Waterborne nitrogen and phosphorus inputs and water flow to the Baltic Sea 1995-2021

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Key Message

Annual water flow in 2021 to the Baltic Sea was approximately 15,700 $m^3 s^{-1}$ which is only 0.8% higher than the average of 1995-2020, but this covers markedly lower flow than average to three basins, higher than average flows to two basins, and average flow for two basins. Annual waterborne input (inputs via rivers and direct point sources discharging directly into the sea) of total nitrogen (TN) was approximately 599,000 tonnes in 2021 or about 3% lower than the average of 2011-2020. Compared with 2020 when flow was 16,400 $m^3 s^{-1}$ the waterborne TN inputs n 2021 was 26,000 tonnes (or 5%) higher than average. The annual waterborne total phosphorus inputs (TP) amounted to approximately 21,900 tonnes, which is about 16% lower than the average of 2011-2020, and about 400 tonnes (2%) lower than in 2020.

Inputs of nitrogen and phosphorus from direct point sources have decreased with approximately 56% and 81% since 1995, respectively. In 2021, inputs from direct point sources constituted 4.5% TN and 5.4% TP of the corresponding total waterborne input to the Baltic Sea. In 1995, the proportions of the direct inputs were 7.7% 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 basins since 1995. Both TN and TP concentrations decreased significantly for the total riverine inputs to the Baltic Sea since 1995, 17% and 41% respectively.

Finland re-reported all waterborne TN and TP input data for 1995-2020 with rather big annual changes in annual data but on the average of 1995-2020 the inputs remain close to former reported values.

[1] The authors want to thank colleagues contributing to data reporting, quality assuring and data management related to this BSEFS:
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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 1995-2021. 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 2022a and b).

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 1995-2020) (HELCOM. 2023), 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 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 or by 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) (Svendsen & Tornbjerg, 2022)[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 about 92% of TP inputs in 2019 (HELCOM 2023).

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 1995-2021 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.

In connection with reporting 2021 data Finland have re-reported 1995-2020 data. The annual waterborne TN inputs to Archipelago (a part of Bothnian Sea) has been changes with in average 4.3% (between -12 and +36%), and TP in average with -6.4% (between -27% and 35%). The corresponding numbers for Bothnian Bay are TN -1.3% (between -5% and +2%) and TP +0.9% (between -7% to +7%). For Bothnian Sea excluding Archipelago the numbers are for TN -5.1% (between -18% and +5%) and for TP -2.3% (between -21% og +30%). For Gulf of Finland the annual changes are in average for TN - 4.1% (between -12% til +8%) and for TP 4.5% (between -8% and +18%). The changes are particularly high on the direct inputs (points sources).

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 about 95% of both TN and TP waterborne inputs to the Baltic Sea in 2021. In the evaluation of progress towards MAI/ NIC as published in HELCOM (2023), Svendsen et al. (2022 and 2023), 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 2021. Flows are compared with the long-term average (1995-2020), but as there have been marked reductions in TN and TP input in the early part of the timeseries, TN and TP inputs in 2021 are compared with the corresponding latest ten years average (2011-20). Table 1 also includes the catchment and sea surface areas of the sub-basins allowing for calculation of area specific flow (in l s^{-1} km^{-2}), and for TN and TP inputs per catchment area and per sea area (in kg km^{-2}). Flow to the Baltic Sea in 2021 was about 15,700 m^3 s^{-1} or only 0.8% higher than the 1995-2020 average. The flow was higher to Bothnian Bay (13%), Bothnian Sea (10%), but lower to Baltic Proper (11%), Gulf of Riga (20%), and to the Danish Straits (15%) as compared with the average, while flow to Gulf of Finland and Kattegat were as the 1995-2020 average.

Waterborne TN inputs in 2021 were 599,000 tons or 3.2% lower than average of TN inputs during 2011-20. The corresponding TP inputs were 21,890 tons or 16% lower than average of 2011-2020. Compared with 2020 the flow in 2021 was 700 m^3 s^{-1} lower (4.3%), while TN waterborne inputs was 26,000 tonnes higher (4.5%), and TP waterborne inputs was 430 tonnes lower (1.9%). Flow close to long term average should imply waterborne inputs close to average if there is no trend in inputs and if weather conditions during the year and in the former year have not been extreme. But the average flow conditions are an average for Baltic Sea, covering rather high flow to Bothnian Bay and Bothnian Sea, but lower than average flow to Baltic Proper, Danish Straits and particularly to Gulf of Riga. The latter three basins constitute nearly 59% of TN and 54% of TP inputs to the Baltic Sea in 2021. While waterborne phosphorus inputs have been overall decreasing to all basins since 1995, there have been assessed significant increases in waterborne nitrogen inputs to some basins (e.g. to Baltic Proper and from some countries to Gulf of Riga and to Kattegat (Svendsen et al, in prep)). The pattern is however complex since both interannual flow variations and long-term trends in nutrient inputs varies across sub-basins. TN inputs in 2021 were 8.8% (Bothnian Sea), 4.2% (Bothnian Bay), and 0.9% (Gulf of Riga), respectively, higher than average (2011-2020). The remaining four basin had waterborne inputs lower than average in 2021: Danish Straits (17%), Kattegat (7.0%), Baltic Proper (5.8%) and Gulf of Finland (2.1%). Waterborne TP inputs in 2021 were lower than average (2011-2020) for six basins: Gulf of Riga (33%), Baltic Proper (24%), Danish Straits (23%), Kattegat (14%) Bothnian Bay (4.5%) and Bothnian Sea (3.9%). Only for Gulf of Finland it was higher than average (4.5%). In 2021 the north and north-eastern part of the Baltic Sea catchment had high precipitation while the southern part of the catchment had rather dry conditions, and close to average in the western part of the catchment area, which was close to the situation in 2020.

Annual flow-weighted riverine concentration (calculated by dividing annual riverine nutrient input with the corresponding water flow[3]) in 2021 to the Baltic Sea was 1.16 mg N l^{-1} or equal with the average TN concentration during 2011-20. For TP it was 0.041 mg P l^{-1} or 12% lower than average (2011-20). Flow-weighted TN concentrations were lower than average for four basins, Kattegat (8.9%), Bothnian Bay (4.0%), Bothnian Sea (1.4%) and Danish Straits (1.3%), and higher to two basins: Gulf of Riga (20%), and Baltic Proper (6.2%). For Gulf of Finland the concentrations in 2021 was nearly as the average of the former 10 years average. It seems like the significant increase in waterborne TN in recent years to some basins is affecting the discharge weighted concentrations even though it should be taken into account that flow was lower than average to Baltic Proper and Gulf of Riga. The 20% higher flow-weighted riverine concentration than average to Gulf of Riga in 2021 might be the result that 2019 and 2020 was very dry years, resulting in a building up nitrogen surplus in the soils. Flow-weighted TP was lower than average for 6 basins: Kattegat (19%), Gulf of Riga (18%), Bothnian Sea (18%), Baltic Proper (13%), Bothnian Bay (10%), and Danish Straits (4.7%). TP flow weighted riverine concentrations was much higher to Gulf of Finland (21%) than the average, and there is not provided any obvious explanation of why. The Footnote 4 provides some explanation on events in 2021 that can explain some of the patterns seen in 2021[4].

Area specific waterborne catchment inputs in 2021 were highest to the Danish Straits (1,063 kg N km^{-2}, 34 kg P km^{-2}), reflecting high population density and high agricultural land-use. The lowest area specific inputs are for the Bothnian Bay and the Bothnian Sea (approximately 210 kg N km^{-2} and 8.6 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. 340 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 Riga (4,000 kg N km^{-2}) and Gulf of Finland (155 kg P km^{-2}) but lowest to the Bothnian Sea (653 kg N km^{-2}, 24 kg P km^{-2}). Average for the Baltic Sea is approx. 1,430 kg N km^{-2} and 52 kg P km^{-2}).

[3] In accordance with the HELCOM PLC-water (HELCOM, 2022b), 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.

[4] Catchment to Bothnian Bay and Bothnian Sea received a lot more precipitation than normal in 2021. Flow from Finnish side was 22% higher than average to Bothnian Bay leading also to higher than average to high inputs of nitrogen and organic carbon.

Estonia estimated inputs from Narva River based on measurements from only up to the middle course of the river.

In Latvian catchment draining to Gulf of Riga there was heavy rain in May leading to higher than average leaching of nitrogen from intense cultivate areas (e.g. catchments of Lielupe, Barta and Venta Rivers) particularly because very dry conditions in 2019 and 2020 have built up a surplus of nitrogen in cultivated soils.

Denmark have developed a new model modelling diffuse phosphorus concentration used for estimating diffuse inputs in unmonitored areas and use for the time series 1995 and onward. For the main basins diffuse inputs to the sea for the entire period is changed with -1%, but higher for some years, and for some minor catchments.

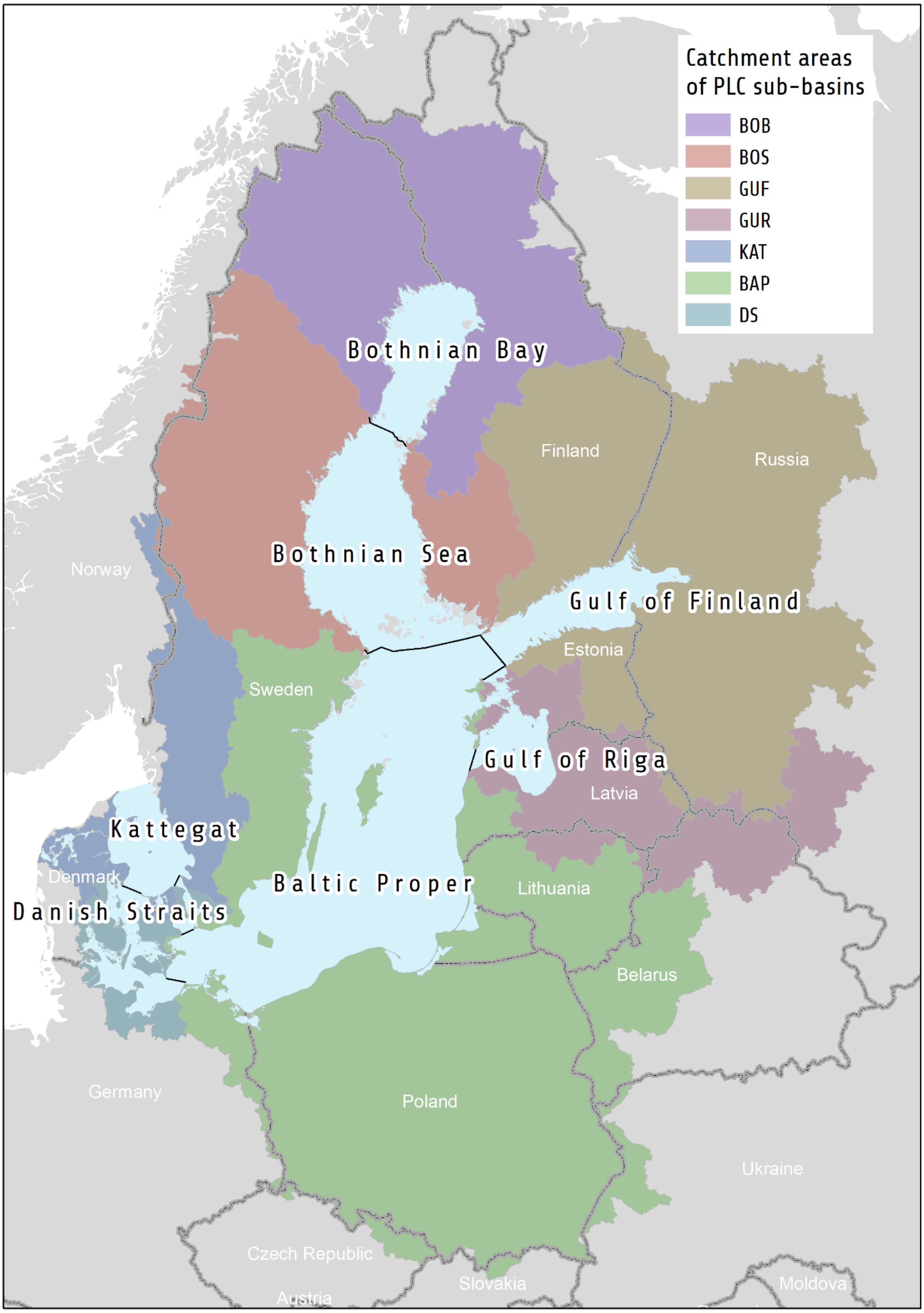
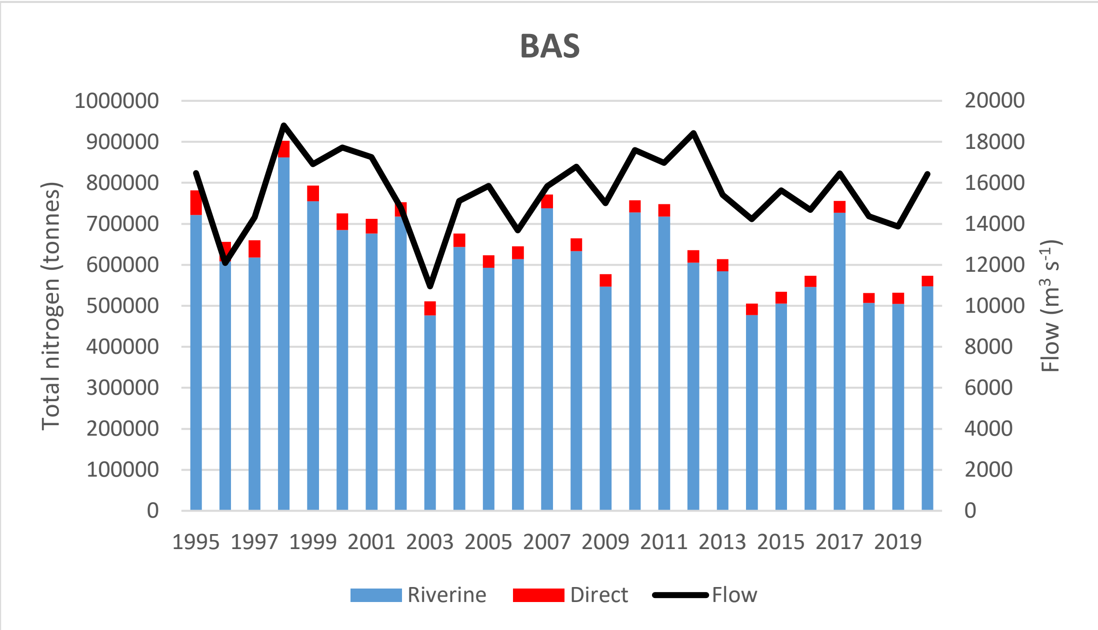


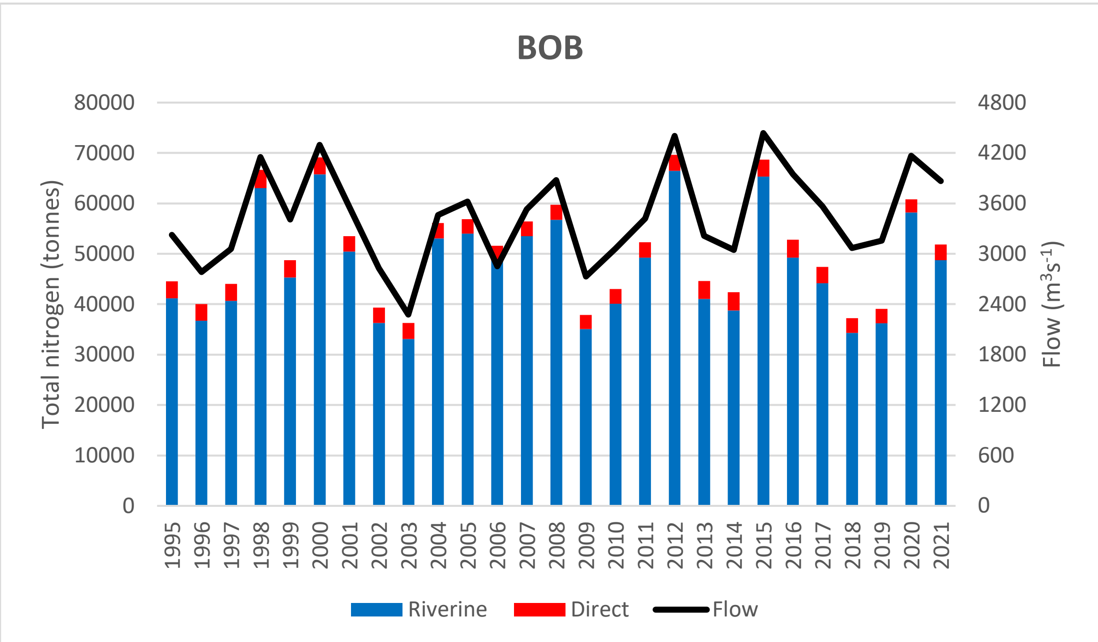
Figure 1. The catchment of the Baltic Sea is shared by nine HELCOM Contracting Parties - Denmark (DK), Estonia (EE), Finland (FI), Germany (DE), Latvia (LV), Lithuania (LT), Poland (PL), Russia (RU) and Sweden (SE) and 5 transboundary countries (Belarus, Czech Republic, Slovakia, Norway and Ukraine). For the purposes of assessment of nutrient load, the Baltic Sea (BAS) is divided into 7 main basins: Bothnian Bay (BOB); Bothnian Sea (BOS) including 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).

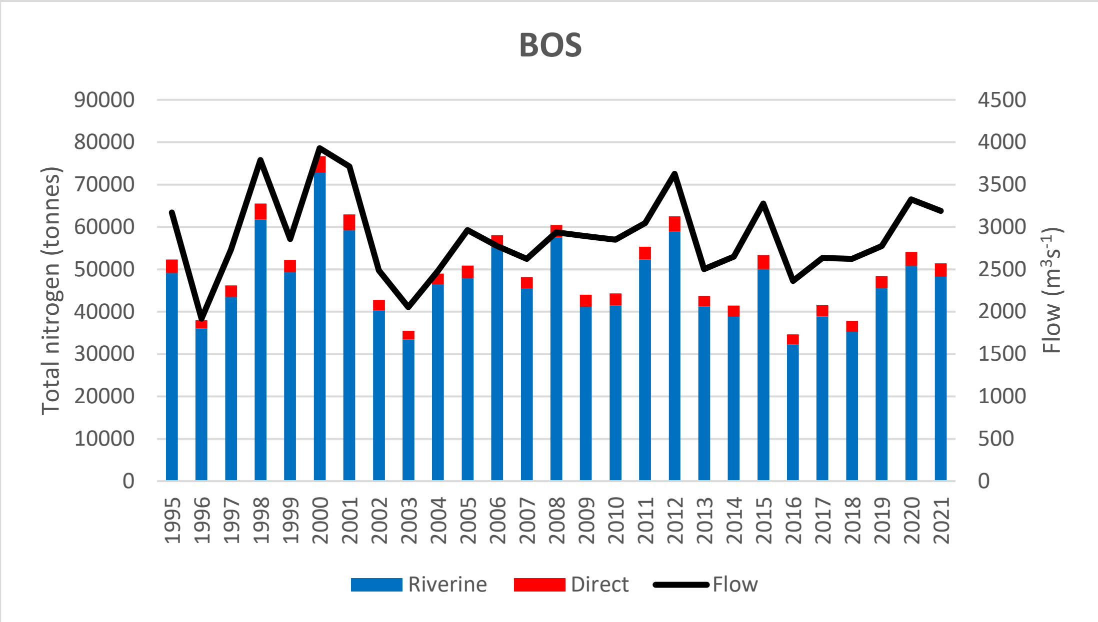
Table 1. Catchment area to and sea area of the seven sub-basins of the Baltic Sea (km^2). Annual waterborne flow ($m^3\ s^{-1}$), area specific flow ($l\ s^{-1}\ km^{-2}$), waterborne total nitrogen (TN) and phosphorus inputs TP (tonnes) in 2021 and on average of 1995-2020 for flow and 2011-2020 for TN and TP. Flow weighted TN and TP concentrations ($mg\ l^{-1}$) of annual riverine inputs in 2021 and on average of 2011-2020. 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.

