Waterborne nitrogen and phosphorus inputs and water flow to the Baltic Sea 1995-2022

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Key Message

Annual water flow in 2022 to the Baltic Sea was approximately 14,400 m^3 s^{-1} which is 7.6% higher than the average of 1995-2021. This this covers markedly lower flow than average to four, and close to average for the remaining three basins. Annual waterborne input (inputs via rivers and direct point sources discharging directly into the sea) of total nitrogen (TN) was approximately 563,000 tonnes in 2022 or about 9% lower than the average of 2012-2021. Compared with 2021 the flow in 2022 was 1,300 m^3 s^{-1} (8.3% lower) and the waterborne TN inputs was 35,700 tonnes (or 6.0%) lower. The annual waterborne total phosphorus inputs (TP) in 2022 amounted to approximately 17,500 tonnes, which is about 21% lower than the average of 2012-2021, and about 4,400 tonnes (or 20%) lower than in 2021.

Inputs of nitrogen and phosphorus from direct point sources have decreased with approximately 58% and 84% since 1995, respectively. In 2022, inputs from direct point sources constituted 4.5% TN and 5.8% TP of the corresponding total waterborne input to the Baltic Sea. In 1995, the proportions of the direct inputs were 7.8% for TN and 15% for TP, respectively.

Annual flow weighted riverine TN concentration decreased significantly (95% confidence) to the Bothnian Bay, 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, 15% and 48% respectively.

Annual precipitation in 2022 was lower than normal (1991-2020) in most of the Baltic Sea catchment areas in Denmark, Estonia, Germany, Poland, Latvia, Lithuania, Southern half of Sweden, while Finland, northern half of Sweden and Russia where close to average and some part a little higher than normal. Particularly big part of Poland and Lithuania and part of Latvia had precipitation up to 20-30 % below average.

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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 1995-2022. 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 2023a 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 1995-2021) (Svendsen et al, 2024), 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 76% of TN and about 92% of TP inputs in 2021 (Svendsen et al, 2024).

Time series with information on annual nutrient inputs is needed following 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 1995-2022 are included include in tables 2-8 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 (Gauss, 2023a).

In connection with reporting 2022 data Finland have reported some missing direct point source data during 1995-2021. Estonia made some adjustments in riverine inputs, and Russia made minor adjustments of the waterborne inputs to Gulf of Finland for 2021, but these updates don't make any significant changes in the dataset for the seven basins.

Estonia estimated inputs from Narva River based on measurements from only up to the middle course of the river that are recalculated for the entire river.

Weather in 2022 in the Baltic Sea catchment

Particularly precipitation and temperature have an impact on the amount and distribution of flow to the Baltic Sea from different part of the catchment, and thereby on inputs of nitrogen and phosphorus. Overall rainfall over the average will result in higher-than-average flow and higher inputs of riverine total nitrogen and total phosphorus than with low rainfall and flow. High accumulation of snow on the surface combined with high temperature and snowfall can result in high flow og nutrient loads in rivers - and surface erosion. When soils in autumn and winter are saturated precipitation will tend to end very quickly in surface waters, will rain can be absorb in dry soils during spring and summer. The type, intensity, amount and distribution of precipitation during the year is therefore of key importance for flow and input of nutrient to the Baltic Sea.

Map on 2022 precipitation in Europe deviation from the reference period 1991-2020 are provided in the annex figures A.1-A.4 and are taken from Copernicus Climate Change web-site – see the annex. Annual precipitation in 2022 was lower than normal (1991-2020) in most of the Baltic Sea catchment areas in Denmark, Estonia, Germany, Poland, Latvia, Lithuania, Southern half of Sweden, while Finland, northern half of Sweden and Russia where close to average and some part a little higher than normal, while catchment to Archipelago was lower than average. Particularly big part of Poland and Lithuania and part of Latvia had precipitation up to 20-30 % below average.

Winter (December 2021-February 2022) was 5-20 % wetter than average in the southern and eastern part of Baltic Sea catchment areas and about or a 5-20 % drier than average in the northern og northwestern part of the catchment. Spring was overall 10-30 % drier besides norther part of Sweden og Finland where it was close to normal. Summer 2022 precipitation was close to normal or are little bit higher than average in norther half of Sweden and Finland, in the norther part of the Baltic Sea catchment area, Estonia and Latvia, while the remaining part of the catchment had lower than average precipitation particularly Poland and Germany with up to 20-40% lower precipitation. Autumn was overall at little bit (0-5 %) or drier (5-20%) in most of the catchment to the Baltic Sea.

Denmark had record hight precipitation in February (as rain), but with most of the remaining months in 2022 being with lower than average precipitation

In Estonia had a very early break of frost in February resulting in replacing usual spring flood by couple of smaller peaks. Summer low flow lasted almost to the end of December while it usually lasts until late September/early October.

For Finland to Archipelago the flow peaked in winter times with frozen soil leading to modest nutrient concentrations (and low nutrient inputs).

