} km^{-2} on average for 1995-2019, 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, the Gulf of Riga and the Danish Straits during 1995-2019. There is a remarkable increase in the flow weighted TN concentration from 2018 to 2019 to the Danish Straits and the Kattegat. It is related to a rather severe drought in 2018, with poor harvest, accumulation of nitrogen in the soils with a subsequent leaching out of to the rivers during a wet late summer and autumn 2019, with rather high flow at least in the Danish catchments to the Danish Straits and Kattegat. A corresponding pattern was seen for Swedish catchment to Kattegat. The higher than average TP inputs and TP flow weighted concentration in 2020 (Table 1) to Bothnian Sea are also visible in figure 4.







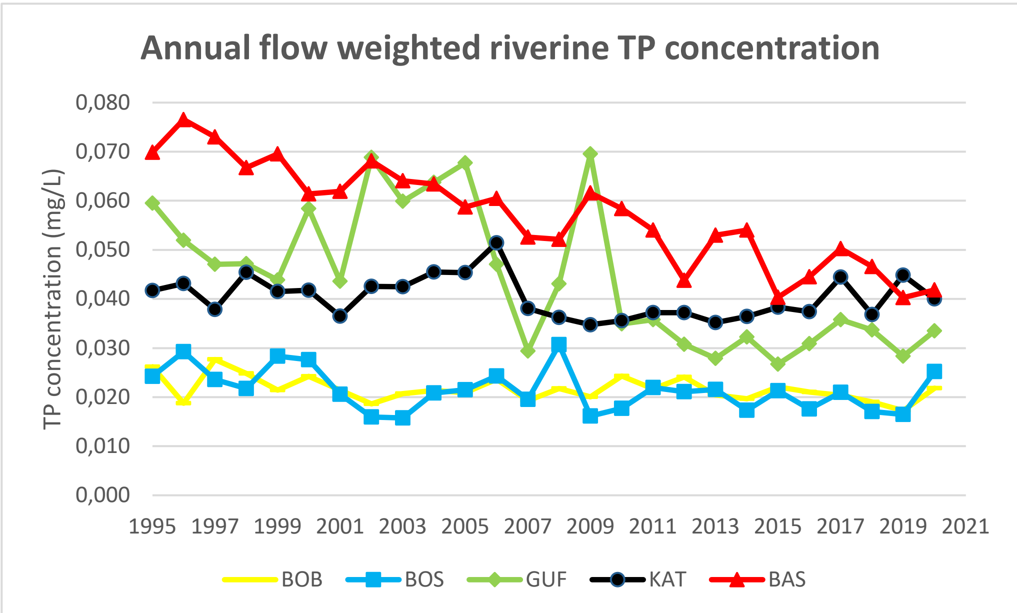


Figure 4. Annual average flow weighted riverine TN (the two uppermost figures) and TP (the two lowermost figures) concentrations for the seven Baltic Sea sub-basins and the Baltic Sea (calculated as total annual riverine inputs divided with the corresponding annual flow) during 1995-2020. Baltic Proper, Gulf of Riga and Danish Straits are in separate figures (1 and 3 from the top down) due to higher flow-weighted concentrations than to the

remaining sub-basins (2 and 4 from the top down). For an explanation of the basin abbreviations, see the caption to Figure 1. Remark: Concentration range between 0 and 8 mg/L for TN and 0-0,250 mg/L for TP.

Composition of the riverine nutrient inputs 2020

In addition to inputs of TN and TP, data is available on inputs of reduced inorganic nitrogen (ammonia, NH_4) and oxidized inorganic nitrogen (reported either as nitrite, NO_2, and nitrate, NO_3, or as the sum of these, NO_{23}), and inputs of phosphate (PO_4) for the rivers and unmonitored areas. The average share of the inorganic inputs for the sub-basins in 2020 is shown in Figure 5. The organic portion is calculated by difference between total and inorganic. Especially for nitrogen, the differences in catchment characteristics and land use are clearly reflected. For example, in the highly forested and mountainous Bothnian Bay catchment the share of inorganic nitrogen is about 30%, to be compared with close to 90% in Danish Straits with a very high percentage of agricultural land. For phosphorus, the differences are less extreme, however, it should be remembered that in absolute numbers, the concentration differences are very large as shown above.