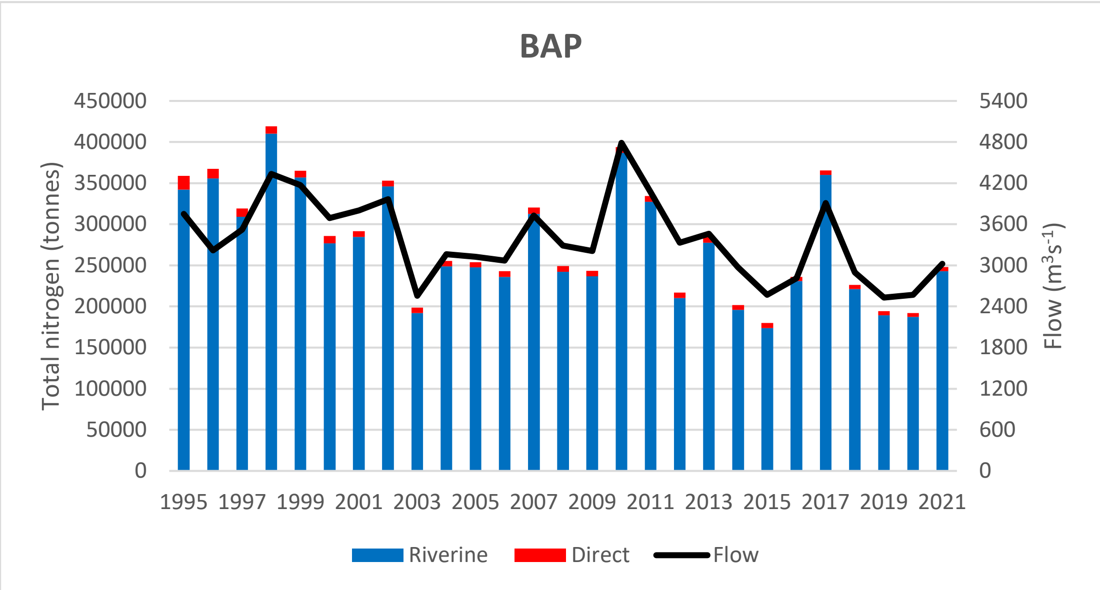
	Catchm. area	**Sub-basin sea area**	**Flow 2021**	**Flow 1995-2020**	**Flow 2021**	**Flow 1995-2020**	**TN water-borne 2021**	**TN water-borne 2011-2020**	**TN flow-weight. river conc. 2021**	**TN flow-weight. River conc. 2011-2020**	**TN water-borne /catch. area 2021**	**TN water-borne /sea area 2021**	**TP water-borne 2021**	**TP water-borne 2011-2020**	**TP flow-weight. river conc. 2021**	**TP flow-weight. River conc. 2011-2020**	**TP water-borne /catch. area 2021**	**TP water-borne /sea area 2021**
	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	3,864	3,429	14.7	13.0	51,834	49,723	0.40	0.42	197	1,440	2,394	2,508	0.019	0.021	9.1	66
BOS	228,000	79,000	3,189	2,884	14.0	12.7	51,625	47,464	0.48	0.49	226	653	1,873	1,949	0.017	0.020	8.2	24
BAP	576,000	209,000	3,024	3,404	5.3	5.9	247,947	263,277	2.56	2.41	430	1,186	9,433	12,415	0.097	0.112	16	45
GUF	423,000	30,000	3,538	3,536	8.4	8.4	98,230	100,365	0.80	0.79	232	3,274	4,663	4,462	0.039	0.032	11	155
GUR	138,000	19,000	847	1,057	6.1	7.7	76,210	75,561	2.84	2.36	552	4,011	1,442	2,163	0.053	0.064	10	76
DS	27,000	21,000	184	216	6.8	8.0	28,691	34,644	4.70	4.77	1,063	1,366	911	1,180	0.130	0.136	34	43
KAT	87,000	24,000	1,080	1,075	12.4	12.4	44,492	47,823	1.26	1.38	511	1,854	1,176	1,372	0.032	0.039	14	49
BAS	**1,742,000**	**418,000**	**15,726**	**15,602**	**9.0**	**9.0**	**599,029**	**618,857**	**1.16**	**1.16**	**344**	**1,433**	**21,892**	**26,049**	**0.041**	**0.047**	**13**	**52**

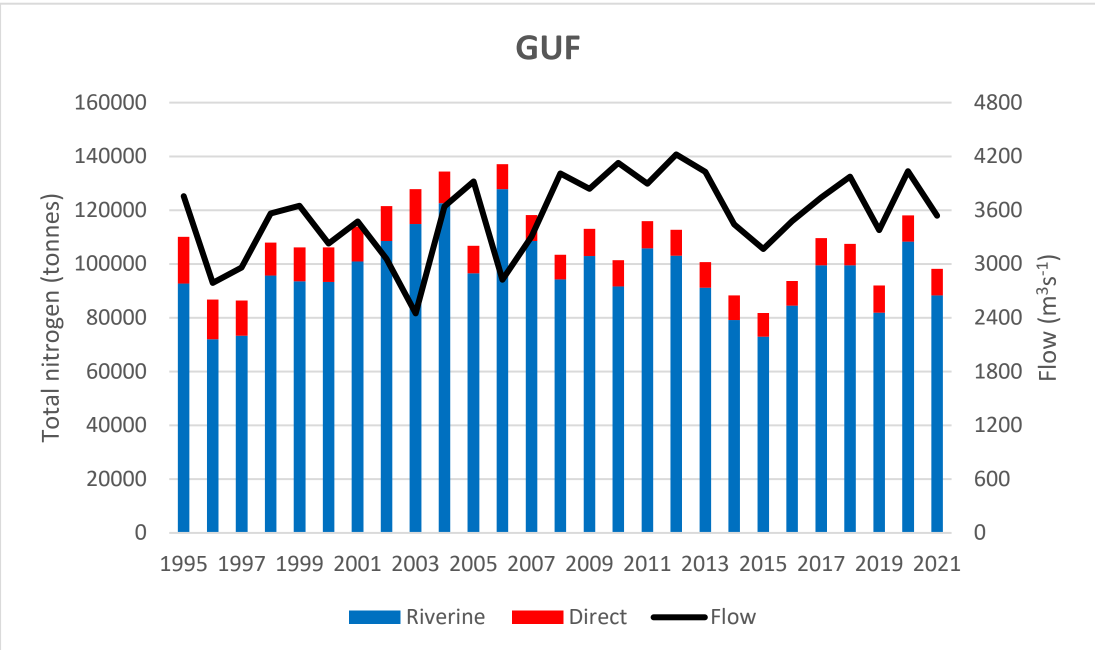
The annual water flow, direct inputs of TN and TP and riverine TN and TP inputs during 1995-2021 to the Baltic Sea basins and to the Baltic Sea are shown in Figure 2a and b as well as in Tables 2-8 in the "Data" section. There are significant reductions in total direct nitrogen inputs from 1995 to 2021 to the Baltic Sea (56%). Significant reduction of direct TN inputs is seen to all basins except to Bothnian Bay. The highest reduction in direct TN inputs is seen to Danish Straits (74%), Baltic Proper (70%) and to Gulf of Riga (66%). There are significant reductions of direct TP inputs to all basins, the highest Gulf of Riga (90%), Baltic proper (87%), and Gulf of Finland (86%) resulting in a total reduction of 81% to the Baltic Sea from these sources, although data on direct inputs are more uncertain in the beginning of the time series. The reduction by 2021 in TN and TP from direct point sources since 1995 was some few percentages lower for most basins compared with status by 2020. Direct inputs to the Baltic Sea in 2021 constitute only a minor share of the waterborne TN and TP waterborne inputs (4.5 and 5.4%, respectively), but they provide large proportions of the nutrient inputs to some sub-basins e.g., the Danish Straits (12%) and Gulf of Finland (10%) for TN, and the Danish Straits (23%) and Bothnian Sea (8.6%) for TP.

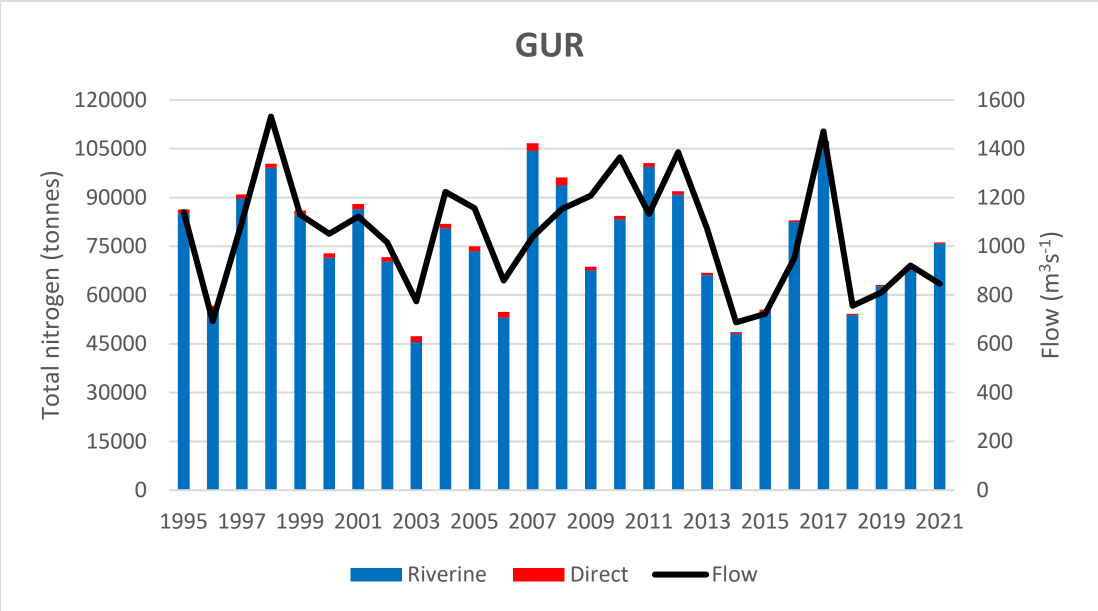


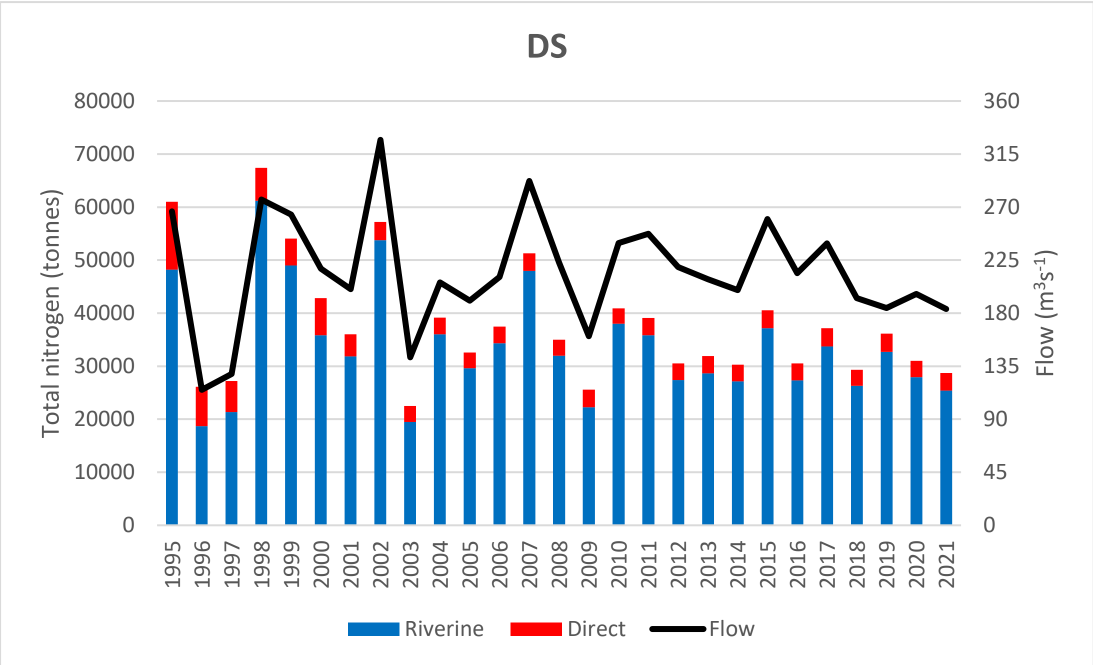



BOS
Total nitrogen (tonnes)
Flow (m3s-1)
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021
Riverine
Direct
Flow


BAP
Total nitrogen (tonnes)
Flow (m3s-1)
450000
400000
350000
300000
250000
200000
150000
100000
50000
0
5400
4800
4200
3600
3000
2400
1800
1200
600
0
1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017 2019 2021
Riverine
Direct
Flow


GUF
Total nitrogen (tonnes)
Flow (m3s-1)
160000
140000
120000
100000
80000
60000
40000
20000
0
4800
4200
3600
3000
2400
1800
1200
600
0
1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017 2019 2021
Riverine
Direct
Flow


GUR
Total nitrogen (tonnes)
Flow (m3s-1)
Riverine
Direct
Flow


DS
Total nitrogen (tonnes)
Flow (m3s-1)
Riverine
Direct
Flow

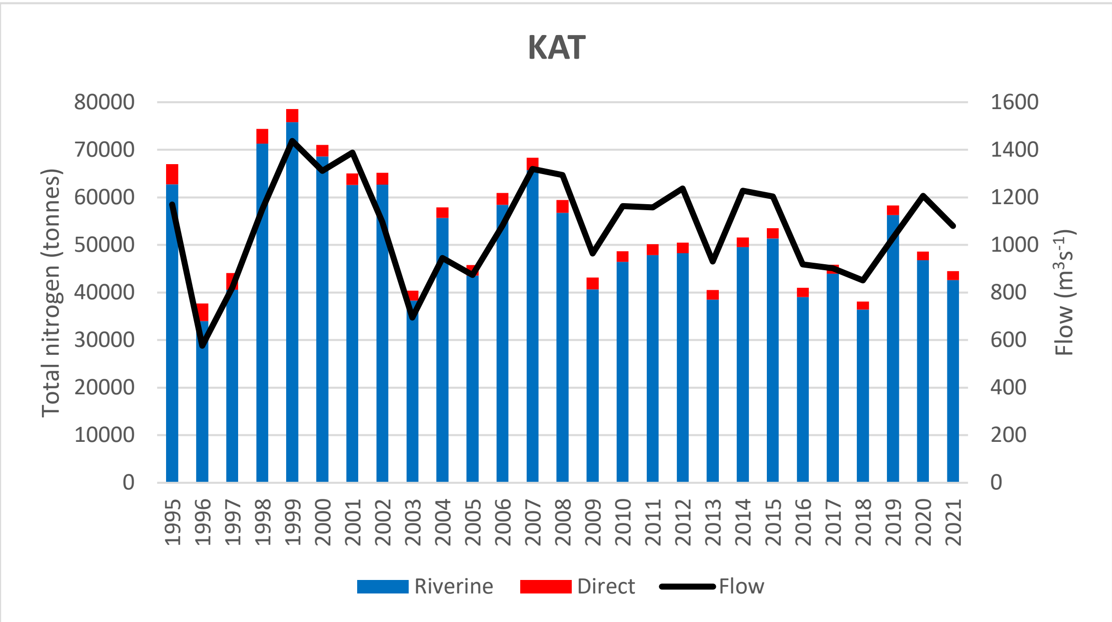
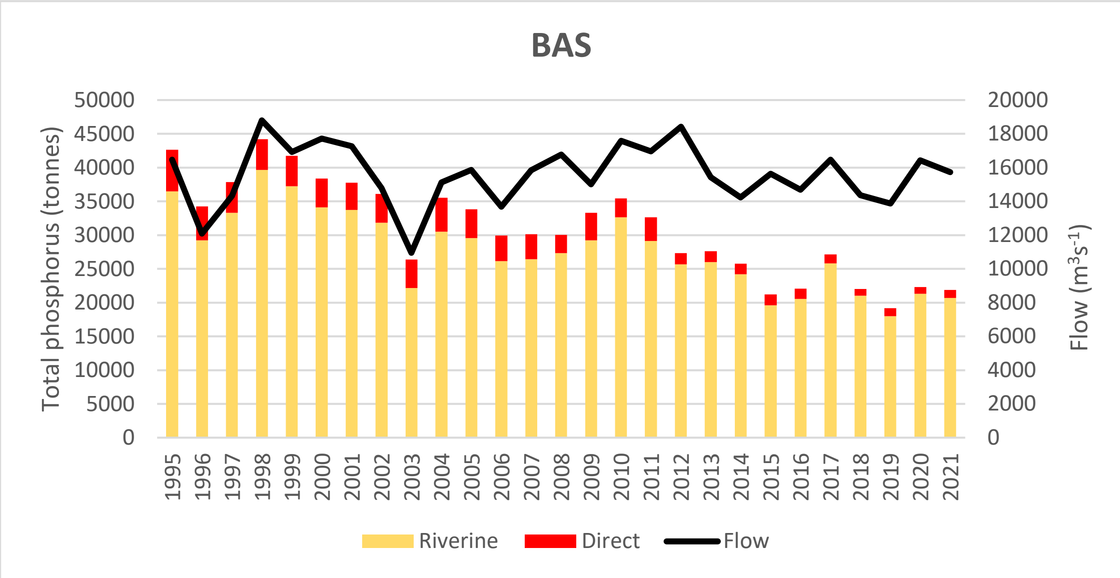
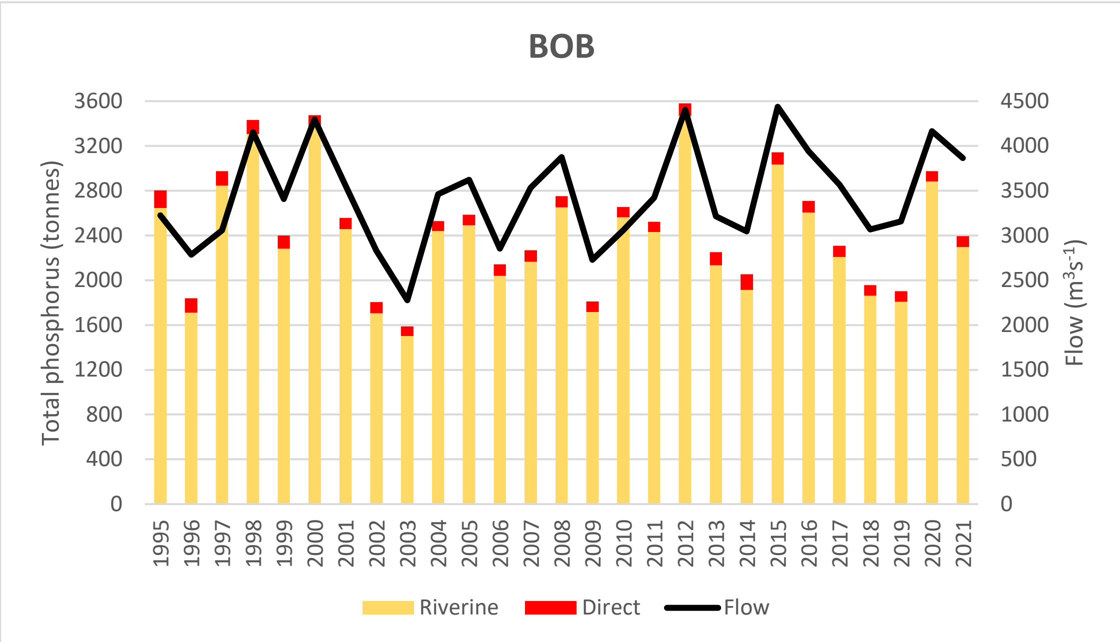
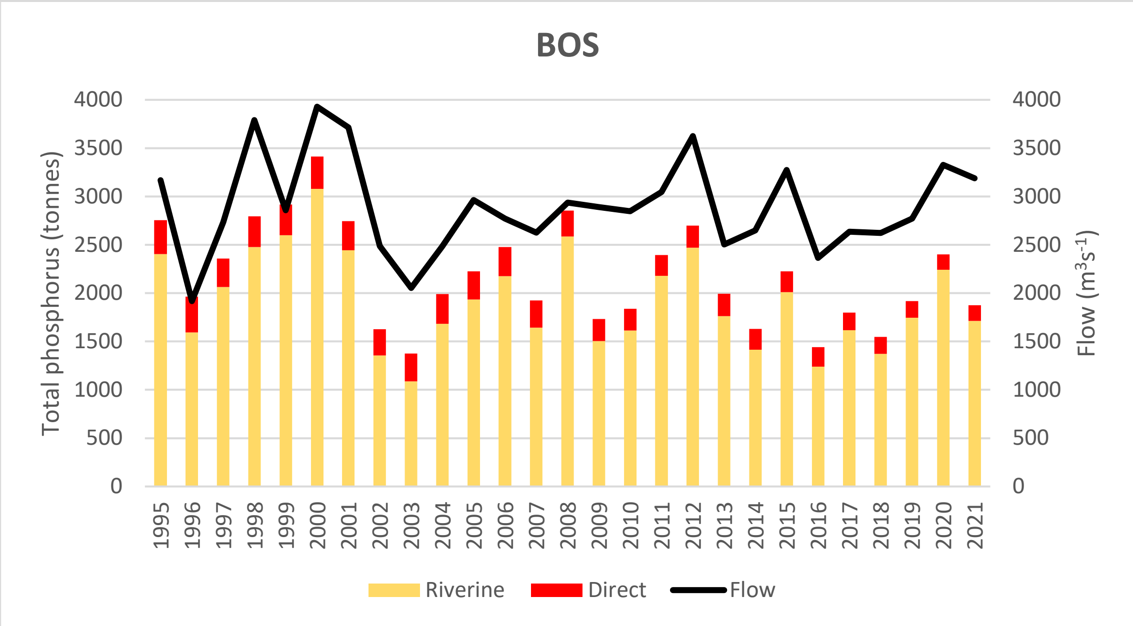
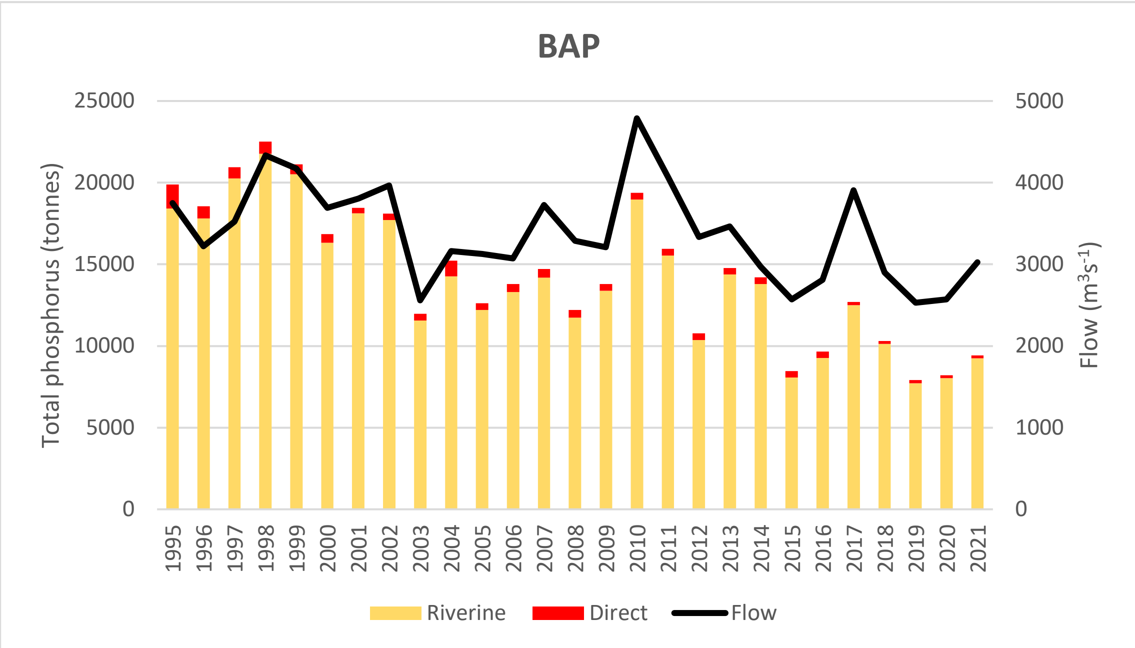