Germany had very low precipitation during summer, while February and September had higher than average precipitation and 15 % lower precipitation in 2022 compared with reference period 1991-2020. There was a mass mortality of fish in the lower Oder River (Germany and Poland) in August 2022 due to a harmful algal bloom (HAB) of *Prymnesium parvum* linked to the very dry and warm summer conditions and mining activities that have caused a significant increase in salinity concentrations in the river.

In Lithuania catchment some part received over average precipitation and other areas under the average precipitation, resulting in over average annual flow for some rivers and under for some others.

In Poland precipitation was very low in 2022 besides during January-February 2022.

Results

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 Svendsen et al. (2022, 2023 and 2024), 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 1a (nitrogen) and b (phosphorus) 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 2022. Flows are compared with the long-term average (1995-2021), 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 (2012-21). Table 1a and b 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}). Table 1 c provides the deviation in flow, waterborne TN and TP and flow-weighted riverine concentration of TN and TP in 2022 from average in percentages. Flow to the Baltic Sea in 2022 was about 14,400 m^3 s^{-1} or 7.6% lower than the 1995-2021 average. The flow was 30% lower than average to Kattegat and between 11 and 19 % lower to Gulf of Riga, Danish Straits and Baltic Proper. Flow to Bothnian Bay, Bothnian Sea and Gulf of Finland in 2022 was within ± 3% from the 1995-2021 average. Flow from Poland was the 3rd lowest during 1995-2022. The flow is closely related to the precipitation which was low to very low in 2022 compared with the reference period 1991-2020 for the western, southern and southeastern part of the Baltic Sea catchment, and close to or some few percentages over the reference period in the northern part.

Waterborne TN inputs in 2022 were 563,000 tons or 9% lower than average of TN inputs during 2012-2021. The corresponding TP inputs were 17,500 tons or 33% lower than average of 2012-2021. Compared with 2021 the flow in 2022 was more than 1,300 m^3 s^{-1} lower (8.3%), while TN waterborne inputs was 35,700 tonnes lower (6.0%), and TP waterborne inputs was 4,400 tonnes lower (20%). Flow in average 8.0% lower than long term average, and to some basins more than 15% lower, should imply waterborne inputs lower than average if there is no trend in inputs and if weather conditions during the year and in the former year have not been too extreme. The average flow conditions are an average for the Baltic Sea, covering very lower flow than average to Kattegat (30%), Baltic Proper (19%), Danish Straits (14%), and Gulf of Riga (11%) up to 2.4% higher flow than average to Bothnian Bay (table 1.c). The four basins with very low flow in 2022 constituted 68% of total nitrogen inputs during 2012-2021 and 66% of the total phosphorus, but in 2022 the corresponding percentage was 65% and 59%, respectively. Lithuania reported that the rather inputs of nitrogen in 2022 partly are explained by very low flow in 2020 and 2021, as the flow in 2022 was 37% and 27% higher, respectively.

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, 2024). The pattern is however complex since both interannual flow variations and long-term trends in nutrient inputs varies across sub-basins. TN inputs in 2022 were 11% (Gulf of Finland), 6.0% (Gulf of Riga), respectively, higher than average (2012-2021) even with lower flow than the average (table 1.c). The remaining five basins had in 2021 waterborne inputs lower than average: Kattegat (28%), Danish Straits (22%), Bothnian Sea (16%), Baltic Proper (15%) and Bothnian Bay (6.9), respectively, but flow in 2022 was 19% lower than average to Baltic Proper (table 1c). Waterborne TP inputs in 2022 were lower than average (2012-2021) to all basins: Gulf of Riga (42%), Baltic Proper (41%), Kattegat (35%), Danish Straits (26%), Bothnian

Sea (25%), Bothnian Bay (18%) and Gulf of Finland (18%) (table 1.c). For both waterborne TN and TP the overall trend described until 2021 seems to continue in 2022.

Annual flow-weighted riverine concentration (calculated by dividing annual riverine nutrient input with the corresponding water flow[3]) in 2022 to the Baltic Sea was 1.19 mg N l^{-1} or 0,05 mg N l^{-1} (3.7%) higher than the corresponding concentration during 2012-2021. For TP it was 0.036 mg P l^{-1} or 21% lower than the corresponding average of 2012-2021. Flow-weighted TN concentrations were lower than average for only three basins, Bothnian Sea (14%), Danish Straits (7.2%) and Bothnian Bay (5.3%), and higher to three basins: Gulf of Finland (19%), Gulf of Riga (14%), and Baltic Proper (6.2%) (table 1.c). For Kattegat the concentrations in 2022 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 considered that flow was rather much lower than average to e.g. Baltic Proper and Gulf of Riga. It is remarkable that flow in 2022 was 30% lower than average to Kattegat, but the flow-weighted concentration of TN in 2022 nearly as the corresponding average, but flow and nutrient input to Kattegat is to a high degree impacted by inputs from Göta Älv. The catchment to Göta Älv includes some very big lakes, and flow and loads are regulated by dams and channels – see after figure 3c..