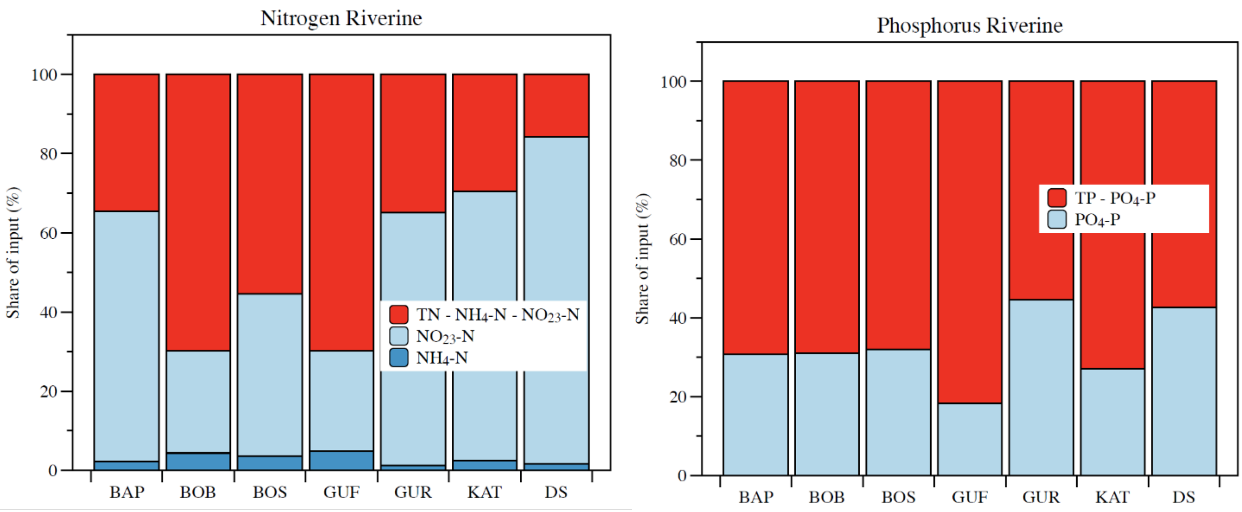


Figure 5. The share of inorganic riverine inputs to the sub-basins.

Policy relevance and policy references[5]

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,

[5] 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).

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.

The original HELCOM Baltic Sea Action Plan (BSAP) was adopted in 2007 by the Baltic Sea coastal countries and the European Union (HELCOM 2007), setting the overall objective of reaching good environmental status in the Baltic Sea by 2021 by addressing eutrophication, hazardous substances, biodiversity and maritime activities. 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 (NIC) for each country and Baltic Sea sub-basin.

The countries decided that the agreed provisional nutrient reduction targets will be revised using a harmonized approach and most updated data as well enhanced modelling. The revision process started in 2008 and was completed in 2013. The nutrient reduction scheme of the Baltic Sea Action Plan was revised in the 2013 HELCOM Ministerial Meeting, based on a new and more complete dataset as well as an improved modelling approach (HELCOM 2013a, 2013b and 2013c). 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 Contracting Parties to act further to achieve national reduction requirements based on Maximum Allowable Inputs of nutrients to the Baltic Sea sub-basins. The 2018 Declaration stated that in the update of the BSAP national commitments should be formulated in a way that ensures fulfillment of MAI.

The updated HELCOM Baltic Sea Action Plan was adopted at the 2021 HELCOM Lübeck Ministerial Meeting (HELCOM, 2021b). In the nutrient input reduction scheme included in the 2021 Baltic Sea Action Plan, the CART were replaced by Nutrient Input Ceilings (NIC) which define maximum inputs via water and air to achieve good status with respect to eutrophication for Baltic Sea sub-basins for each country.