KAT
Total nitrogen (tonnes)
Flow (m3s-1)
Riverine
Direct
Flow

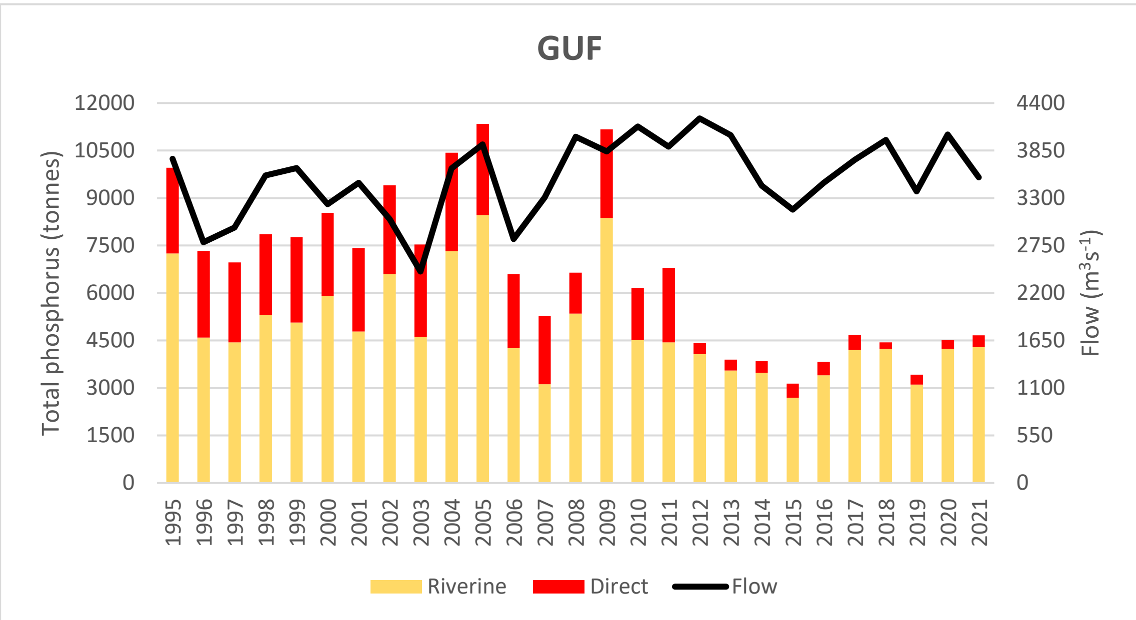
Figure 2A: Annual riverine and direct inputs of total nitrogen in tonnes and annual waterborne flow (m-3 s-1) to the seven Baltic Sea sub-basin and to the Baltic Sea in 1995-2021. Data behind the figures are shown in Tables 2-5. For an explanation of the basin abbreviations, see the caption to Figure 1.

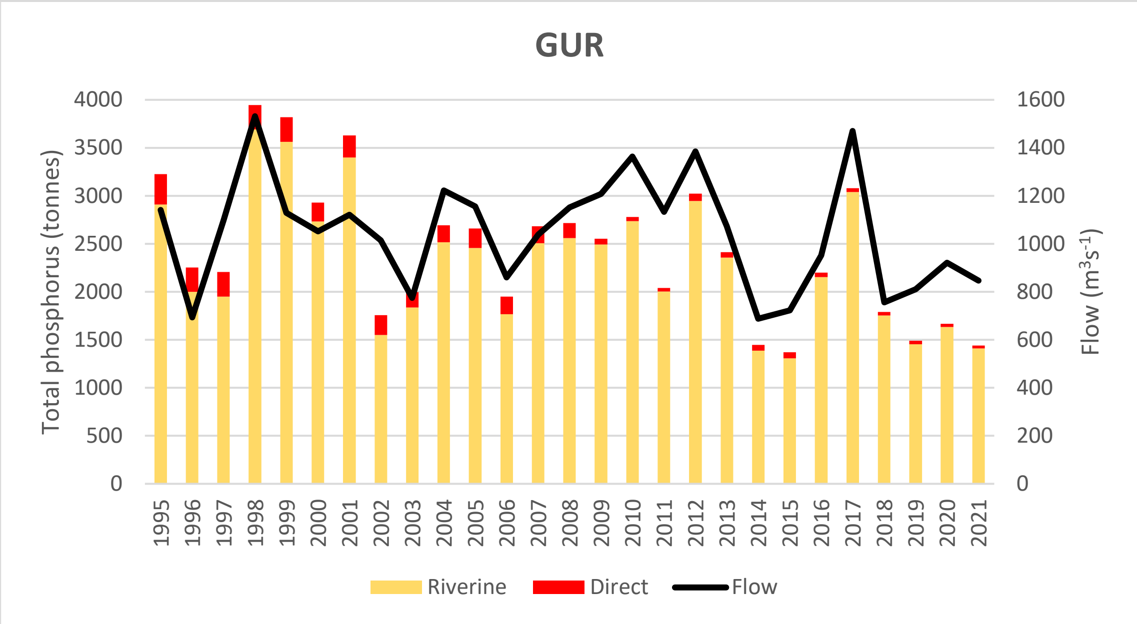





BOS
Total phosphorus (tonnes)
Flow (m3s-1)
Riverine
Direct
Flow


BAP
Total phosphorus (tonnes)
Flow (m3s-1)
Riverine
Direct
Flow


GUF
Total phosphorus (tonnes)
Flow (m3s-1)
Riverine
Direct
Flow


GUR
Total phosphorus (tonnes)
Flow (m3s-1)
0
500
1000
1500
2000
2500
3000
3500
4000
0
200
400
600
800
1000
1200
1400
1600
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
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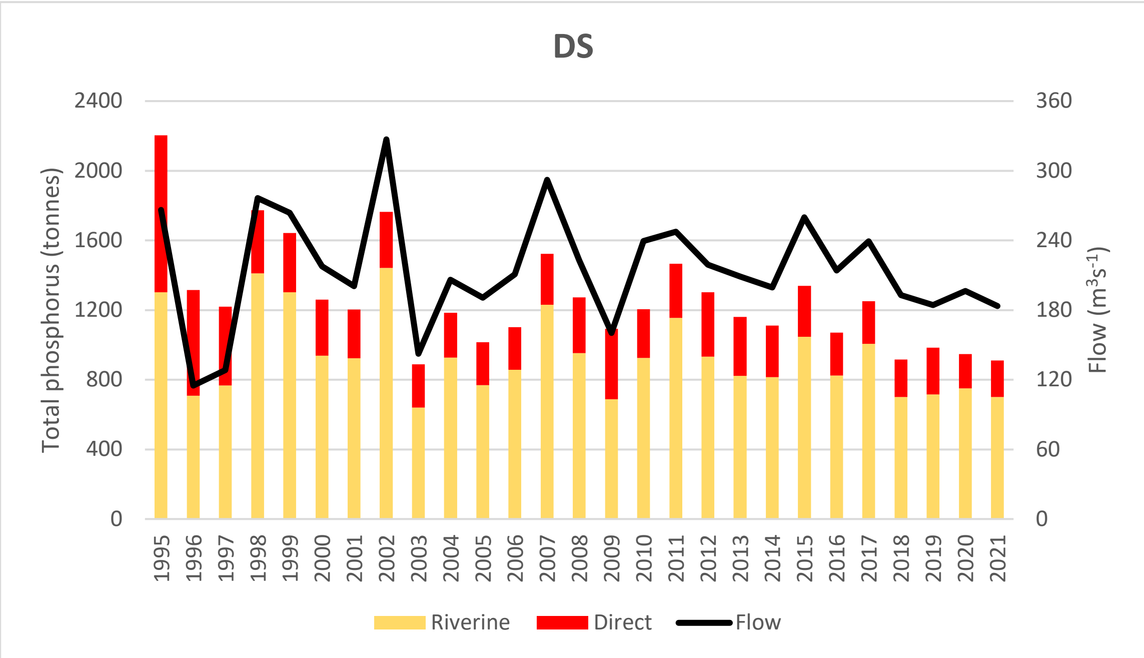
2017
2018
2019
2020
2021
Riverine
Direct
Flow


DS
Total phosphorus (tonnes)
Flow (m3s-1)
0
400
800
1200
1600
2000
2400
0
60
120
180
240
300
360
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
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2011
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2013
2014
2015
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2017
2018
2019
2020
2021
Riverine
Direct
Flow

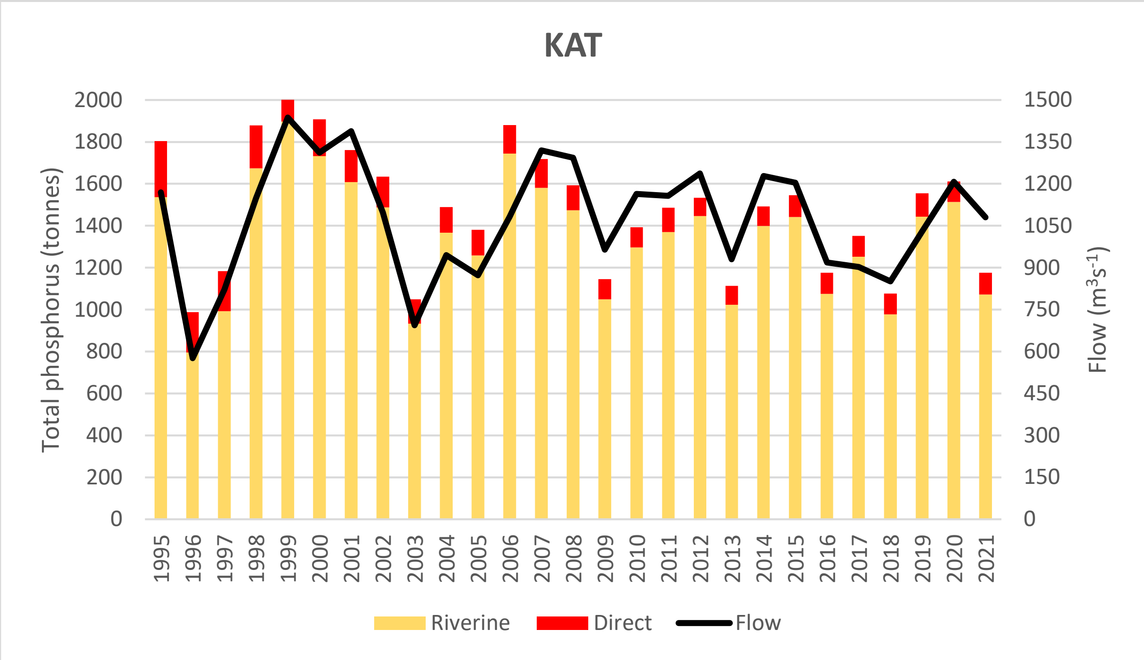
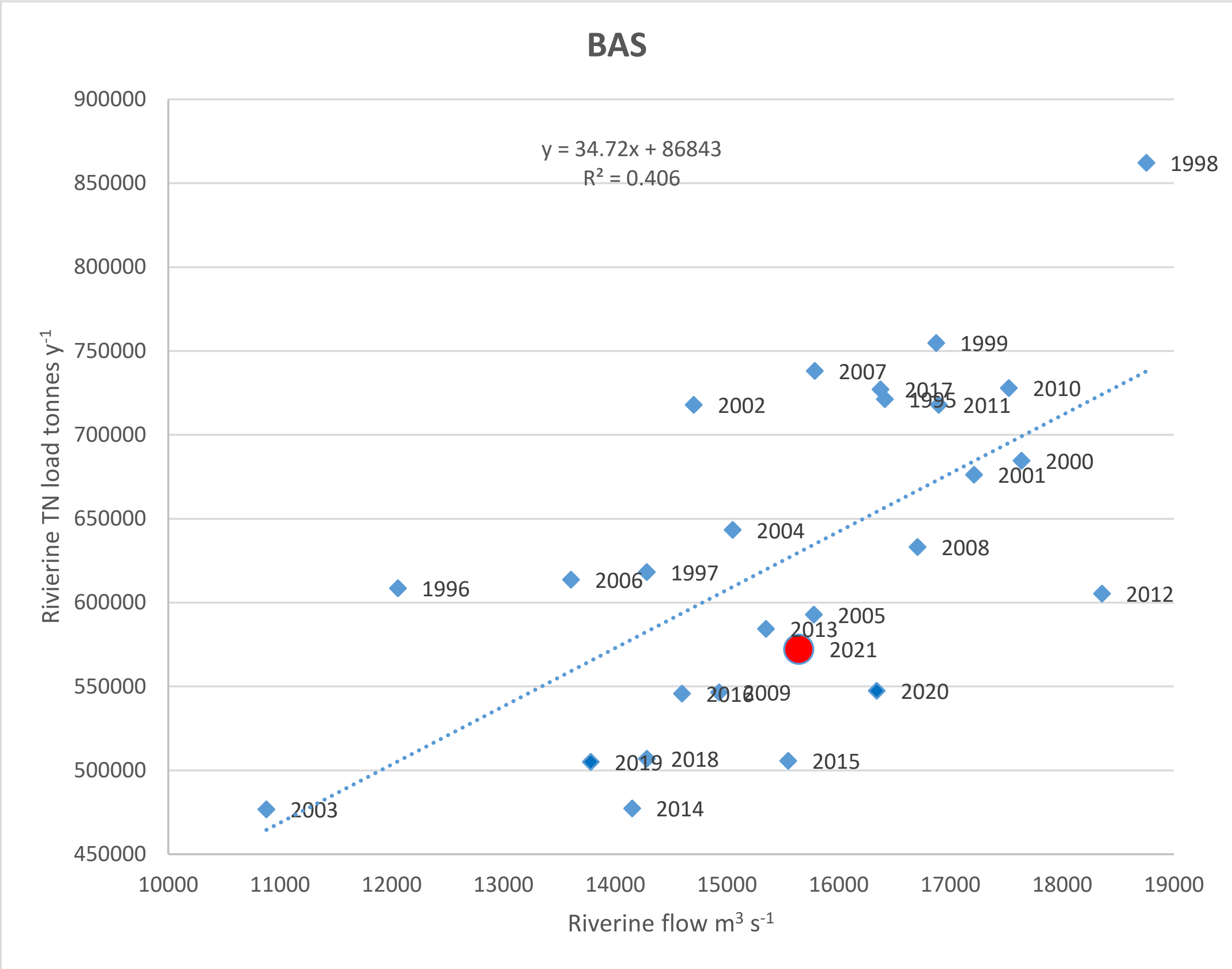


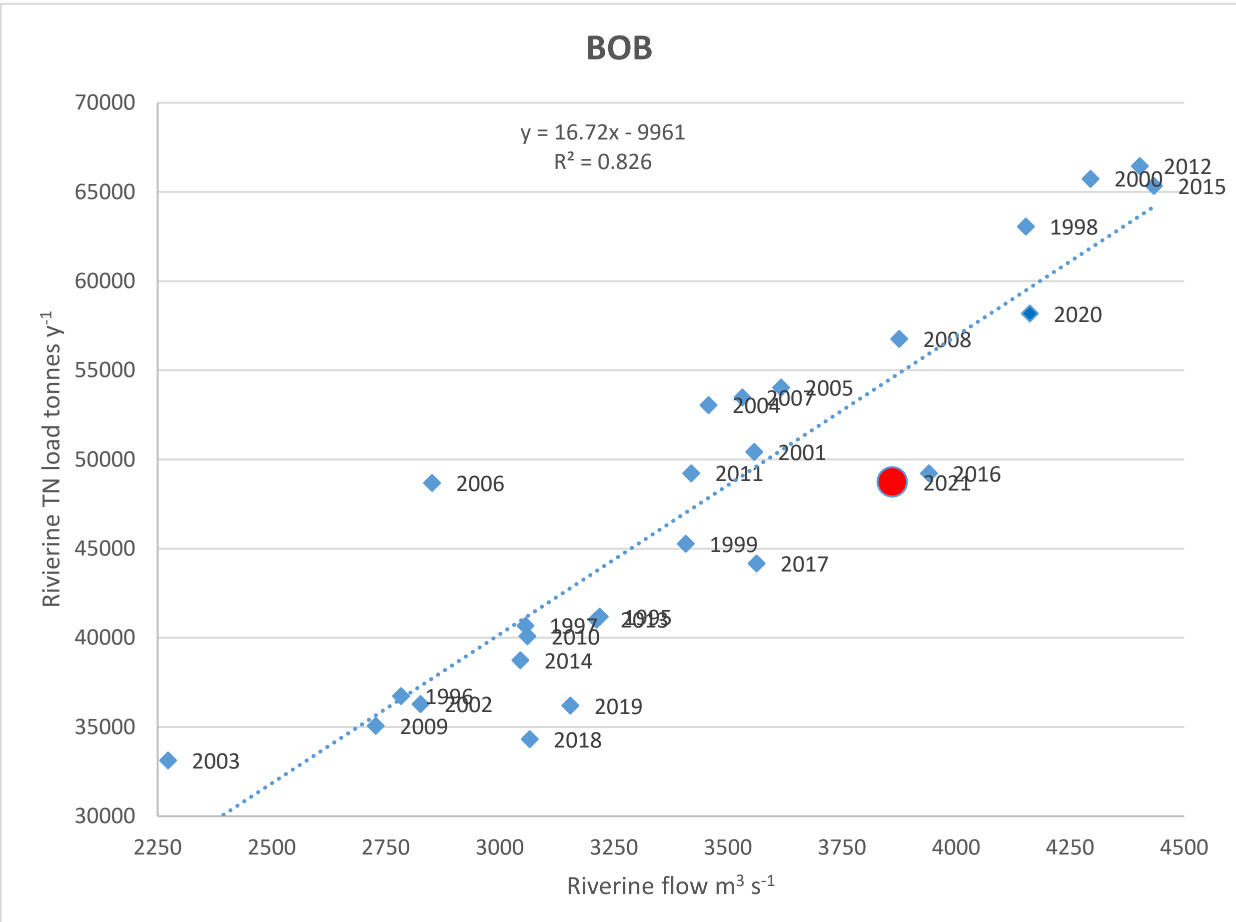
Figure 2B: Annual riverine and direct inputs of total phosphorus in tonnes and annual waterborne flow (m^{-3} s^{-1}) to the seven Baltic Sea sub-basin and to the Baltic Sea in 1995-2021. Data behind the figures are shown in Tables 2 and 6-8. For an explanation of the basin abbreviations, see the caption to Figure 1.