Flow-weighted TP was lower than for all: Gulf of Riga (35%), Baltic Proper (24%), Bothnian Sea (22%), Bothnian Bay (13%), Kattegat (11%), Danish Straits (8.3%), and Gulf of Finland (3.8%) (table 1.c).

On page 3 is information on the overall weather conditions on other events to take into account evaluating the flow, waterborne TN and TN in 2022 to the Baltic Sea and the distribution between basins.

Area specific waterborne catchment nutrient inputs in 2022 were highest to the Danish Straits (998 kg N km^{-2}, 32 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 175 kg N km^{-2} and 7.1 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. 320 kg N km^{-2} and 10 kg P km^{-2}. On the other hand, specific waterborne inputs per sea area are highest to the Gulf of Riga (4,200 kg N km^{-2}) and Gulf of Finland (122 kg P km^{-2}) but lowest to the Bothnian Sea (506 kg N km^{-2}, 18 kg P km^{-2}). Average for the Baltic Sea is approx. 1,350 kg N km^{-2} and 42 kg P km^{-2}).

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[3] In accordance with the HELCOM PLC-water Guideline (HELCOM, 2022), nutrient input data is reported as annual loads for individual rivers. Calculation of annual mean flow-weighted concentrations for the Baltic Sea sub-basins is a simple method to illustrate changes in waterborne nutrient loads smoothening inter annual variation. These back-calculated annual nutrient concentrations differ from originally measured values (e.g. 12 monitored values per year) and should not be mixed up with these.