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	m3/s	actual						
Sum	**BOB**	**BOS**	**BAP**	**GUF**	**GUR**	**DS**	**KAT**	**BAS**
1995	3263	3217	3754	3788	1164	267	1179	16630
1996	2805	1951	3222	2820	706	115	585	12205
1997	3092	2779	3525	2964	1111	129	833	14432
1998	4198	3846	4334	3542	1541	277	1171	18910
1999	3445	2907	4171	3647	1138	264	1453	17024
2000	4349	3981	3691	3217	1052	218	1321	17828
2001	3585	3762	3797	3413	1122	200	1402	17282
2002	2829	2524	3965	3029	1026	327	1118	14816
2003	2305	2075	2561	2336	788	142	704	10911
2004	3505	2531	3163	3631	1244	206	958	15238
2005	3701	3015	3130	3972	1187	191	889	16085
2006	2902	2826	3067	2852	864	211	1084	13807
2007	3613	2713	3714	3311	1018	293	1320	15983
2008	3941	3054	3282	3999	1149	223	1294	16942
2009	2802	2943	3207	3833	1193	160	964	15104
2010	3135	2914	4787	4071	1360	239	1163	17669
2011	3466	3077	4066	3908	1147	247	1176	17087
2012	4460	3661	3321	4243	1426	219	1238	18568
2013	3276	2526	3460	4050	1099	209	930	15550
2014	3101	2667	2971	3461	707	200	1228	14336
2015	4486	3277	2570	3176	735	260	1204	15708
2016	4023	2371	2816	3503	973	214	918	14818
2017	3584	2639	3907	3803	1487	239	903	16562
2018	3079	2633	2893	3994	747	193	851	14390
2019	3158	2928	2524	3403	799	184	1029	14024
2020	4237	3480	2569	4051	922	196	1207	16661

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	8850	13129	1400	7007	2447	41752
2001	3047	5392	6953	13285	1521	4168	2438	36804
2002	3047	5169	6830	13318	1430	3431	2506	35730
2003	3246	5199	6693	13258	1815	3037	2086	35333
2004	2911	5364	6555	12130	1442	3157	2280	33839
2005	3013	5336	6409	10229	1573	2959	2219	31738
2006	2729	5377	6899	9328	1768	3134	2475	31711
2007	2788	4916	7718	9750	2379	3357	2635	33543
2008	2900	4965	6911	9266	2460	3022	2700	32223
2009	2712	4659	6434	10164	1277	3272	2466	30984
2010	2823	4422	6919	9890	1121	2907	2233	30315
2011	2996	4348	6972	10242	1143	3244	2306	31251
2012	3311	4697	6627	9898	1107	3145	2198	30982
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	3035	1682	25284
2019	3013	4142	4686	10181	442	3387	2027	27876
2020	2779	3936	4719	9752	348	3114	1846	26494

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	342064	91913	86782	48217	62735	721764
1996	36029	37116	355660	73450	56695	18699	33998	611645
1997	40513	44464	309104	72569	91385	21327	40575	619936
1998	62564	63056	409894	95253	100132	61204	71308	863412
1999	45064	49395	356970	92635	85896	48986	75791	754736
2000	65728	77735	276837	94340	72176	35847	68593	691255
2001	49948	59393	284570	99232	87660	31832	62613	675250
2002	35367	38357	346119	107853	72212	53752	62657	716316
2003	33239	34196	191875	111697	46935	19462	38281	475684
2004	52949	48918	248584	122129	80593	35989	55645	644806
2005	55010	50530	247402	97663	73307	29619	43551	597081
2006	48822	54970	235813	128229	52558	34325	58459	613176
2007	54194	48310	311515	106440	100741	47946	65701	734847
2008	57971	60223	241272	91264	92898	31974	56720	632320
2009	36075	39981	236507	102231	65424	22288	40652	543159
2010	40719	41986	386591	90839	81637	38001	46463	726235
2011	49542	51197	326307	104920	93942	35858	47866	709633
2012	67999	58595	209626	103959	93332	27404	48279	609195
2013	41812	40073	277593	93048	68255	28662	38511	587954
2014	39284	37698	195735	79945	49743	27155	49514	479074
2015	66246	49209	173662	72973	56117	37161	51370	506738
2016	50058	32636	230880	85048	83156	27334	39065	548175
2017	44874	37468	359233	98850	108734	33748	43949	726857
2018	33469	34781	220929	98933	53782	26312	36386	504592
2019	36576	42078	188752	78999	62762	32721	56297	498185
2020	60434	49890	186041	106369	68277	27902	46774	545686