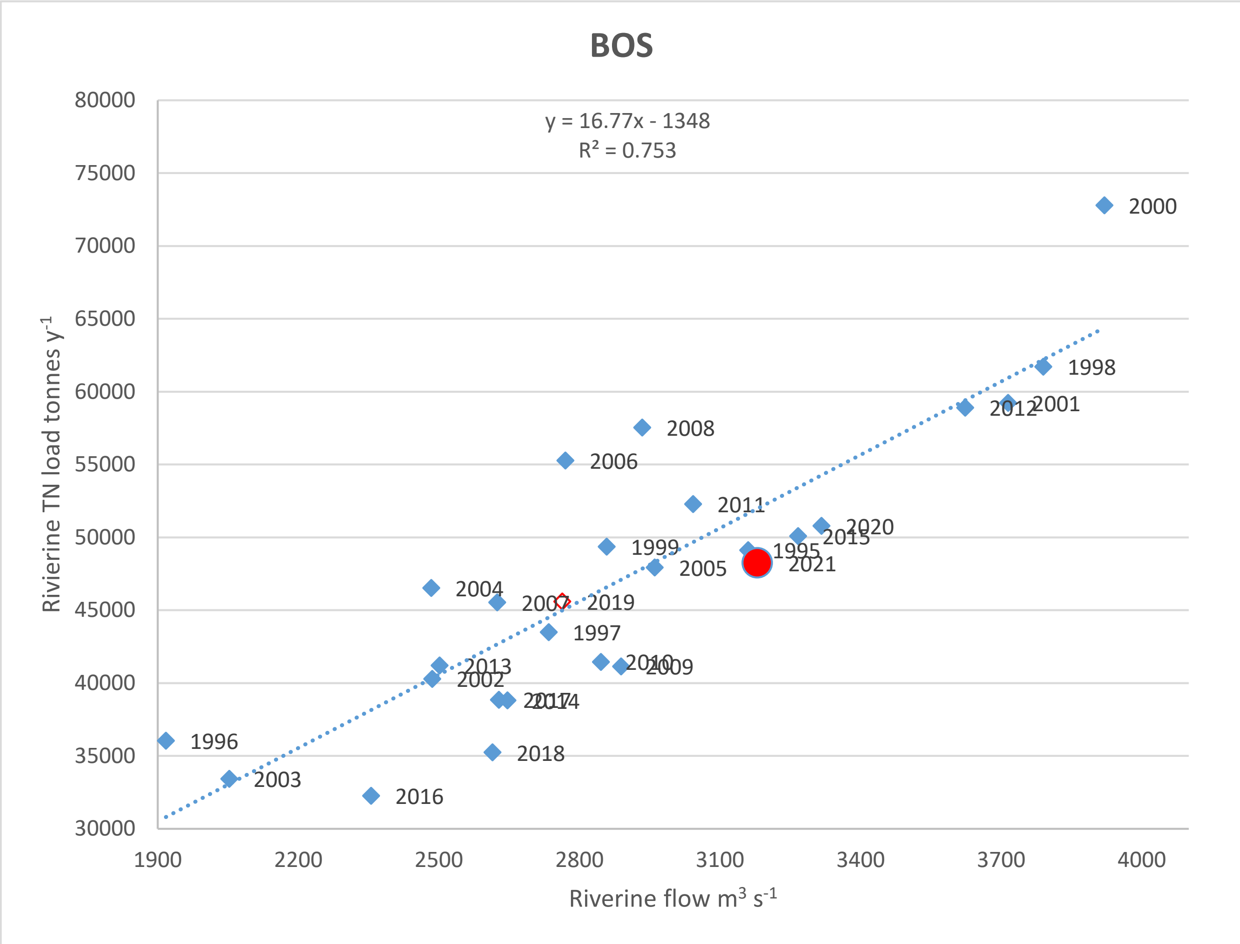
The correlation between the annual riverine TN and TP inputs, respectively, and water flow are shown as scatter and linear regression plots in Figure 3. The significance of the linear regression is tested statistically (see caption to Figure 3). The plots allow for characterization and evaluation of the TN and TP riverine inputs 1995-2021 specifically the inputs in 2021. The linear relation between riverine inputs and flow is significant for both TN and TP for all 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 Gulf of Finland for some unmonitored areas and the nutrient load in some rivers particularly in the 1990s and up to around 2005.

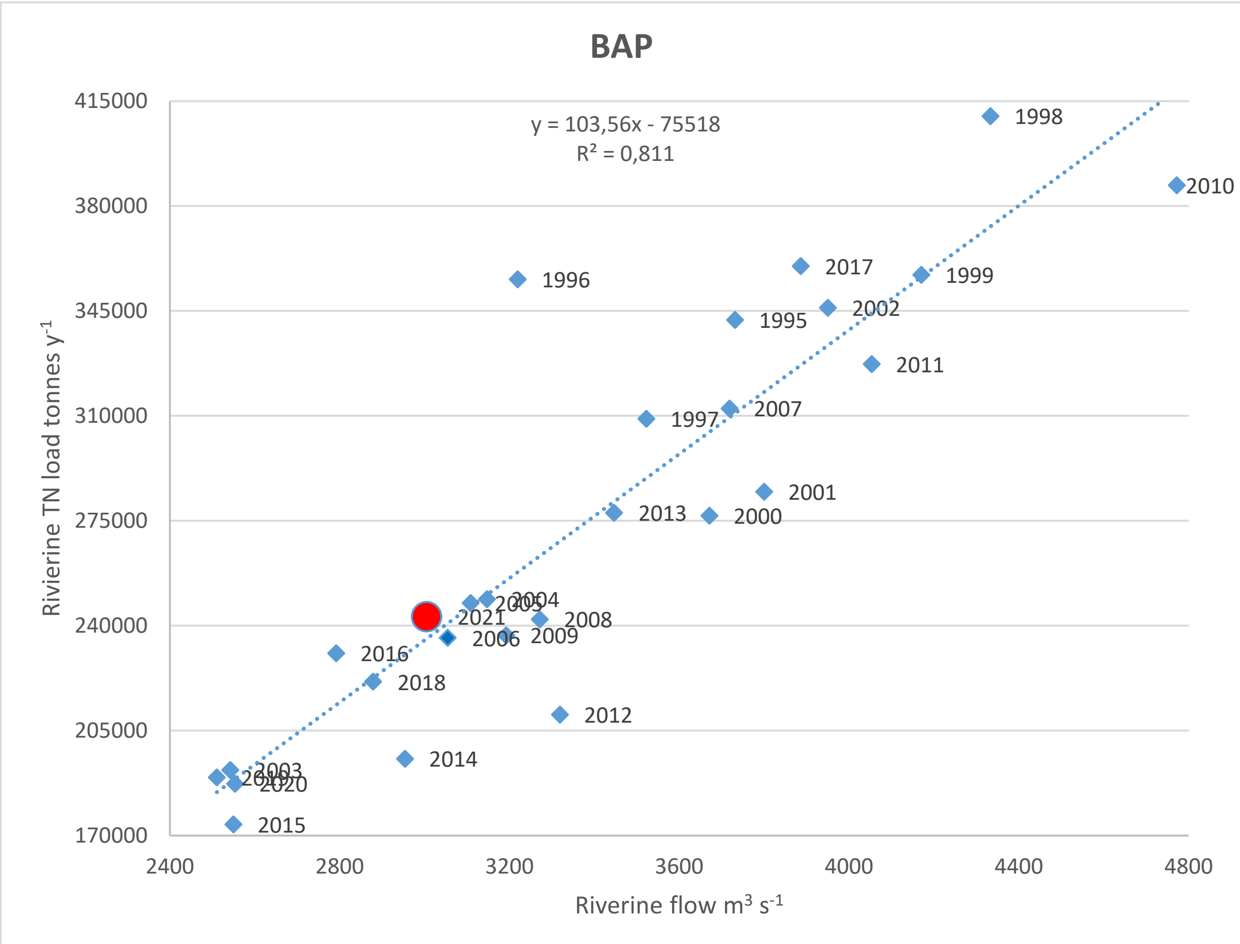
Riverine TN and TP inputs in 2021 were under or markedly under what the regressions line indicates for the magnitude of flow during 1995-2021 to Baltic Sea, except for TN to Gulf of Riga (much over the regression line), and to Baltic Proper (just over the regressions line). For TP riverine inputs was much under the regression line for all basins. For TN to Gulf of Riga the 20% lower flow than average (1995-2020) has resulted in 1% higher TN inputs than average (2011-20) and a 20% and 18% higher flow-weighted TN and TP concentration, respectively, than average of 2011-2020 (see table 1). The higher nutrient inputs can't 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.

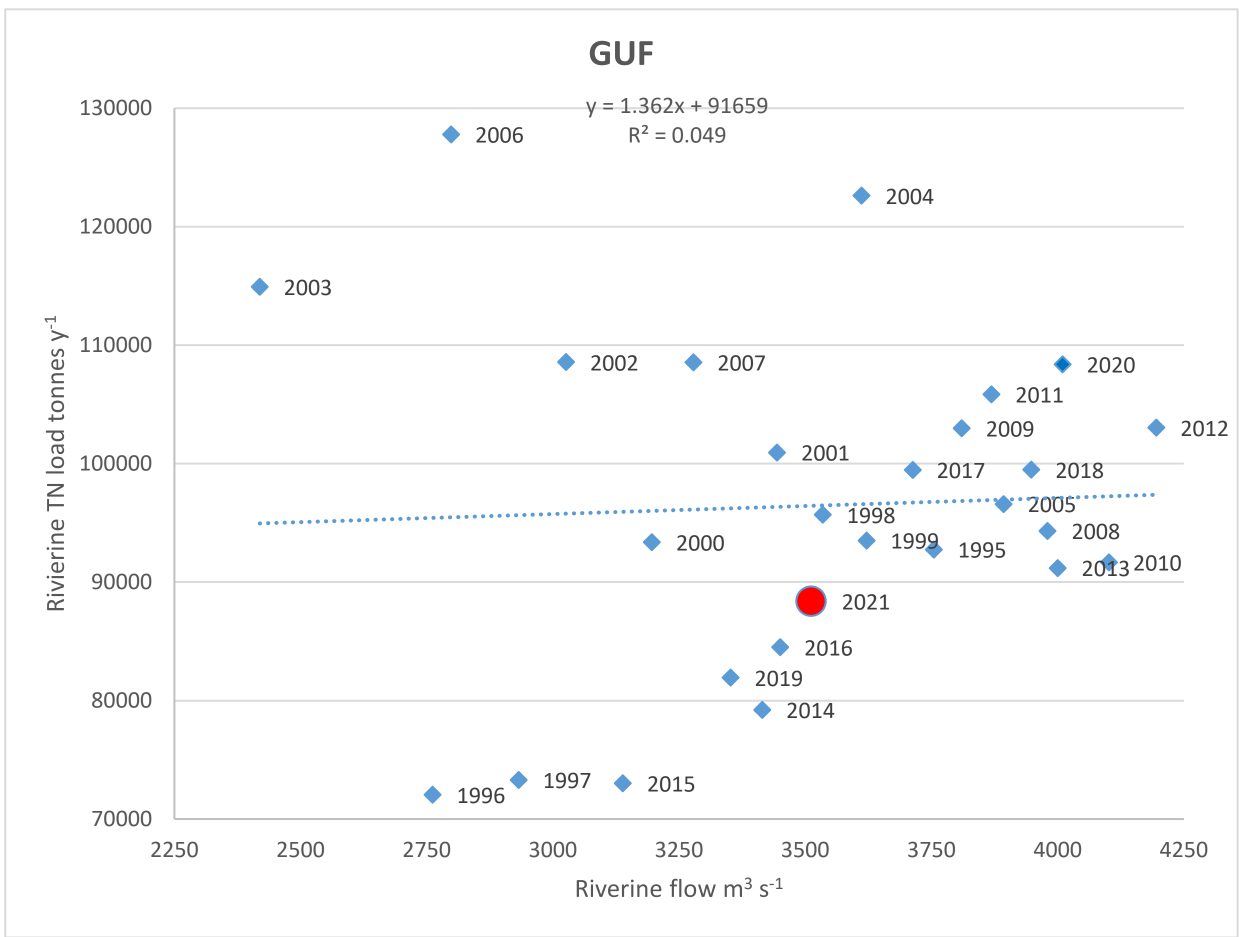
As a rule of thumb, a decrease in riverine TN and/or TP inputs during 1995 to 2021 is significant if most of the inputs of the latest 13-14 years falls below the dotted lines in Figure 3A and B. This is true for many basins. If nutrient inputs from sources with low dependency of flow volume (e.g., as 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.

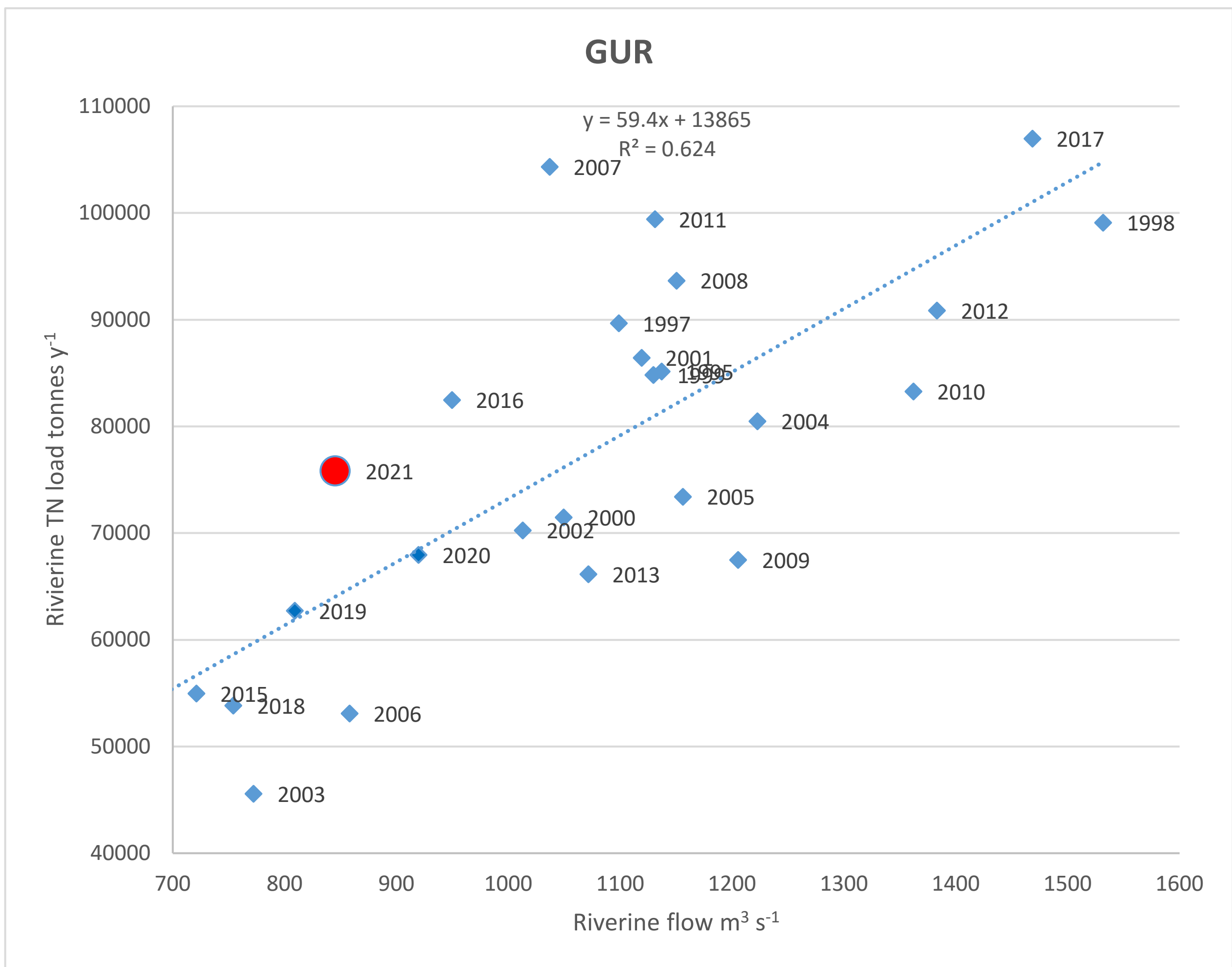

BAS
y = 34.72x + 86843
R² = 0.406
Rivierine TN load tonnes y-1
Riverine flow m3 s-1
1998
1999
2007
2017
1995
2011
2010
2002
2000
2001
2004
2008
1996
2006
1997
2012
2005
2013
2021
2016
2009
2020
2019
2018
2015
2003
2014