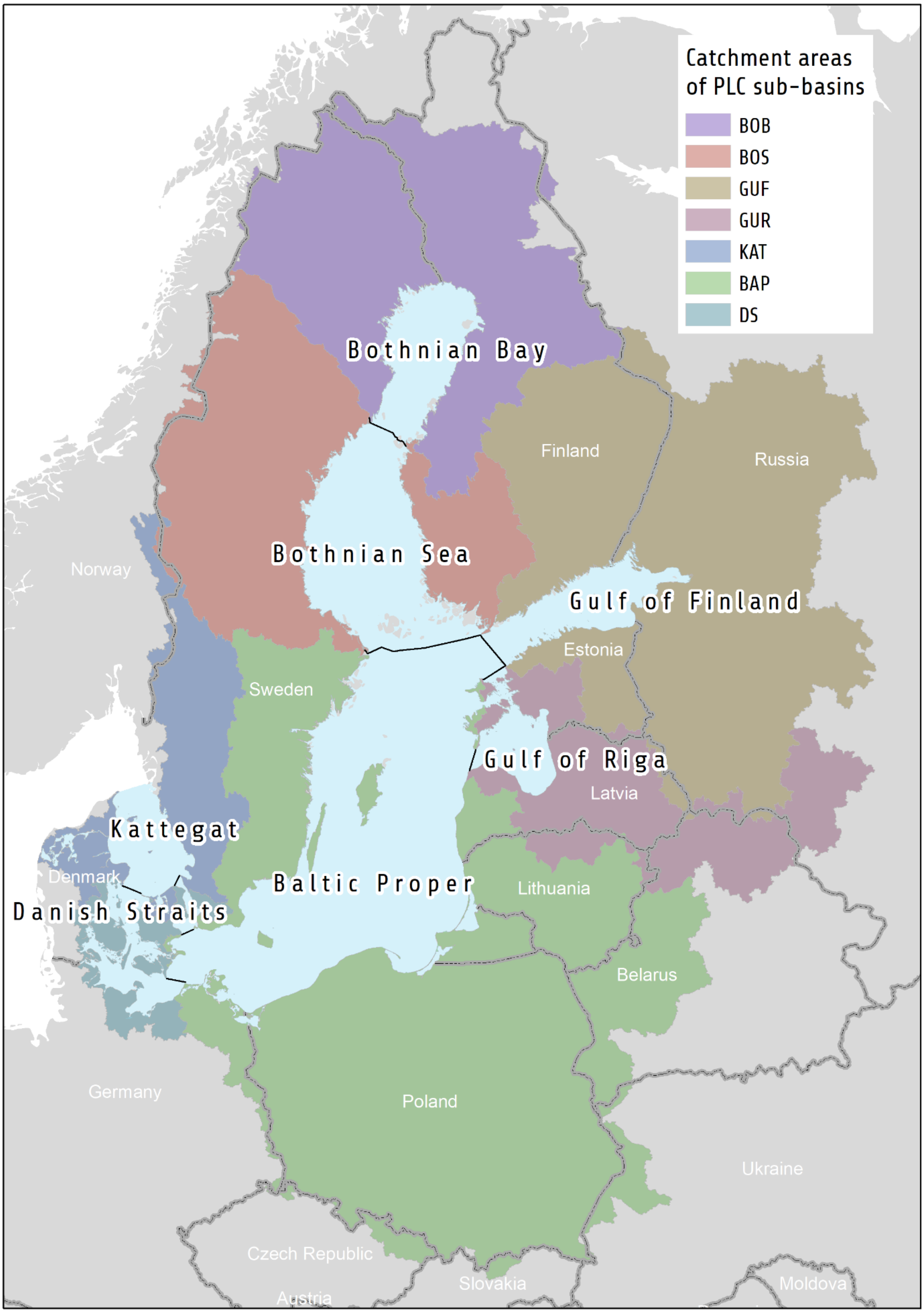


Figure 1. The catchment of the Baltic Sea is shared by nine HELCOM Contracting Parties - Denmark (DK), Estonia (EE), Finland (FI), Germany (DE), Latvia (LV), Lithuania (LT), Poland (PL), Russia (RU) and Sweden (SE) and 5 transboundary countries (Belarus, Czech Republic, Slovakia, Norway and Ukraine). 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.a 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) (tonnes) in 2022 and on average of 1995-2021 for flow and 2012-2021 for TN. Flow weighted TN concentrations (mg l^{-1}) of annual riverine inputs in 2022 and on average of 2012-2021. Further, waterborne inputs of TN are given as specific inputs per km^2 catchment area and per sea area (kg N km^{-2}), respectively. For an explanation of abbreviations, see the caption to figure 1.

	Catchment area km^{-2}	**Sub-basin sea area km^{-2}**	**Flow 2022 m^3 s^{-1}**	**Flow 1995-2021 m^3 s^{-1}**	**Flow 2022 l s^{-1}km^{-2}**	**Flow 1995-2021 l s^{-1}km^{-2}**	**TN water-borne 2022 tonnes**	**TN water-borne 2012-2021 tonnes**	**TN flow-weight. river conc. 2022 mg l^{-1}**	**TN flow-weight. river conc. 2012-2021 mg l^{-1}**	**TN water-borne/ catch.area 2022 kg km^{-2}**	**TN water-borne / sea area 2022 kg km^{-2}**
BOB	263,000	36,000	3,529	3,445	13.4	13.1	46,374	49,822	0.39	0.41	176	1,288
BOS	228,000	79,000	2,799	2,896	12.3	12.7	39,941	47,464	0.41	0.48	175	506
BAP	576,000	209,000	2,738	3,390	4.8	5.9	224,605	263,226	2.56	2.41	390	1,075
GUF	423,000	30,000	3,472	3,537	8.2	8.4	111,045	100,365	0.93	0.78	263	3,701
GUR	138,000	19,000	939	1,049	6.8	7.6	80,061	75,561	2.69	2.36	580	4,214
DS	27,000	21,000	184	215	6.8	8.0	26,944	34,644	4.41	4.75	998	1,283
KAT	87,000	24,000	755	1,075	8.7	12.4	34,372	47,823	1.39	1.38	395	1,432
BAS	**1,742,000**	**418,000**	**14,416**	**15,606**	**8.3**	**9.0**	**563,341**	**618,906**	**1.19**	**1.14**	**323**	**1,348**

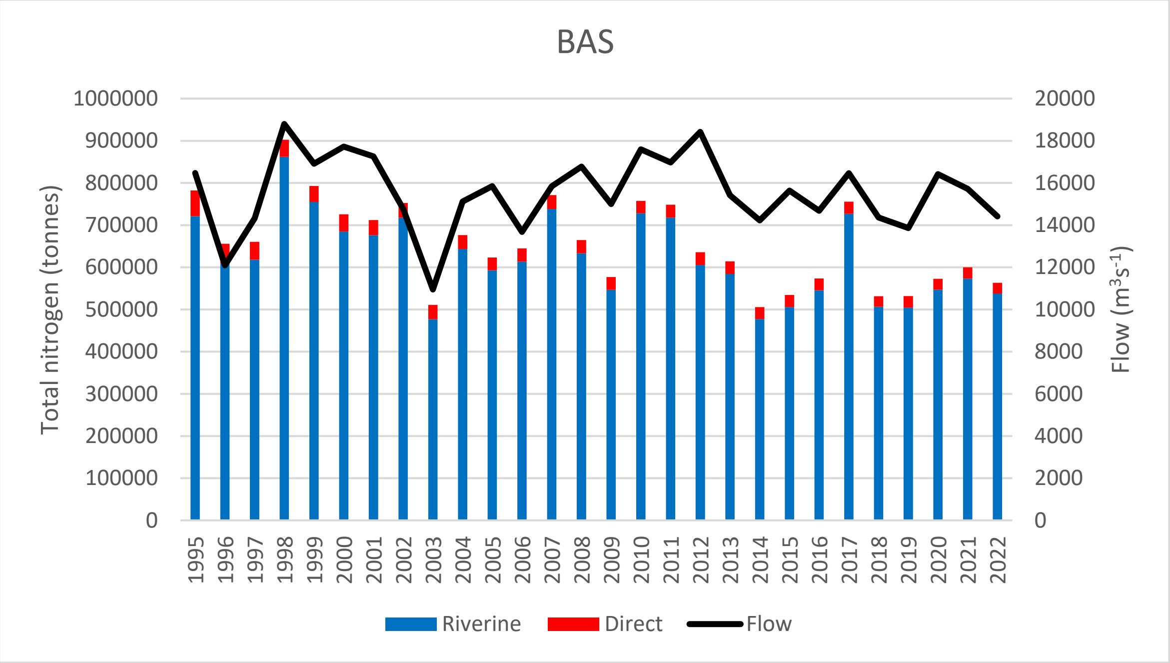
Table 1.b Catchment area to and sea area of the seven sub-basins of the Baltic Sea (km^2). Annual waterborne flow (m^3 s^{-1}), area specific flow (l s^{-1} km^{-2}), waterborne total phosphorus inputs TP (tonnes) in 2022 and on average of 1995-2021 for flow and 2012-2021 for TP. Flow weighted TP concentrations (mg l^{-1}) of annual riverine inputs in 2022 and on average of 2012-2021. Further, waterborne inputs of TP are given as specific inputs per km^2 catchment area and per sea area (kg P km^{-2}), respectively. For an explanation of abbreviations, see the caption to figure 1.