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	358735	109642	87946	61004	66980	784100
1996	39222	42823	367434	88500	57919	26148	37698	659743
1997	43783	50288	319419	85990	92635	27234	44102	663451
1998	66088	68621	419023	107851	101379	67420	74371	904754
1999	48461	54776	365136	105594	87146	54067	78564	793745
2000	69033	83348	285687	107469	73576	42854	71040	733007
2001	52995	64785	291524	112518	89182	36000	65051	712055
2002	38414	43526	352949	121171	73642	57183	65162	752047
2003	36484	39395	198567	124955	48749	22499	40367	511017
2004	55860	54282	255139	134258	82034	39147	57925	678646
2005	58022	55866	253811	107892	74880	32578	45770	628819
2006	51551	60347	242713	137558	54326	37459	60934	644887
2007	56982	53226	319233	116190	103120	51303	68336	768390
2008	60870	65188	248182	100531	95357	34995	59420	664544
2009	38787	44640	242942	112395	66701	25560	43118	574143
2010	43541	46409	393510	100729	82758	40909	48695	756551
2011	52539	55545	333279	115163	95085	39102	50171	740885
2012	71309	63292	216253	113857	94439	30549	50477	640177
2013	45488	44587	284066	102779	68951	31914	40519	618303
2014	43017	41970	201708	89351	50258	30314	51558	508177
2015	69698	53783	179933	81941	56660	40545	53534	536094
2016	53484	36890	236156	94326	83674	30504	41014	576048
2017	48465	41859	364738	108672	109166	37147	45867	755913
2018	36563	38892	225688	107134	54184	29347	38068	529876
2019	39588	46219	193437	89179	63205	36108	58324	526061
2020	63213	53826	190761	116120	68625	31016	48620	572181

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	4	7	2	8	1	10	4	5
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	529	2649	197	322	176	4337
2001	100	332	341	2656	230	281	153	4093
2002	100	296	387	2817	208	323	146	4278
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	498	2356	184	245	136	3849
2007	103	303	529	2181	179	292	137	3726
2008	100	293	472	1303	157	320	120	2763
2009	93	252	398	2811	59	404	97	4113
2010	87	254	416	1667	46	278	98	2845
2011	90	239	416	2370	38	312	116	3580
2012	116	250	418	371	76	369	88	1690
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	216	99	1030
2019	93	190	199	337	38	268	113	1237
2020	94	191	180	266	33	198	97	1060

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	tonnes							
River	**BOB**	**BOS**	**BAP**	**GUF**	**GUR**	**DS**	**KAT**	**BAS**
1995	2678	2440	18421	7084	2949	1301	1537	36410
1996	1653	1799	17807	4579	2038	708	795	29380
1997	2683	2061	20259	4349	1964	767	992	33075
1998	3277	2630	21761	5223	3689	1411	1674	39665
1999	2314	2593	20507	4994	3556	1302	1897	37163
2000	3318	3467	16325	5858	2741	938	1733	34380
2001	2415	2435	18119	4645	3437	923	1609	33583
2002	1654	1268	17712	6498	1564	1442	1488	31627
2003	1493	1027	11550	4345	1856	641	932	21845
2004	2359	1664	14249	7244	2542	926	1366	30351
2005	2428	2039	12201	8414	2496	769	1259	29606
2006	2155	2160	13292	4183	1777	857	1744	26170
2007	2188	1662	14176	3035	2486	1230	1581	26358
2008	2702	2954	11725	5399	2548	953	1473	27755
2009	1766	1498	13380	8334	2442	689	1049	29156
2010	2394	1625	18982	4448	2717	926	1296	32387
2011	2363	2122	15523	4368	2048	1154	1370	28949
2012	3392	2440	10335	4095	2953	933	1446	25594
2013	2103	1712	14367	3529	2288	822	1023	25843
2014	1918	1455	13801	3484	1411	814	1399	24282
2015	3111	2193	8065	2648	1326	1047	1442	19832
2016	2672	1312	9273	3391	2164	823	1076	20712
2017	2296	1736	12485	4250	3054	1007	1252	26079
2018	1837	1405	10120	4204	1745	701	978	20990
2019	1704	1435	7716	3004	1448	715	1443	17464
2020	2906	2644	7983	4256	1636	750	1514	21690