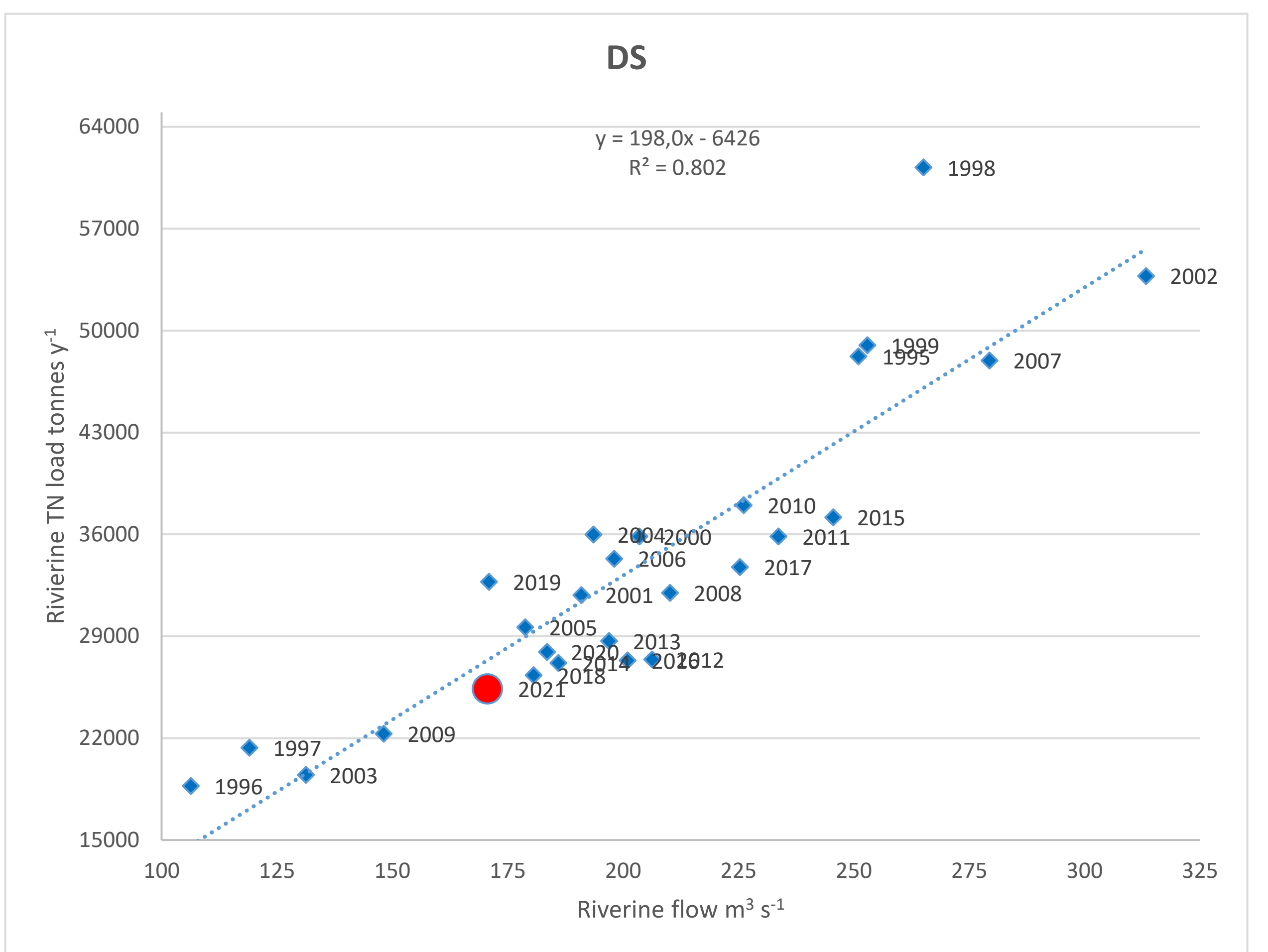

BOB
y = 16.72x - 9961
R² = 0.826
Rivierine TN load tonnes y-1
Riverine flow m3 s-1
2012
2000
2015
1998
2020
2008
2005
2007
2004
2001
2006
2011
2021
2016
1999
2017
1997
2010
1995
2013
2014
1996
2002
2019
2009
2018
2003


BOS
y = 16.77x - 1348
R² = 0.753
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
2012
2001
2008
2006
2011
2020
2015
1995
2021
1999
2005
2004
2007
2019
1997
2010
2009
2013
2002
2017
2014
1996
2018
2003
2016


BAP
y = 103,56x - 75518
R² = 0,811
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
2017
1999
1996
1995
2002
2011
1997
2007
2001
2013
2000
2021
2005
2004
2008
2006
2009
2016
2018
2012
2014
2003
2020
2015


GUF
y = 1.362x + 91659
R² = 0.049
Rivierine TN load tonnes y-1
Riverine flow m3 s-1
130000
120000
110000
100000
90000
80000
70000
2250
2500
2750
3000
3250
3500
3750
4000
4250
2006
2004
2003
2002
2007
2020
2011
2009
2012
2001
2017
2018
2005
1998
2008
2000
1999
1995
2013
2010
2021
2016
2019
2014
1996
1997
2015


GUR
y = 59.4x + 13865
R² = 0.624
Rivierine TN load tonnes y-1
Riverine flow m3 s-1
110000
100000
90000
80000
70000
60000
50000
40000
700
800
900
1000
1100
1200
1300
1400
1500
1600
2017
2007
2011
1998
2008
2012
1997
2001
1995
2016
2010
2004
2021
2005
2000
2002
2020
2013
2009
2019
2015
2018
2006
2003


DS
y = 198,0x - 6426
R² = 0.802
64000
57000
50000
43000
36000
29000
22000
15000
100
125
150
175
200
225
250
275
300
325
Rivierine TN load tonnes y-1
Riverine flow m3 s-1
1998
2002
1999
1995
2007
2010
2015
2004
2000
2011
2006
2017
2019
2001
2008
2005
2013
2020
2014
2016
2012
2018
2021
2009
1997
2003
1996

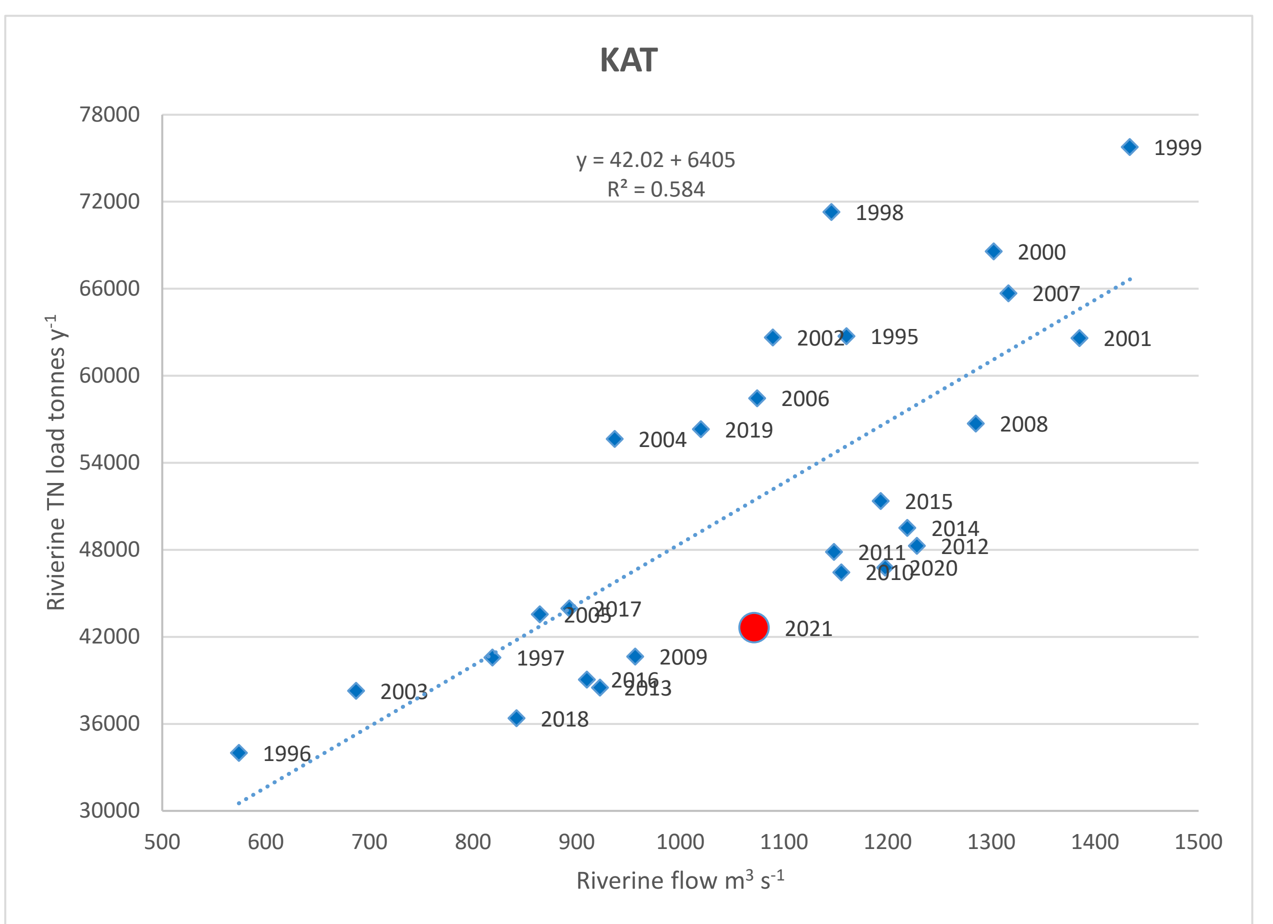
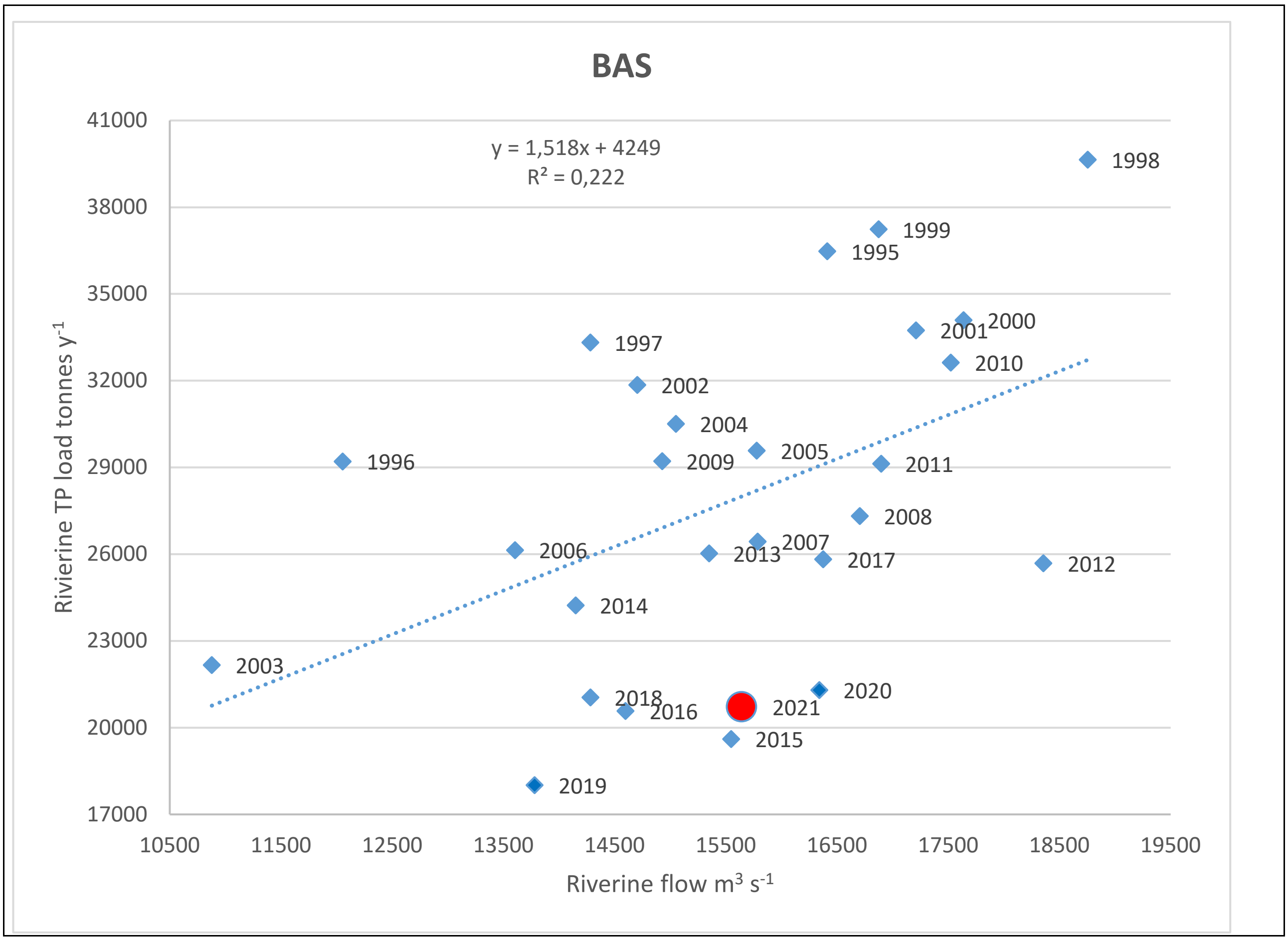
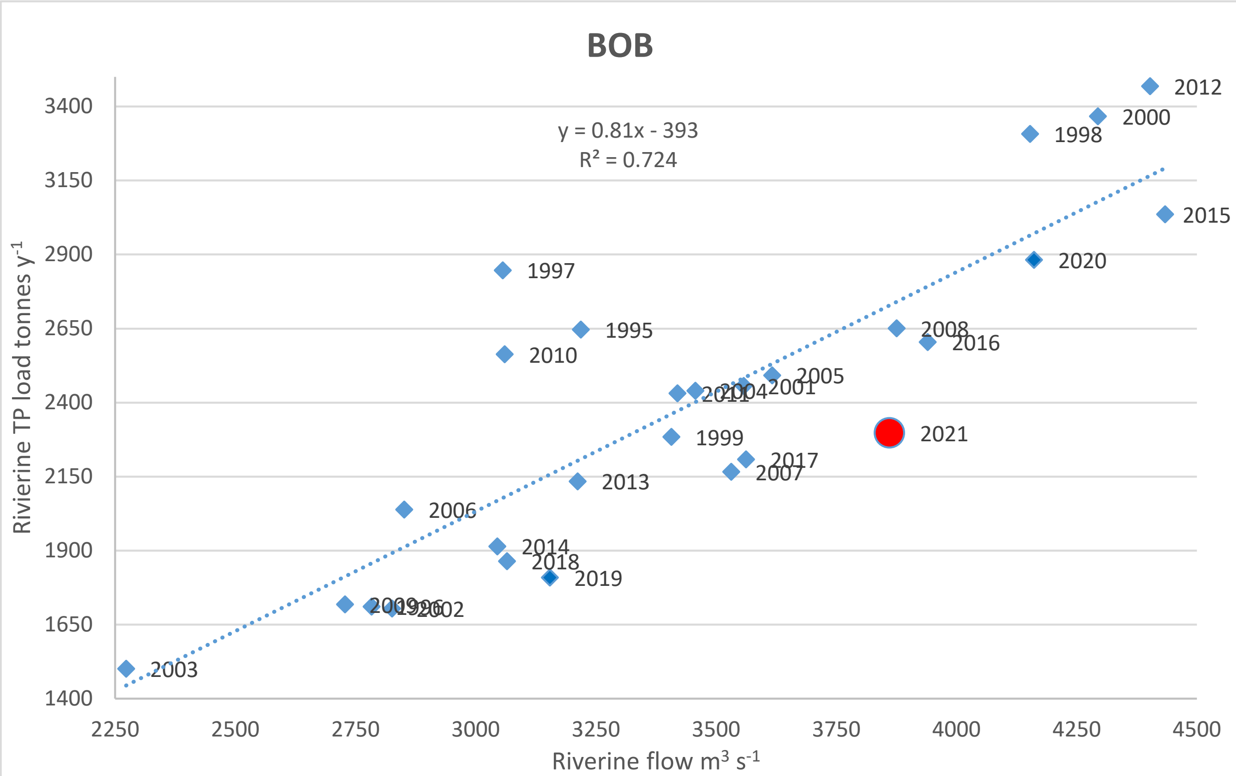
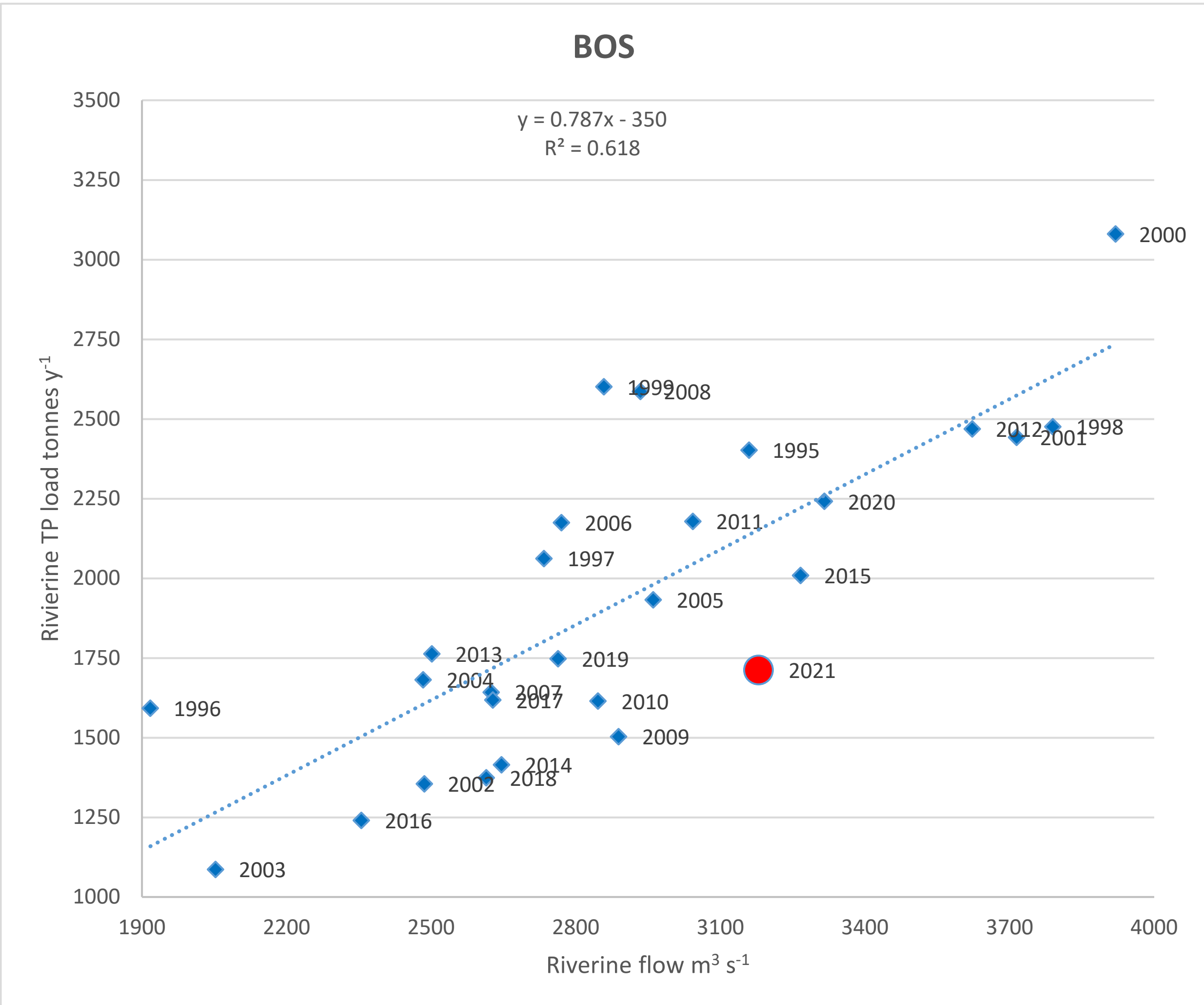
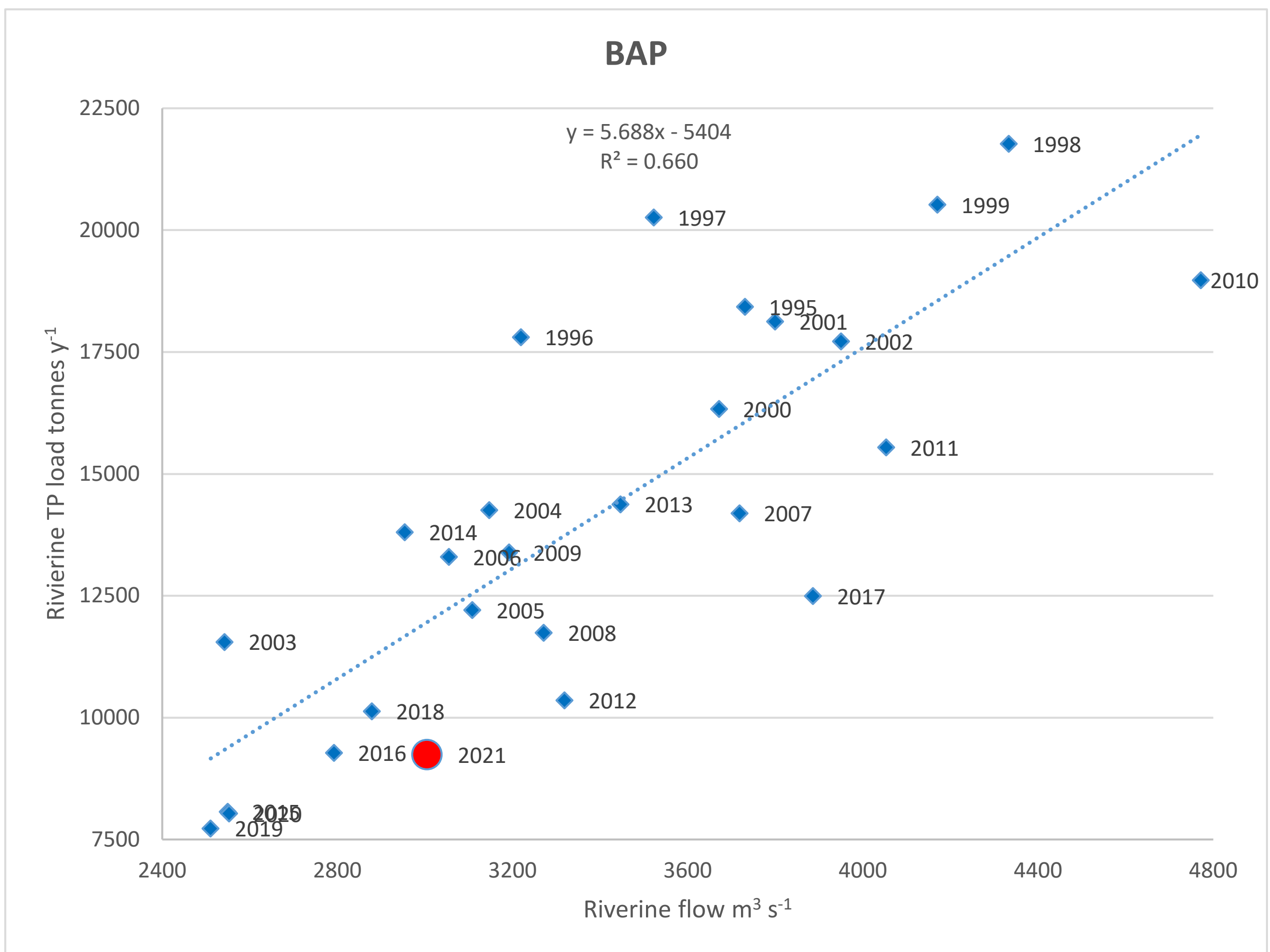