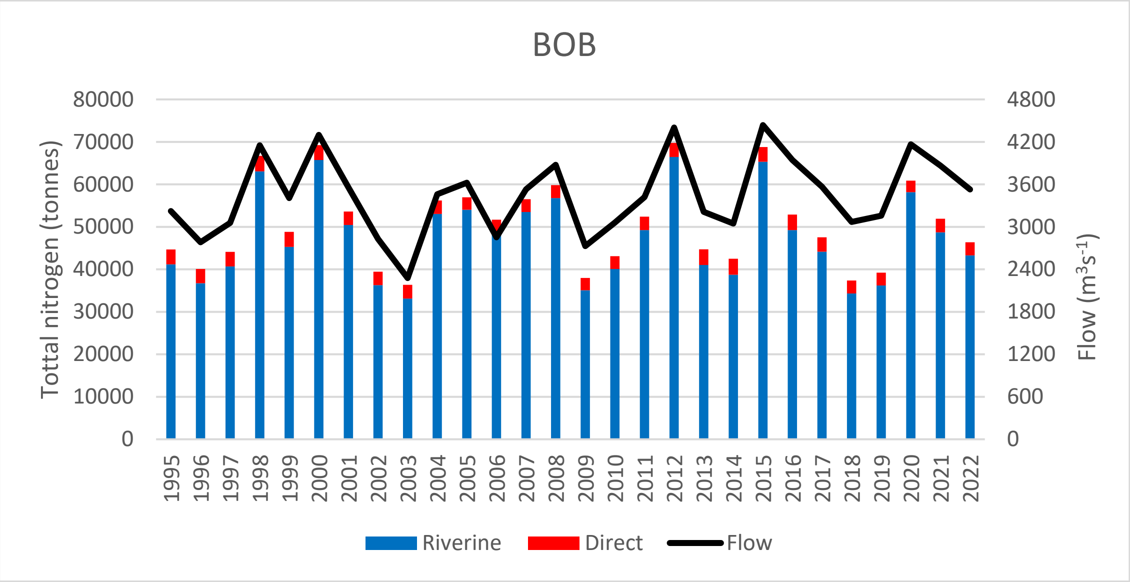
	Catchment area km^{-2}	Sub-basin sea area km^{-2}	Flow 2022 m^3 s^{-1}	Flow 1995-2021 m^3 s^{-1}	Flow 2022 l s^{-1}km^{-2}	Flow 1995-2021 l s^{-1}km^{-2}	TP water-borne 2022 tonnes	TP water-borne 2012-2021 tonnes	TP flow-weight. river conc. 2022 mg l^{-1}	TP flow-weight. river conc. 2012-2021 mg l^{-1}	TP water-borne/ catch.area 2022 kg km^{-2}	TP water-borne / sea area 2022 kg km^{-2}
BOB	263,000	36,000	3529	3,445	13.4	13.1	2,068	2,509	0.018	0.021	7.9	57
BOS	228,000	79,000	2,799	2,896	12.3	12.7	1,458	1,949	0.015	0.019	6.4	18
BAP	576,000	209,000	2,738	3,390	4.8	5.9	7,321	12,413	0.083	0.109	13	35
GUF	423,000	30,000	3,472	3,537	8.2	8.4	3,665	4,462	0.031	0.032	8.7	122
GUR	138,000	19,000	939	1,049	6.8	7.6	1,261	2,163	0.041	0.064	9.1	66
DS	27,000	21,000	184	215	6.8	8.0	870	1,180	0.122	0.134	32	41
KAT	87,000	24,000	755	1,075	8.7	12.4	890	1,372	0.034	0.038	10	37
BAS	**1,742,000**	**418,000**	**14,416**	**15,606**	**8.3**	**9.0**	**17,533**	**26,048**	**0.036**	**0.046**	**10**	**42**

Table 1.c Deviation in 2022 in percentages from average flow during 1995-2021, and for TN and TP flow weighted riverine concentration and total TN and TP waterborne input in 2022 from corresponding averages during 2012-2021.