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							
Sum	**BOB**	**BOS**	**BAP**	**GUF**	**GUR**	**DS**	**KAT**	**BAS**
1995	2848	2925	19884	9821	3263	2204	1804	42750
1996	1779	2197	18562	7339	2291	1314	987	34470
1997	2807	2461	20950	6901	2219	1219	1183	37741
1998	3401	2972	22496	7784	3942	1774	1878	44247
1999	2429	2931	21104	7719	3810	1643	2077	41712
2000	3426	3823	16854	8507	2938	1260	1908	38717
2001	2516	2767	18460	7302	3667	1203	1761	37676
2002	1754	1564	18100	9315	1773	1765	1634	35904
2003	1583	1337	11967	7286	2018	889	1050	26129
2004	2444	2000	15210	10385	2718	1184	1489	35430
2005	2525	2368	12614	11312	2699	1014	1381	33914
2006	2255	2490	13791	6539	1962	1102	1880	30018
2007	2291	1965	14706	5216	2665	1522	1718	30083
2008	2802	3247	12197	6702	2704	1272	1593	30518
2009	1858	1749	13778	11145	2501	1092	1145	33269
2010	2481	1879	19398	6114	2763	1204	1394	35232
2011	2452	2361	15939	6738	2086	1466	1486	32528
2012	3509	2690	10754	4466	3029	1302	1534	27284
2013	2233	1957	14770	3896	2343	1161	1114	27472
2014	2024	1688	14209	3855	1471	1112	1493	25852
2015	3209	2427	8464	3110	1390	1339	1546	21485
2016	2766	1515	9659	3835	2211	1070	1176	22231
2017	2385	1943	12682	4727	3096	1251	1351	27435
2018	1930	1592	10298	4425	1781	917	1077	22019
2019	1796	1624	7916	3341	1486	984	1555	18702
2020	2999	2835	8164	4523	1669	948	1612	22749

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, 2021a and 2021b).

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, 2022a) 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., 2020).

Link to available reported annual water flow, inputs of total nitrogen and total phosphorus from rivers and annual inputs from direct point sources: http://nest.su.se/helcom_plc/.

2. Description of data:

Annual water flow together with load of nitrogen and phosphorus are reported from about 315 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 nearly 500 municipal waste water treatment plants, approx. 200 industries[6] and at least 150 marine fish farms. Further the nine HELCOM Contracting Parties 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 million km^2) are covered by monitoring (monitored part of the catchment which constitutes nearly 90% of the catchment area) or modelling/estimates (unmonitored part of the catchment constituting 10% of the catchment area). It includes catchments in the nine HELCOM Contracting Parties 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 – 2020.

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[6] Some countries report one or more at the point sources aggregated (e.g. municipal wastewater treatment plants, industry and/or the marine fish farms. The number given are average of the past reported years.

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, 2022b).

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, 2022b). 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, 2022b). For some rivers monthly average concentration are multiplied with the corresponding flow.

Unmonitored parts of the catchment

The nine HELCOM Contracting Parties 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, 2022b and HELCOM, 2021a). In average 10% of the catchment is unmonitored, ranging from 4% unmonitored catchment (Gulf of Finland) to 48% (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, 2022b) 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 1995-2020 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 in 2021 has re-reported all flow and input data (monitored, unmonitored and direct) for 1995-2019.

Weakness: Data from some parts of the Baltic Sea catchment and some of the direct inputs in the beginning of the time series (1995-2020) 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 implementation 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. Regular laboratory intercalibration are performed and results reported (Lassen & Larsen, 2021). Changing laboratory it is important with a sufficient period with concurrent analysis of samples to allow for evaluation of and correction for systematic bias between laboratories.