KAT
y = 42.02 + 6405
R² = 0.584
78000
72000
66000
60000
54000
48000
42000
36000
30000
500
600
700
800
900
1000
1100
1200
1300
1400
1500
Rivierine TN load tonnes y-1
Riverine flow m3 s-1
1999
1998
2000
2007
2002
1995
2001
2006
2008
2004
2019
2015
2014
2011
2012
2010
2020
2005
2017
2021
1997
2009
2003
2016
2013
2018
1996

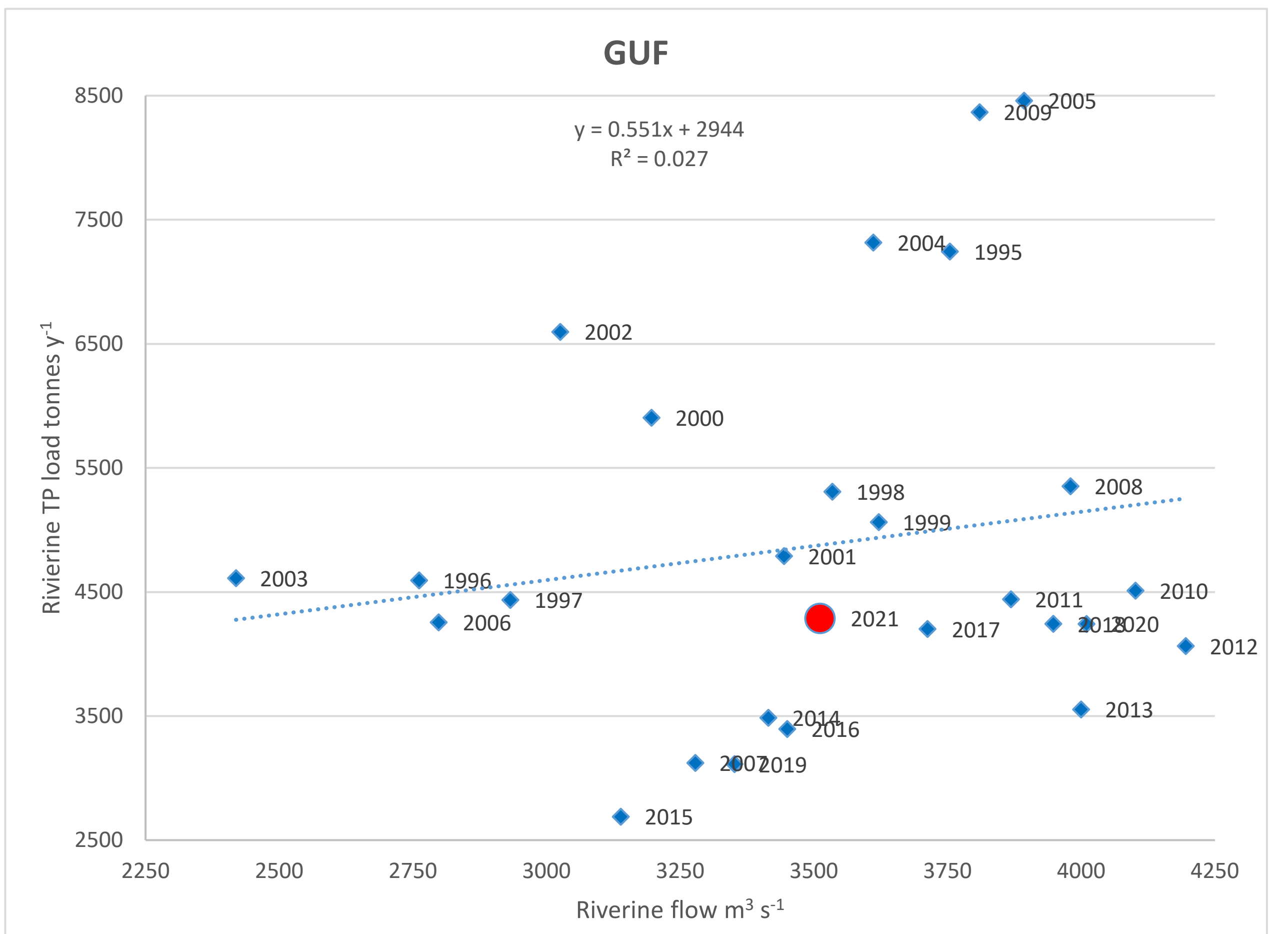
Figure 3A. Linear regression plots of annual riverine flows ($m^3 s^{-1}$) against annual riverine total nitrogen inputs (TN) to the seven Baltic Sea sub-basins and to the Baltic Sea during 1995-2021. Most recent year (2021) is marked with a big red dot and "2021" to the right of the dot. The linear 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.

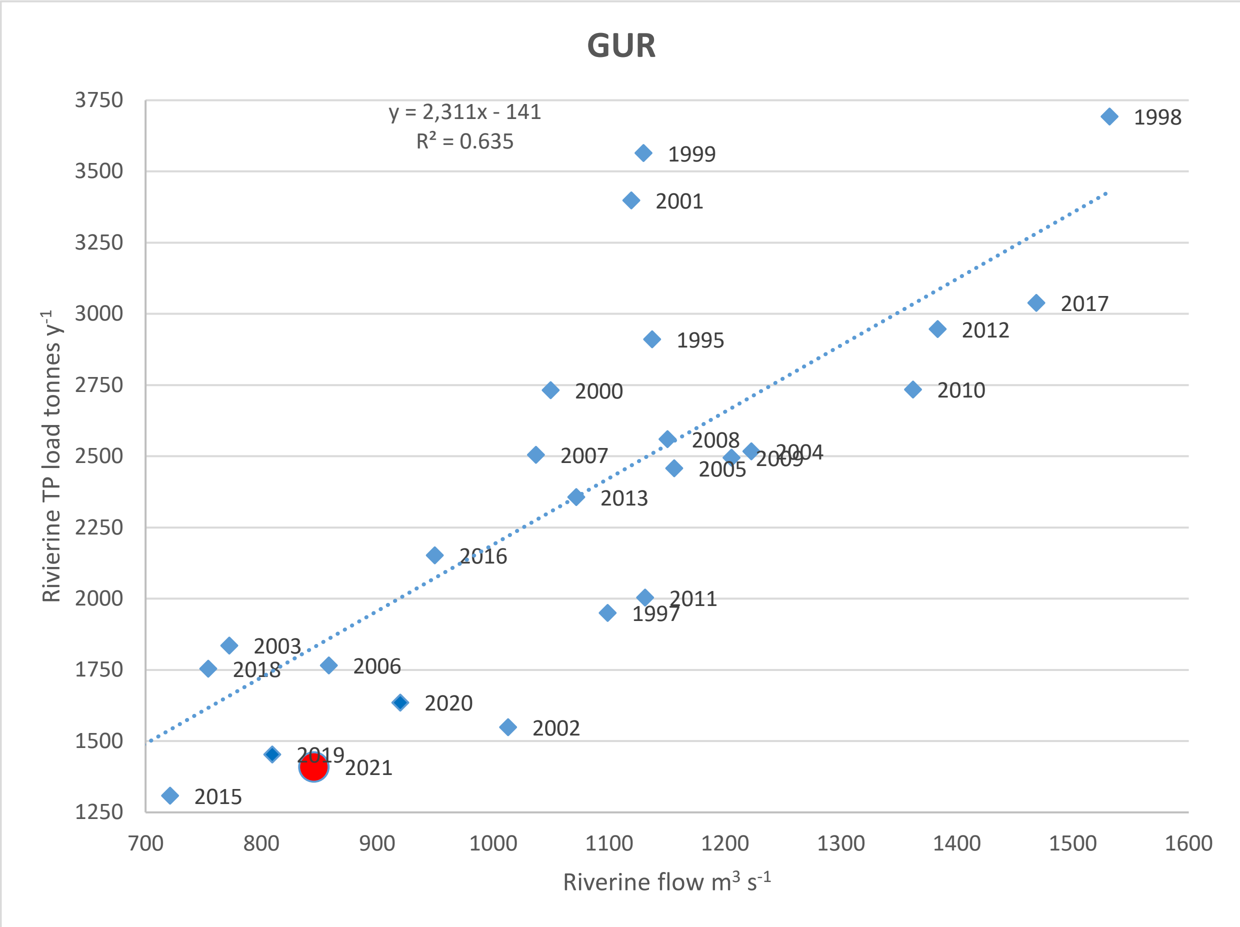


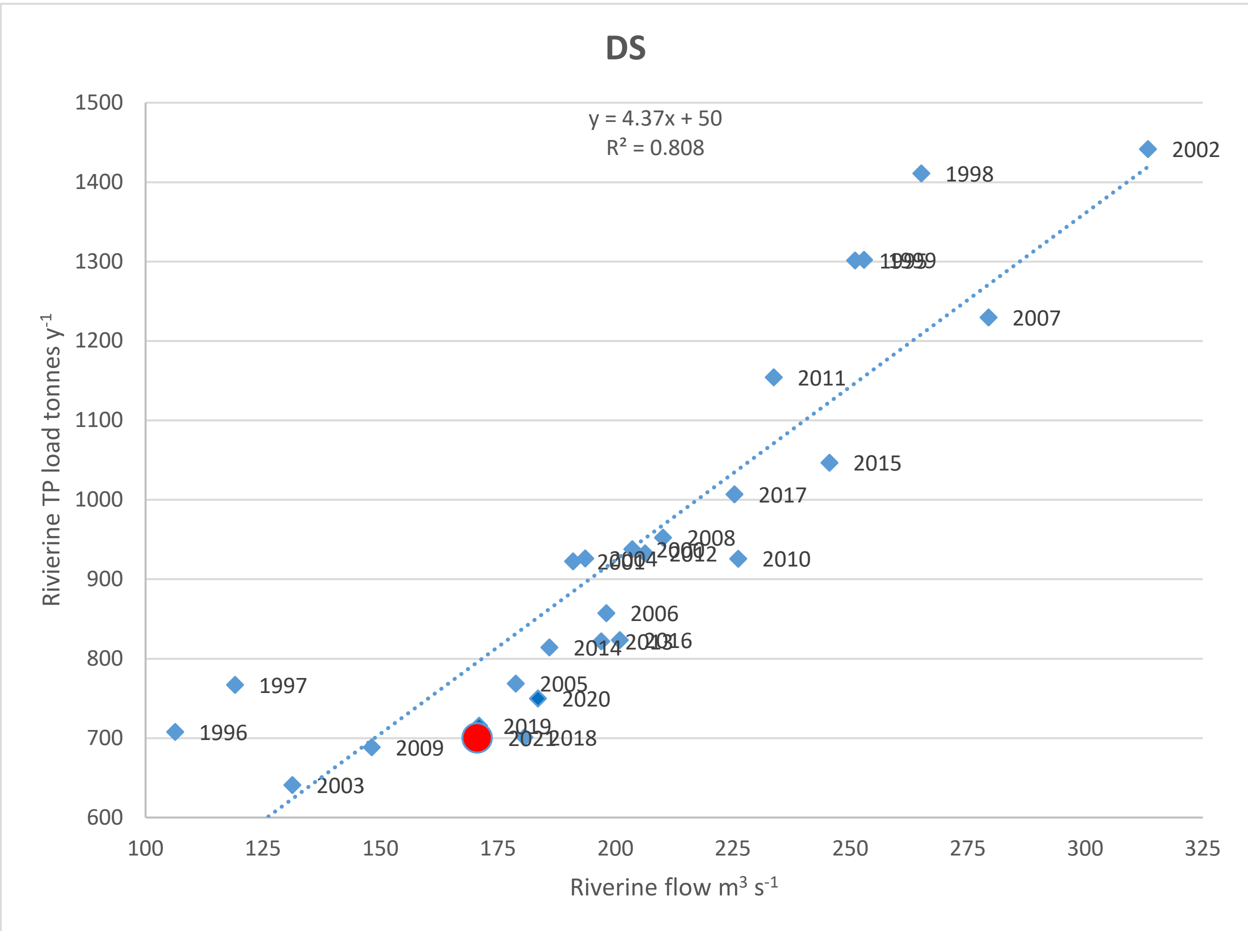

BOB
y = 0.81x - 393
R² = 0.724
Rivierine TP load tonnes y-1
Riverine flow m3 s-1
3400
3150
2900
2650
2400
2150
1900
1650
1400
2250
2500
2750
3000
3250
3500
3750
4000
4250
4500
2012
2000
1998
2015
2020
1997
1995
2010
2008
2016
2005
2001
2021
1999
2017
2007
2013
2006
2014
2018
2019
2003


BOS
y = 0.787x - 350
R² = 0.618
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
1995
1998
2001
2012
2020
2006
2011
1997
2015
2005
2013
2019
2021
2004
2007
2017
2010
1996
2009
2014
2018
2002
2016
2003


BAP
y = 5.688x - 5404
R² = 0.660
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
2017
2005
2008
2003
2018
2012
2016
2021
2020
2015
2019


GUF
y = 0.551x + 2944
R² = 0.027
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
1998
2008
1999
2001
2003
1996
1997
2010
2011
2021
2006
2017
2018
2020
2012
2013
2014
2016
2007
2019
2015


GUR
y = 2,311x - 141
R² = 0.635
Rivierine TP load tonnes y-1
Riverine flow m3 s-1
1998
1999
2001
2017
2012
1995
2010
2000
2008
2007
2004
2009
2005
2013
2016
2011
1997
2003
2018
2006
2020
2002
2019
2021
2015


DS
y = 4.37x + 50
R² = 0.808
Rivierine TP load tonnes y-1
Riverine flow m3 s-1
2002
1998
1999
2007
2011
2015
2017
2008
2000
2012
2004
2001
2010
2006
2014
2013
2016
1997
2005
2020
2019
2021
2018
1996
2009
2003