	Flow **Deviation %** **From 1995-2021**	**TN flowconc.** **Deviation %** **From 2012-2021**	**Total N** **Deviation %** **From 2012-2021**	**TP flowconc.** **Deviation %** **From 2012-2021**	**Total P** **Deviation %** **From 2012-2021**
BOB	2.4	-5.3	-6.9	-13.1	-17.6
BOS	-3.3	-13.7	-15.9	-22.2	-25.2
BAP	-19.2	6.2	-14.7	-24.1	-41.0
GUF	-1.8	19.3	10.6	-3.8	-17.9
GUR	-10.5	13.8	6.0	-35.0	-41.7
DS	-14.4	-7.2	-22.2	-8.3	-26.3
KAT	-29.8	1.0	-28.1	-10.6	-35.1
BAS	**-7.6**	**3.7**	**-9.0**	-20.5	-32.7

The annual water flow, direct inputs of TN and TP and riverine TN and TP inputs during 1995-2022 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 (58%). Significant reduction of direct TN inputs is seen to all basins except to Bothnian Bay, to which the reduction is not statistic significant. The highest reduction in direct TN inputs is seen to Danish Straits (76%), Baltic Proper (71%) and to Gulf of Riga (668). There are significant reductions of direct TP inputs to all basins, the highest Gulf of Finland (89%), Gulf of Riga (88%), Baltic proper (87%), and resulting in a total reduction of 84% 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 2022 in TN and TP from direct point sources since 1995 was some few percentages higher for nearly all basins compared with status by 2021. Direct inputs to the Baltic Sea in 2022 constitute only a minor share of the waterborne TN and TP waterborne inputs (4.5 and 5.8%, respectively), but they provide large proportions of the nutrient inputs to some sub-basins e.g., the Danish Straits (11%) and Gulf of Finland (8.3%) for TN, and the Danish Straits (24%) and Bothnian Sea (9.7) for TP, and the importances is highest in years with low flow as 2022.




BOB
Tottal nitrogen (tonnes)
80000
70000
60000
50000
40000
30000
20000
10000
0
Flow (m^3s^{-1})
4800
4200
3600
3000
2400
1800
1200
600
0
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
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2011
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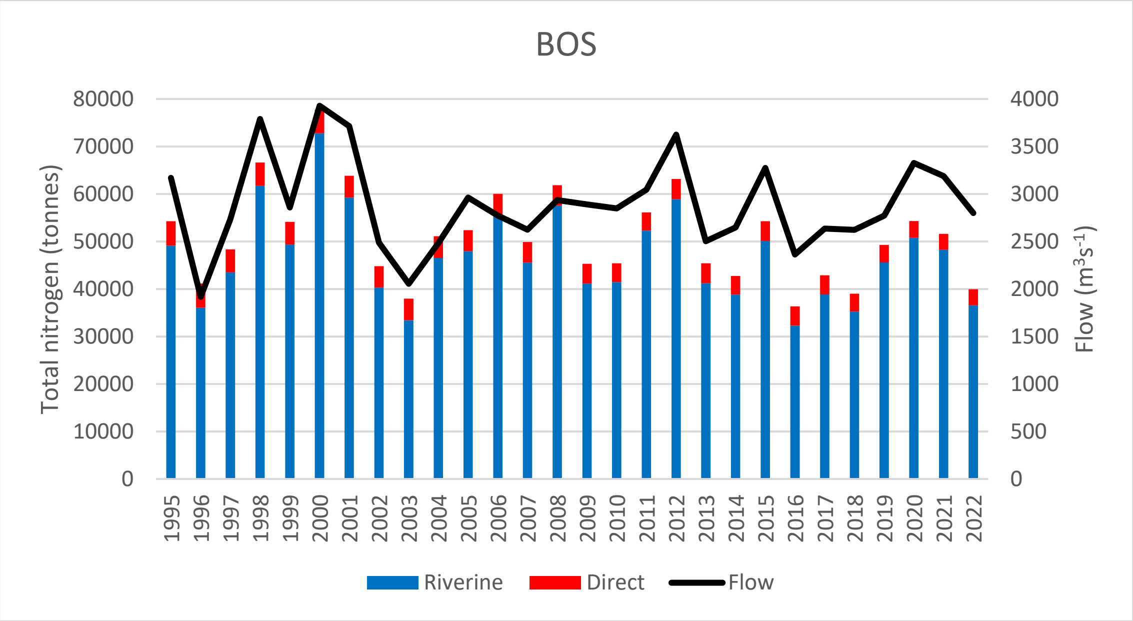
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
Riverine
Direct
Flow