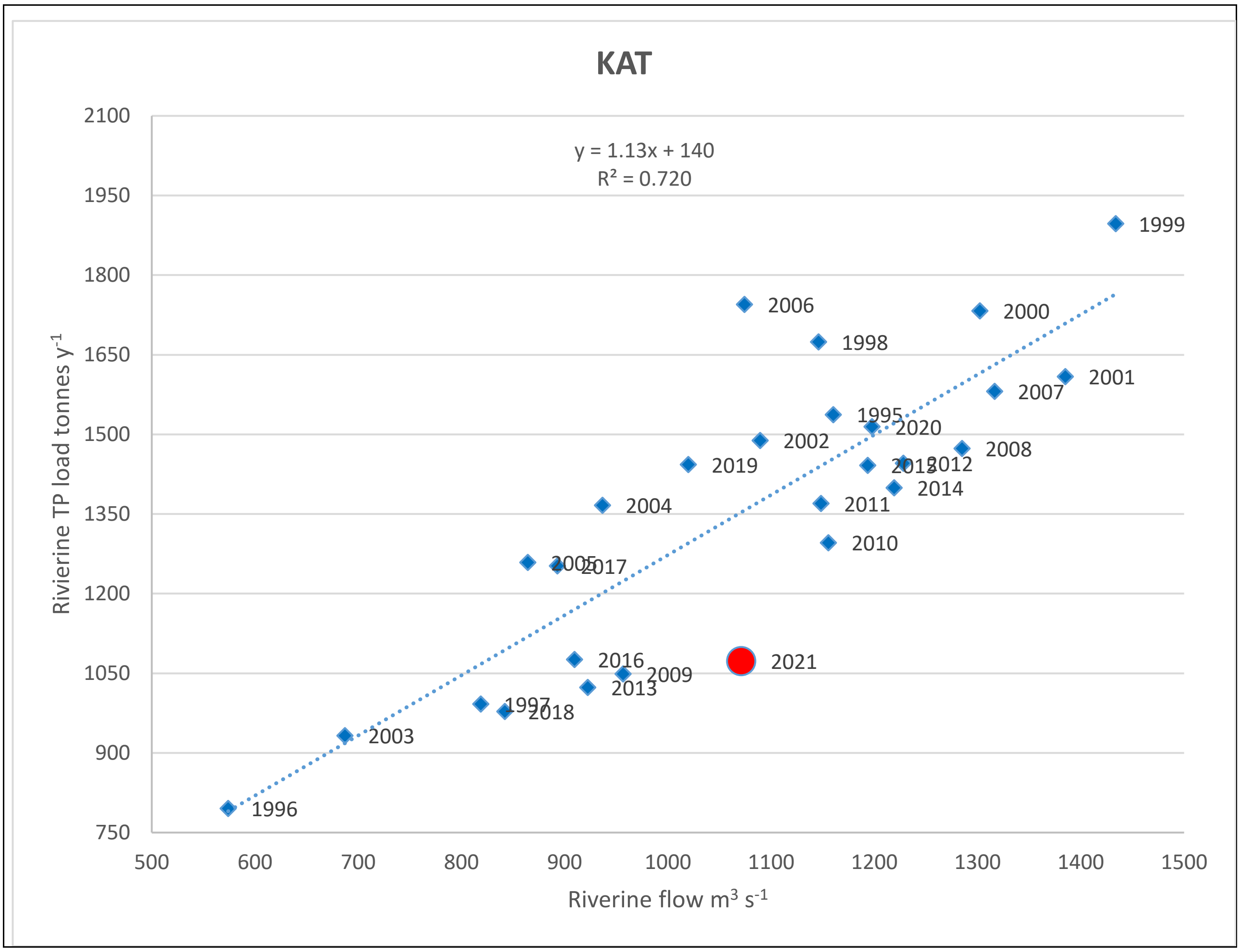
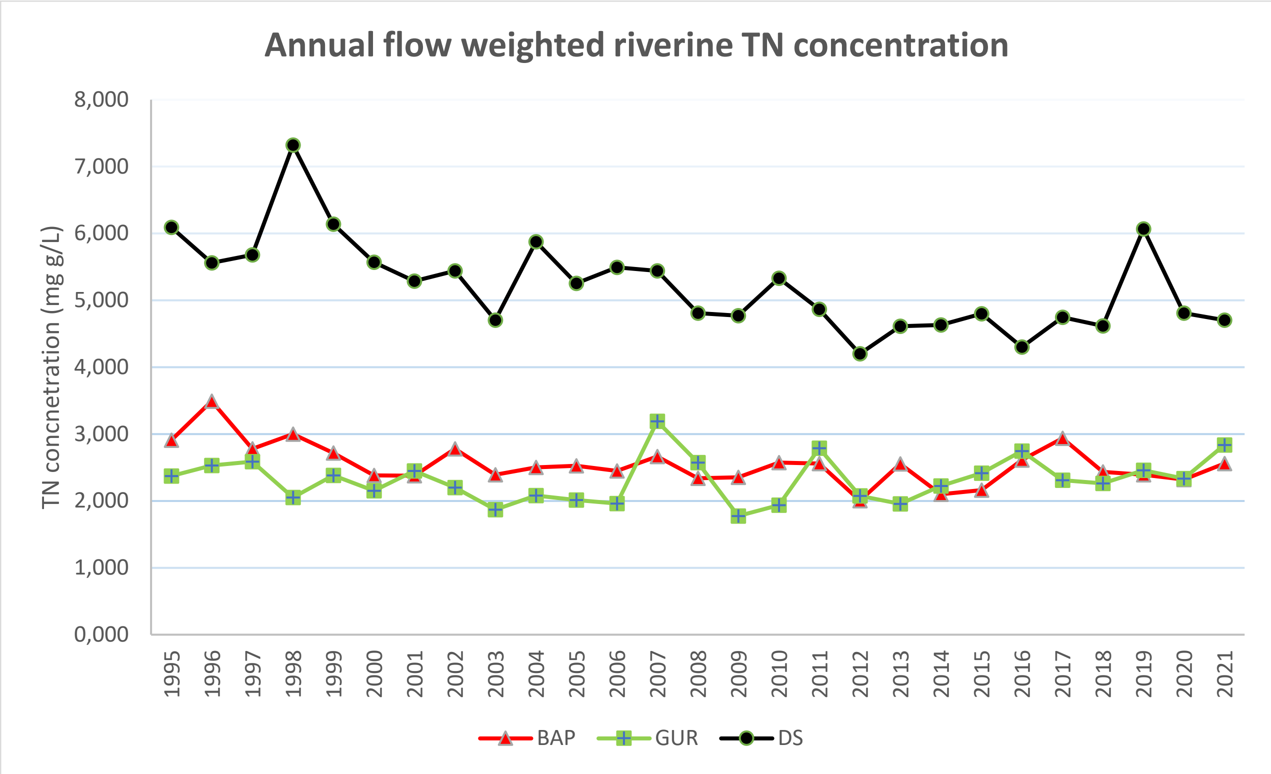
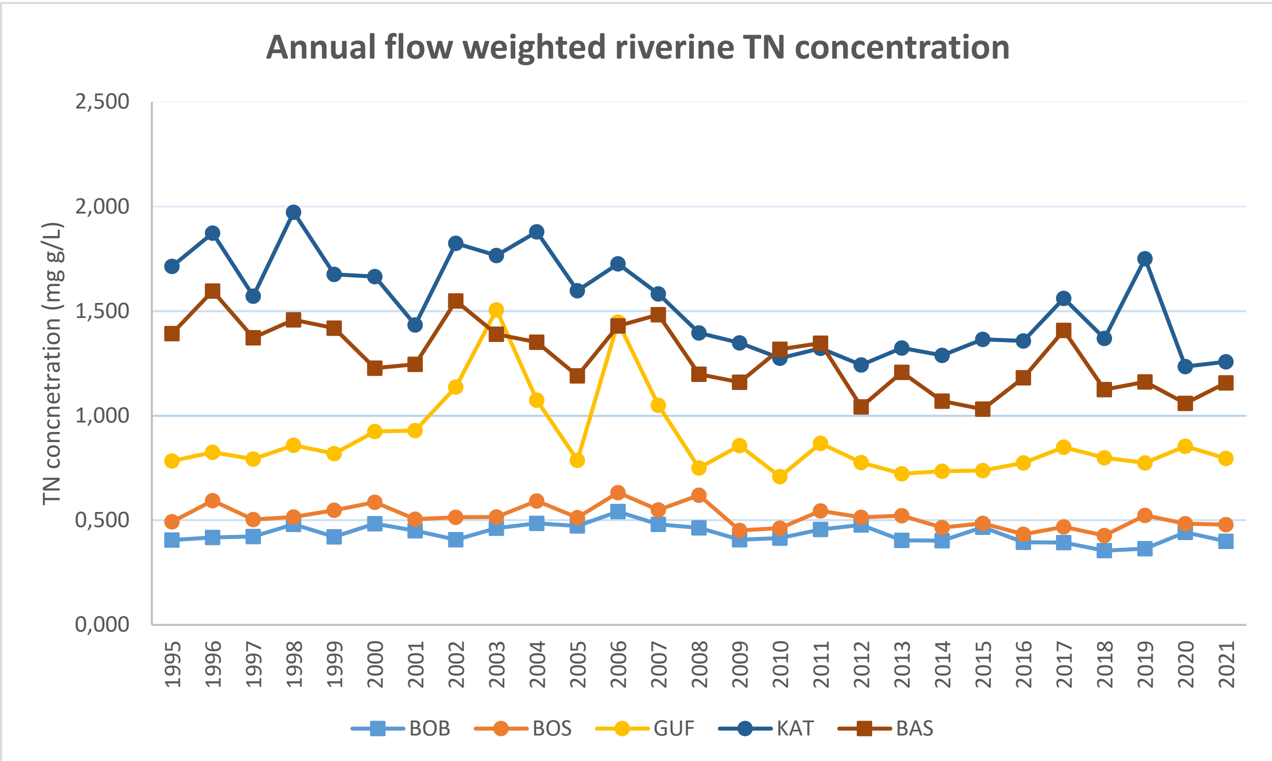


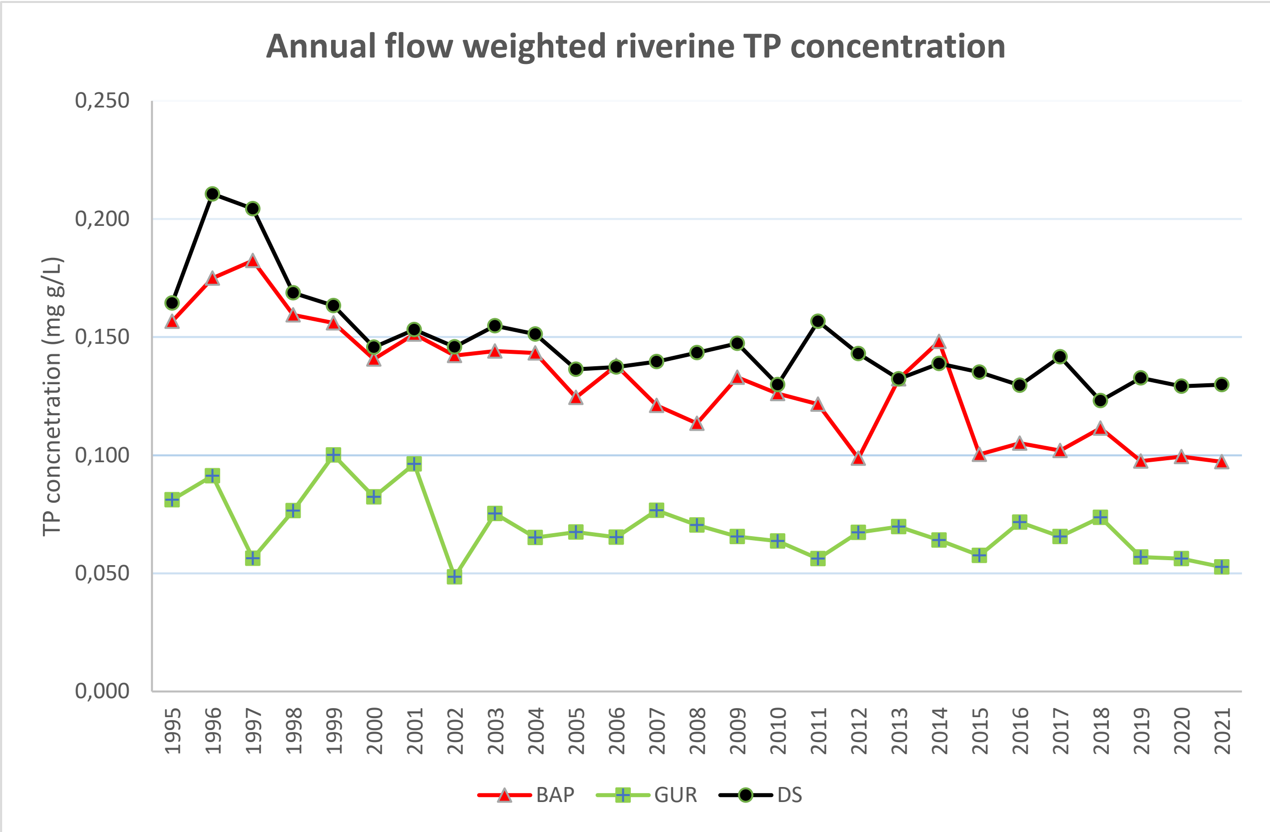
Figure 3B. As figure A but for total phosphorus 1995-2021. All relations besides TP to GUF are significant. For an explanation of abbreviations, see the caption to Figure 1.

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 1995-2021 are shown for the Baltic Sea and its seven 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 Bothnian Sea, Baltic Proper, Danish Straits, Kattegat and the Baltic Sea. The discharged weighted TP riverine concentrations decreased significantly to all seven basins and to the Baltic Sea.

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 basins. Particularly flow-weighted TN and TP concentrations to Bothnian Bay and Bothnian Sea are of an order of magnitude lower than for the flow weighted inputs to Danish Straits concentrations. This is the result of both scarce population and low agricultural pressures combined together with high area specific flow to these basins: Bothnian Bay, Bothnian Sea, and Kattegat have area specific flow of 12-13 l s^{-1} km^{-2} on average during 1995-2020, see Table 1. On average, the area specific flow to the Baltic Sea is 9 l s^{-1} km^{-2} (and also in 2021) and with only 5.9 to 8.4 l s^{-1} km^{-2} to the Baltic Proper, the Gulf of Finland, the Gulf of Riga and the Danish Straits during 1995-2020. 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. Annual flow weighted TN concentration to GUR in 2021 was among the highest during 1995-2021 aften two year (2019 and 2020) with very dry conditions. Flow weighted TP concentration to Gulf of Finland was rather heigh in 2021 compared with the former 9 years, and no obvious explanation have been provided .







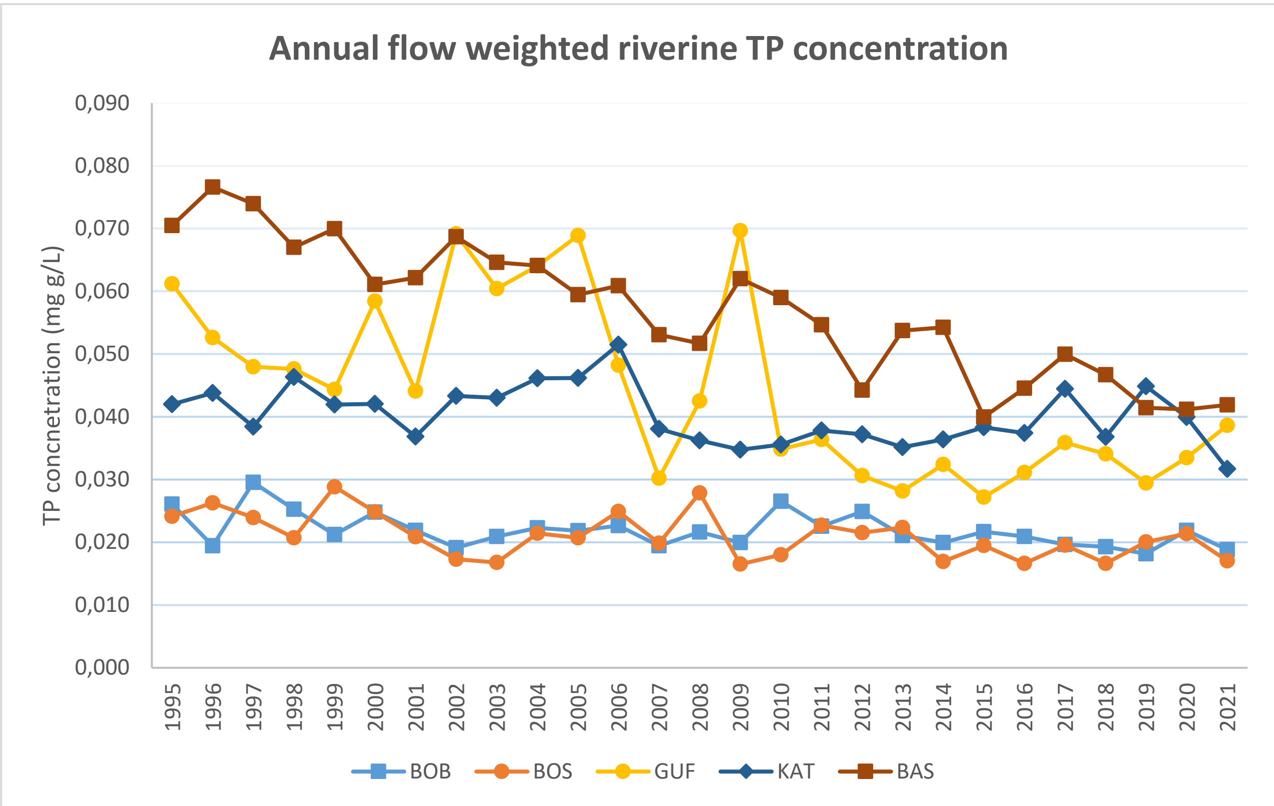
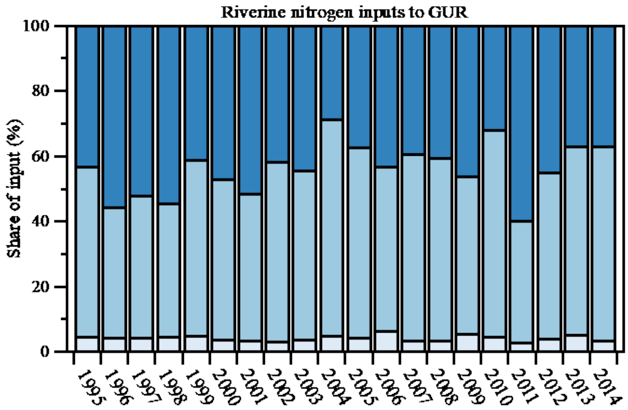
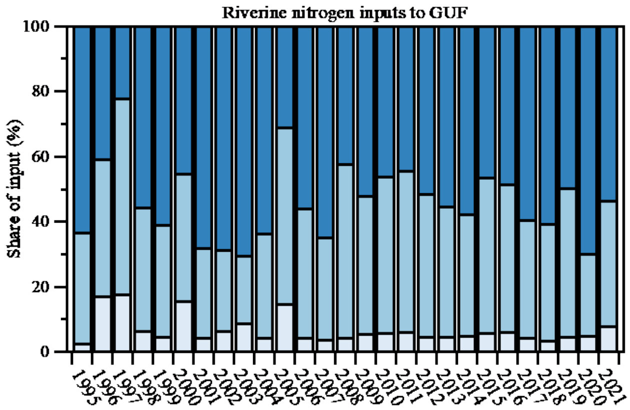


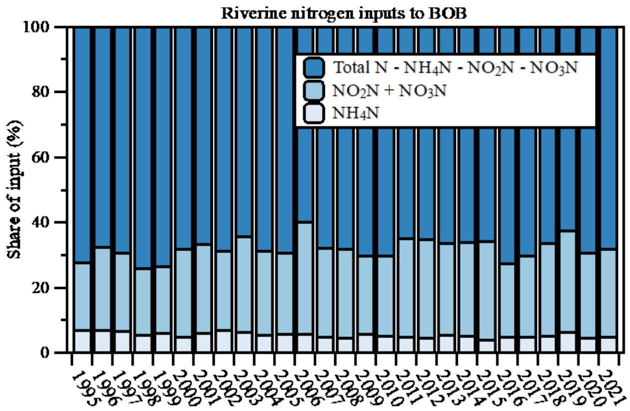
Figure 4. Annual average flow weighted riverine total nitrogen (the two uppermost figures) and total phosporus (the two lowermost plots) concentrations for the seven Baltic Sea basins and the Baltic Sea (calculated as total annual riverine inputs divided with the corresponding annual flow) during 1995-2021 (in mg/L). 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 basins (plot 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.

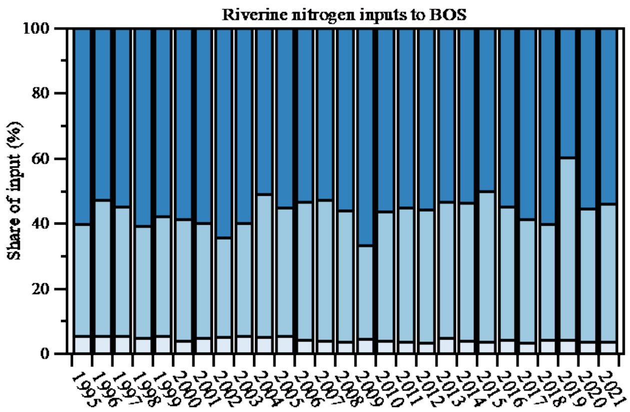
Composition of the riverine nutrient inputs 2020

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 the unmonitored areas. The time-series of the share of annual riverine inputs of inorganic nutrient inputs of the total nutrient inputs for the seven basins are shown in Figure 5 for nitrogen and Figure 6 for phosphorus. The organic portion could be found as the difference between total and inorganic nitrogen and phosphorus. 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 over 80% 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 4).


Riverine nitrogen inputs to GUR
Share of input (%)
0
20
40
60
80
100
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014


Riverine nitrogen inputs to GUF
Share of input (%)
0
20
40
60
80
100
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021


Riverine nitrogen inputs to BOB
Share of input (%)
0
20
40
60
80
100
Total N - NH_4N - NO_2N - NO_3N
NO_2N + NO_3N
NH_4N
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021


Riverine nitrogen inputs to BOS
Share of input (%)
0
20
40
60
80
100
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021

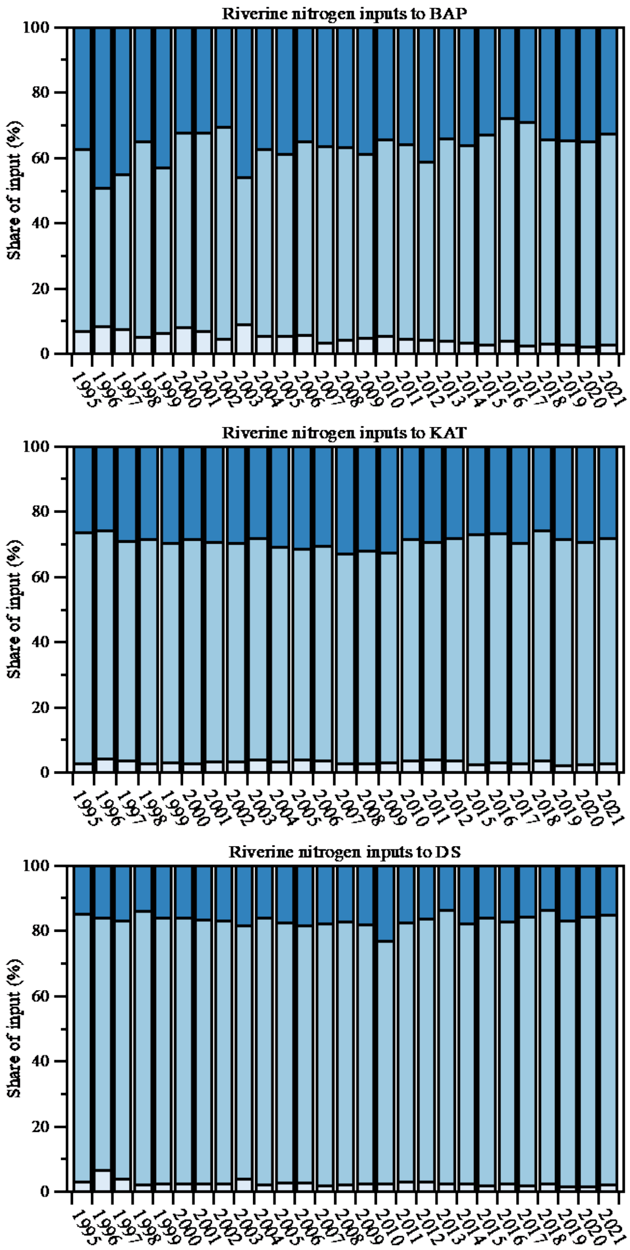
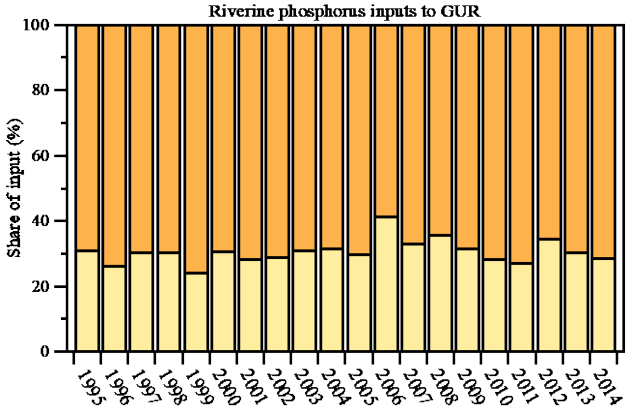
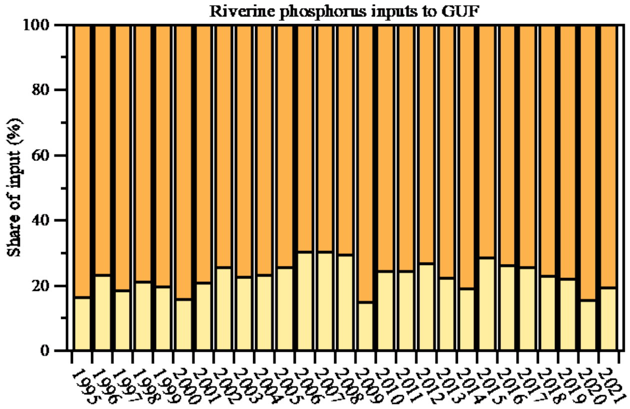
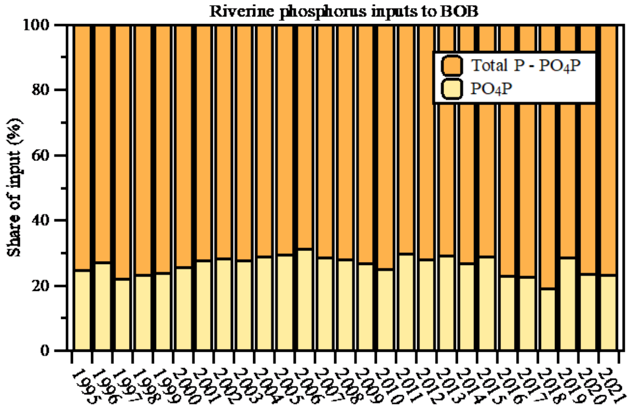
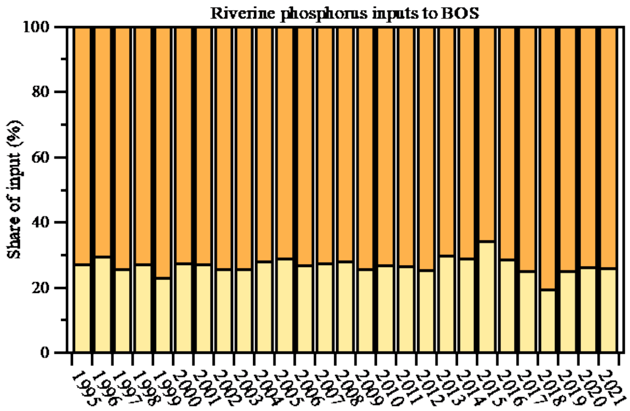


Figure 5. Shares of nitrogen fractions of the total annual nitrogen inputs to the seven Baltic Sea basins during 1995-2021.


Riverine phosphorus inputs to GUR
Share of input (%)
0 20 40 60 80 100
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014


Riverine phosphorus inputs to GUF
Share of input (%)
0 20 40 60 80 100
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021


Riverine phosphorus inputs to BOB
Share of input (%)
0 20 40 60 80 100
Total P - PO_4P
PO_4P
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021


Riverine phosphorus inputs to BOS
Share of input (%)
0 20 40 60 80 100
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021

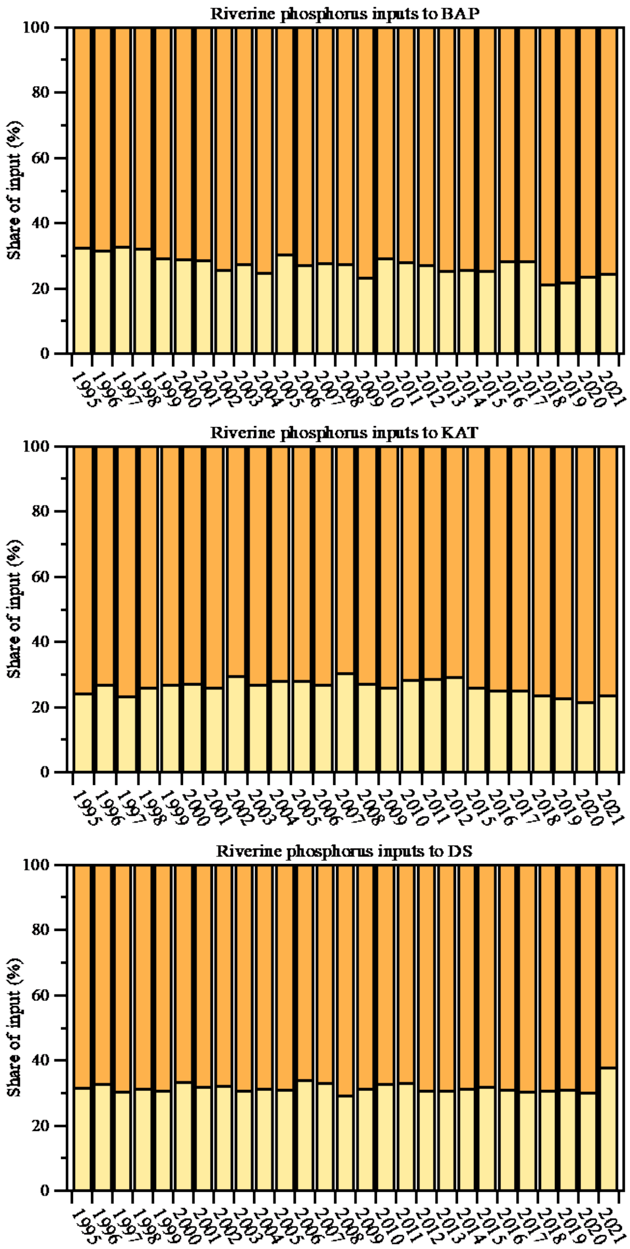


Figure 6. Shares of phosphorus fractions of the total annual phosphorus inputs to the seven Baltic Sea basins during 1995-2021.

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

[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).

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.

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 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 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	3224	3170	3750	3755	1141	266	1170	16475
1996	2784	1917	3221	2789	693	115	576	12095
1997	3056	2734	3524	2959	1099	128	821	14323
1998	4153	3790	4335	3562	1532	276	1149	18797
1999	3407	2858	4172	3648	1130	264	1437	16916
2000	4298	3929	3691	3227	1052	218	1311	17726
2001	3557	3714	3804	3475	1121	200	1388	17260
2002	2830	2488	3964	3055	1015	327	1098	14778
2003	2277	2055	2557	2449	774	142	694	10949
2004	3461	2484	3162	3643	1223	206	945	15123
2005	3623	2963	3127	3920	1156	191	873	15853
2006	2853	2773	3071	2826	860	211	1083	13675
2007	3532	2625	3726	3306	1039	292	1320	15840
2008	3876	2937	3289	4008	1152	223	1294	16779
2009	2729	2891	3209	3839	1207	160	964	15000
2010	3061	2848	4788	4128	1364	239	1163	17593
2011	3420	3045	4071	3896	1133	247	1158	16969
2012	4403	3625	3333	4222	1385	219	1237	18425
2013	3213	2504	3463	4027	1073	209	930	15419
2014	3046	2648	2972	3442	688	200	1228	14222
2015	4437	3275	2570	3165	723	260	1204	15635
2016	3944	2364	2811	3477	951	214	918	14680
2017	3566	2636	3908	3742	1471	239	903	16464
2018	3069	2622	2898	3974	756	193	851	14363
2019	3158	2772	2530	3378	811	184	1029	13864
2020	4165	3326	2572	4036	922	196	1207	16424
2021	3864	3189	3024	3538	847	184	1080	15726

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	3383	4863	16671	17386	1164	12786	4245	60498
1996	3278	5117	11774	14708	1224	7449	3700	47250
1997	3367	4557	10314	13080	1250	5907	3527	42002
1998	3596	4935	9128	12305	1247	6216	3063	40490
1999	3456	4798	8167	12618	1251	5082	2773	38144
2000	3392	4980	8850	12838	1400	7007	2447	40914
2001	3091	4634	6953	12960	1521	4168	2438	35765
2002	3072	4534	6830	13007	1430	3431	2506	34810
2003	3138	4545	6693	12905	1815	3037	2086	34218
2004	3070	4592	6555	11810	1442	3157	2280	32907
2005	2848	4456	6409	10169	1573	2959	2219	30633
2006	2907	4762	6899	9306	1768	3134	2475	31252
2007	2931	4351	7718	9610	2379	3357	2635	32981
2008	2941	4309	6911	9155	2460	3022	2700	31497
2009	2800	4169	6434	10055	1277	3272	2466	30473
2010	2911	3967	6919	9711	1121	2907	2233	29770
2011	3047	3837	6972	10076	1143	3244	2306	30624
2012	3213	4256	6627	9708	1107	3145	2198	30253
2013	3584	4203	6472	9506	696	3251	2009	29722
2014	3649	3955	5973	9178	516	3160	2044	28475
2015	3366	4190	6271	8806	543	3384	2164	28724
2016	3553	4088	5276	9135	518	3171	1950	27689
2017	3260	4028	5505	10210	432	3399	1918	28752
2018	2954	3787	4759	7970	402	3035	1682	24589
2019	2916	3698	4686	10099	442	3387	2027	27256
2020	2639	3515	4719	9672	348	3114	1846	25854
2021	3106	3379	4961	9855	394	3317	1875	26888

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							
Riverine	**BOB**	**BOS**	**BAP**	**GUF**	**GUR**	**DS**	**KAT**	**BAS**
1995	41185	49122	342047	92747	85143	48217	62735	721196
1996	36744	36042	355572	72043	55485	18699	33998	608582
1997	40695	43484	309048	73289	89654	21327	40575	618071
1998	63059	61715	410043	95686	99101	61204	71308	862116
1999	45276	49349	357061	93503	84813	48986	75791	754779
2000	65745	72777	276785	93369	71477	35847	68593	684592
2001	50427	59217	284755	100936	86421	31832	62613	676201
2002	36291	40286	346127	108561	70246	53752	62657	717920
2003	33127	33422	191896	114916	45561	19462	38281	476666
2004	53050	46526	248911	122618	80488	35989	55645	643229
2005	54038	47933	247598	96587	73410	29619	43551	592736
2006	48685	55282	235950	127773	53096	34325	58459	613570
2007	53491	45534	312552	108547	104323	47946	65701	738094
2008	56768	57529	242203	94303	93654	31974	56720	633149
2009	35075	41142	236836	102985	67471	22288	40652	546449
2010	40094	41454	386967	91665	83258	38001	46463	727902
2011	49237	52274	327310	105839	99413	35858	47866	717797
2012	66448	58895	210386	103024	90863	27404	48279	605300
2013	41023	41204	277663	91184	66131	28662	38511	584379
2014	38748	38805	195699	79197	48130	27155	49514	477247
2015	65338	50081	173783	73003	54953	37161	51370	505687
2016	49233	32258	230827	84492	82469	27334	39065	545678
2017	44162	38843	359921	99448	106954	33748	43949	727024
2018	34306	35232	221298	99476	53821	26312	36386	506830
2019	36190	45584	189457	81926	62697	32721	56297	504873
2020	58173	50781	187339	108360	67939	27902	46774	547268
2021	48728	48246	242986	88374	75816	25374	42617	572142

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	44569	53985	358718	110133	86307	61004	66980	781694
1996	40022	41159	367345	86751	56709	26148	37698	655832
1997	44061	48041	319362	86368	90904	27234	44102	660073
1998	66655	66650	419171	107991	100348	67420	74371	902606
1999	48732	54147	365227	106121	86064	54067	78564	792923
2000	69137	77756	285635	106207	72877	42854	71040	725506
2001	53517	63851	291708	113895	87942	36000	65051	711966
2002	39364	44820	352957	121568	71676	57183	65162	752730
2003	36265	37966	198589	127822	47376	22499	40367	510884
2004	56121	51118	255466	134428	81930	39147	57925	676136
2005	56887	52389	254007	106757	74983	32578	45770	623370
2006	51592	60045	242850	137079	54864	37459	60934	644822
2007	56422	49885	320270	118158	106701	51303	68336	771074
2008	59708	61838	249114	103458	96113	34995	59420	664646
2009	37874	45311	243270	113041	68748	25560	43118	576922
2010	43005	45422	393887	101376	84379	40909	48695	757673
2011	52284	56111	334281	115914	100556	39102	50171	748421
2012	69661	63151	217012	112732	91970	30549	50477	635553
2013	44607	45408	284136	100690	66827	31914	40519	614101
2014	42397	42760	201672	88375	48645	30314	51558	505721
2015	68704	54270	180054	81809	55495	40545	53534	534411
2016	52785	36346	236103	93627	82988	30504	41014	573368
2017	47422	42871	365425	109659	107386	37147	45867	755776
2018	37259	39019	226057	107446	54223	29347	38068	531420
2019	39106	49283	194143	92025	63139	36108	58324	532128
2020	60812	54296	192058	118033	68288	31016	48620	573122
2021	51834	51625	247947	98230	76210	28691	44492	599029

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	6,0	6,5	2,0	10,0	0,5	11,6	4,2	4,5
Direct	**BOB**	**BOS**	**BAP**	**GUF**	**GUR**	**DS**	**KAT**	**BAS**
1995	156	353	1463	2707	314	902	267	6162
1996	128	373	755	2738	253	606	192	5046
1997	127	294	691	2534	255	452	191	4544
1998	126	318	735	2542	253	363	204	4541
1999	117	318	596	2705	254	340	181	4511
2000	109	334	529	2631	197	322	176	4297
2001	102	302	341	2630	230	281	153	4038
2002	100	272	387	2800	208	323	146	4238
2003	87	287	416	2920	163	248	117	4238
2004	87	308	961	3117	175	258	123	5029
2005	93	292	413	2881	203	246	123	4251
2006	103	301	498	2340	184	245	136	3807
2007	104	281	529	2163	179	292	137	3686
2008	102	266	472	1289	157	320	120	2726
2009	94	230	398	2801	59	404	97	4082
2010	91	222	416	1650	46	278	98	2801
2011	91	214	416	2354	38	312	116	3541
2012	112	231	418	353	76	369	88	1647
2013	119	229	404	347	55	339	91	1584
2014	138	215	409	356	61	297	93	1569
2015	107	215	400	447	64	292	105	1629
2016	103	200	385	430	46	246	100	1511
2017	100	182	197	471	42	244	99	1335
2018	94	175	178	203	36	216	99	1001
2019	93	172	199	307	38	268	113	1190
2020	93	161	180	264	33	198	97	1027
2021	97	161	195	376	33	211	103	1176

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							
Riverine	**BOB**	**BOS**	**BAP**	**GUF**	**GUR**	**DS**	**KAT**	**BAS**
1995	2647	2403	18427	7246	2911	1301	1537	36471
1996	1711	1593	17804	4595	2000	708	795	29205
1997	2847	2062	20261	4438	1950	767	992	33317
1998	3307	2476	21770	5310	3693	1411	1674	39641
1999	2283	2601	20520	5064	3564	1302	1897	37231
2000	3366	3080	16331	5905	2732	938	1733	34085
2001	2456	2443	18121	4790	3398	923	1609	33739
2002	1704	1355	17715	6598	1549	1442	1488	31851
2003	1501	1087	11551	4612	1835	641	932	22160
2004	2440	1682	14256	7316	2518	926	1366	30504
2005	2492	1933	12202	8461	2458	769	1259	29573
2006	2038	2175	13295	4257	1765	857	1744	26133
2007	2166	1643	14190	3122	2505	1230	1581	26436
2008	2650	2587	11740	5352	2560	953	1473	27315
2009	1718	1504	13386	8368	2495	689	1049	29207
2010	2562	1615	18972	4512	2735	926	1296	32617
2011	2431	2179	15541	4441	2003	1154	1370	29119
2012	3468	2469	10355	4064	2946	933	1446	25680
2013	2134	1763	14374	3554	2356	822	1023	26026
2014	1914	1415	13802	3488	1387	814	1399	24219
2015	3035	2009	8067	2691	1308	1047	1442	19599
2016	2605	1241	9273	3397	2152	823	1076	20568
2017	2208	1618	12492	4201	3038	1007	1252	25815
2018	1863	1373	10126	4241	1754	701	978	21036
2019	1809	1747	7723	3112	1453	715	1443	18002
2020	2882	2241	8029	4245	1635	750	1514	21295
2021	2297	1712	9238	4287	1409	700	1073	20717

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	2803	2756	19889	9952	3225	2204	1804	42633
1996	1839	1965	18559	7332	2253	1314	987	34251
1997	2973	2356	20953	6971	2205	1219	1183	37861
1998	3433	2794	22505	7852	3946	1774	1878	44183
1999	2400	2919	21116	7769	3818	1643	2077	41742
2000	3475	3414	16860	8535	2929	1260	1908	38382
2001	2558	2745	18462	7421	3628	1203	1761	37777
2002	1804	1627	18102	9399	1757	1765	1634	36089
2003	1588	1374	11967	7532	1998	889	1050	26398
2004	2527	1990	15216	10433	2693	1184	1489	35534
2005	2585	2225	12615	11342	2661	1014	1381	33824
2006	2141	2476	13793	6597	1950	1102	1880	29940
2007	2269	1923	14719	5285	2684	1522	1718	30122
2008	2752	2853	12212	6641	2717	1272	1593	30041
2009	1812	1734	13784	11169	2554	1092	1145	33289
2010	2653	1837	19388	6162	2781	1204	1394	35418
2011	2522	2393	15957	6796	2041	1466	1486	32661
2012	3580	2700	10773	4417	3022	1302	1534	27327
2013	2252	1993	14778	3901	2411	1161	1114	27610
2014	2053	1630	14210	3844	1448	1112	1493	25788
2015	3142	2224	8466	3138	1372	1339	1546	21228
2016	2707	1441	9659	3827	2199	1070	1176	22078
2017	2308	1800	12689	4671	3080	1251	1351	27149
2018	1957	1549	10304	4445	1789	917	1077	22037
2019	1901	1919	7923	3419	1491	984	1555	19192
2020	2975	2402	8209	4509	1668	948	1612	22322
2021	2394	1873	9433	4663	1442	911	1176	21892

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, 2022a and 2022b).

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, 2023) 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., 2022).

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 – 2021.

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).

[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.

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 obtained from a stage-discharge relationship and daily concentration by linear interpolation between days with chemical sampling (HELCOM, 2022b). For some rivers monthly average concentrations 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 EG 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 1995-2021 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, and Finland in 2022 rereported all data from 1995-2019 (se Key message on the importance of updated Finish data).

Weakness: Data from some parts of the Baltic Sea catchment and some of the direct inputs in the beginning of the time series (1995-2020) 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.