BOS
Total nitrogen (tonnes)
80000
70000
60000
50000
40000
30000
20000
10000
0
Flow (m^3s^{-1})
4000
3500
3000
2500
2000
1500
1000
500
0
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
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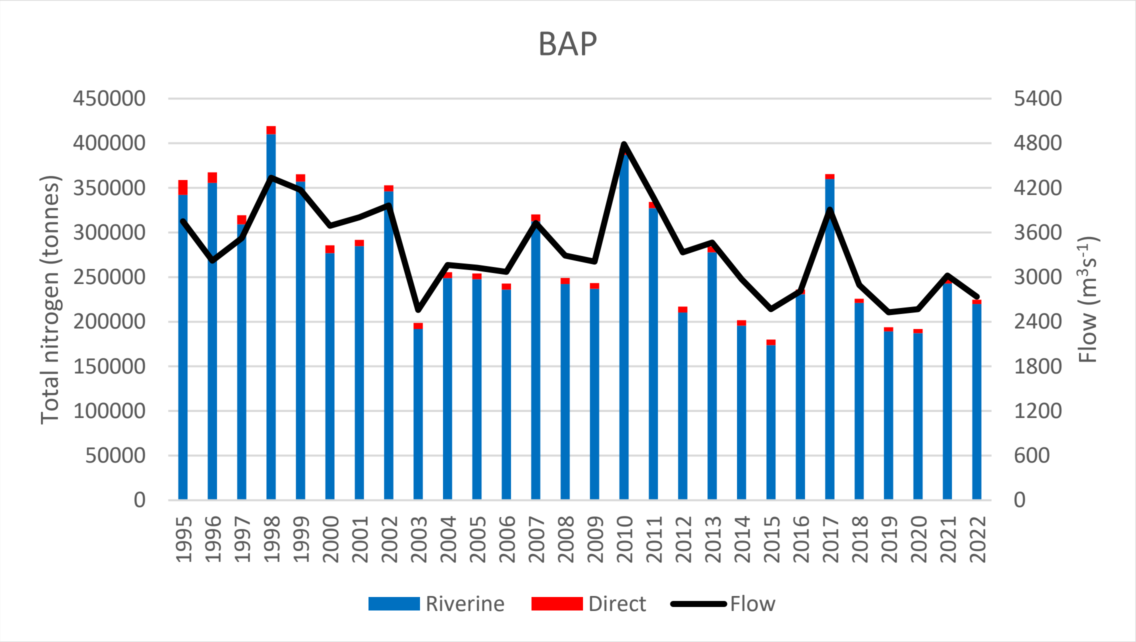
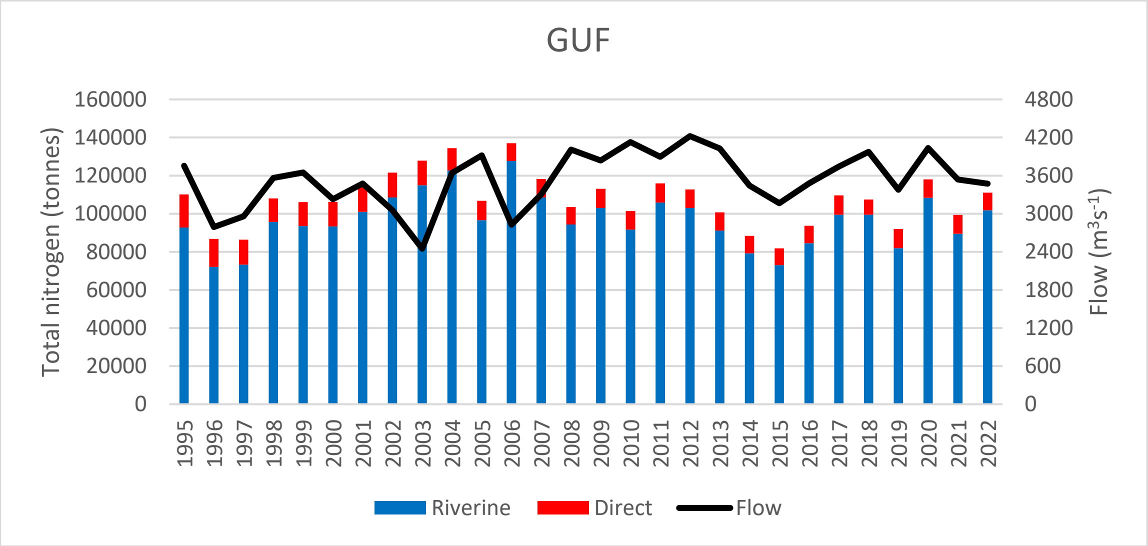
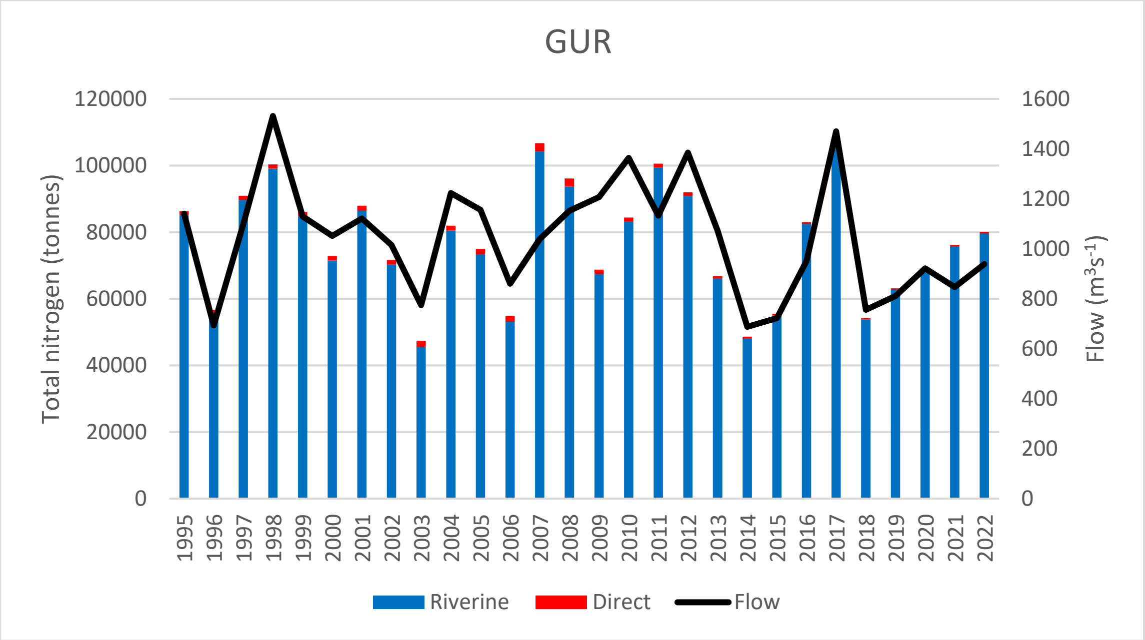
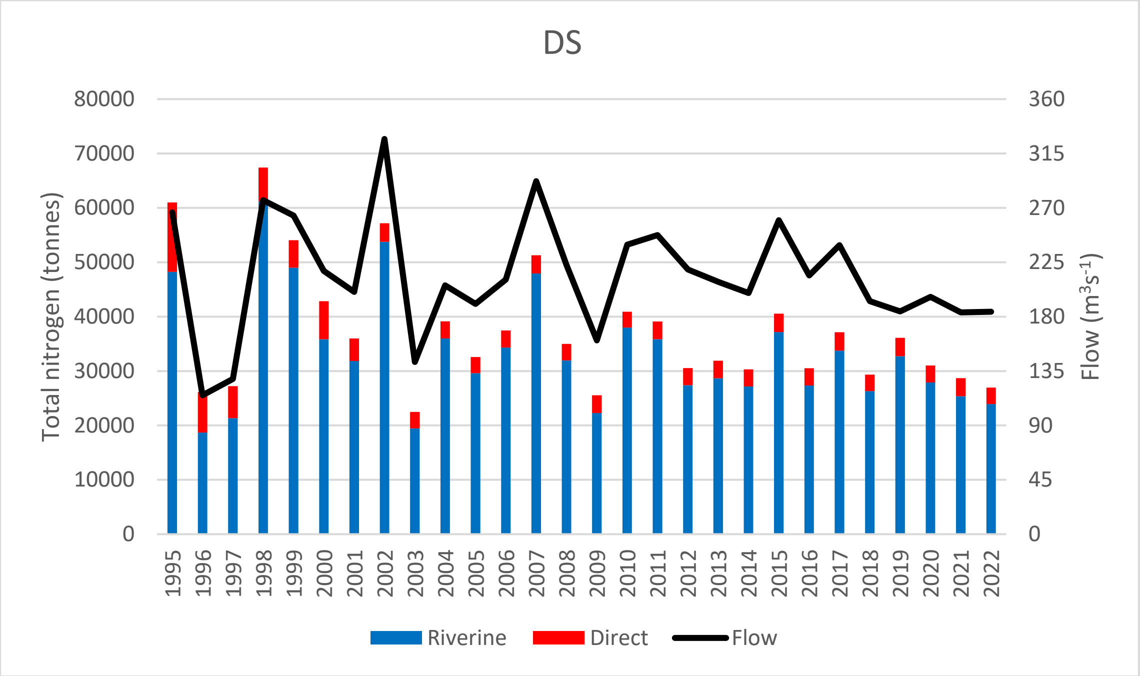
2022
Riverine
Direct
Flow


BAP
Total nitrogen (tonnes)
450000
400000
350000
300000
250000
200000
150000
100000
50000
0
Flow (m^3s^{-1})
5400
4800
4200
3600
3000
2400
1800
1200
600
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
2022
Riverine
Direct
Flow


GUF
Total nitrogen (tonnes)
160000
140000
120000
100000
80000
60000
40000
20000
0
Flow (m^3s^{-1})
4800
4200
3600
3000
2400
1800
1200
600
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 2022
Riverine
Direct
Flow


GUR
Total nitrogen (tonnes)
120000
100000
80000
60000
40000
20000
0
Flow (m^3s^{-1})
1600
1400
1200
1000
800
600
400
200
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 2022
Riverine
Direct
Flow


DS
Total nitrogen (tonnes)
80000
70000
60000
50000
40000
30000
20000
10000
0
Flow (m^3s^{-1})
360
315
270
225
180
135
90
45
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 2022
Riverine
Direct
Flow

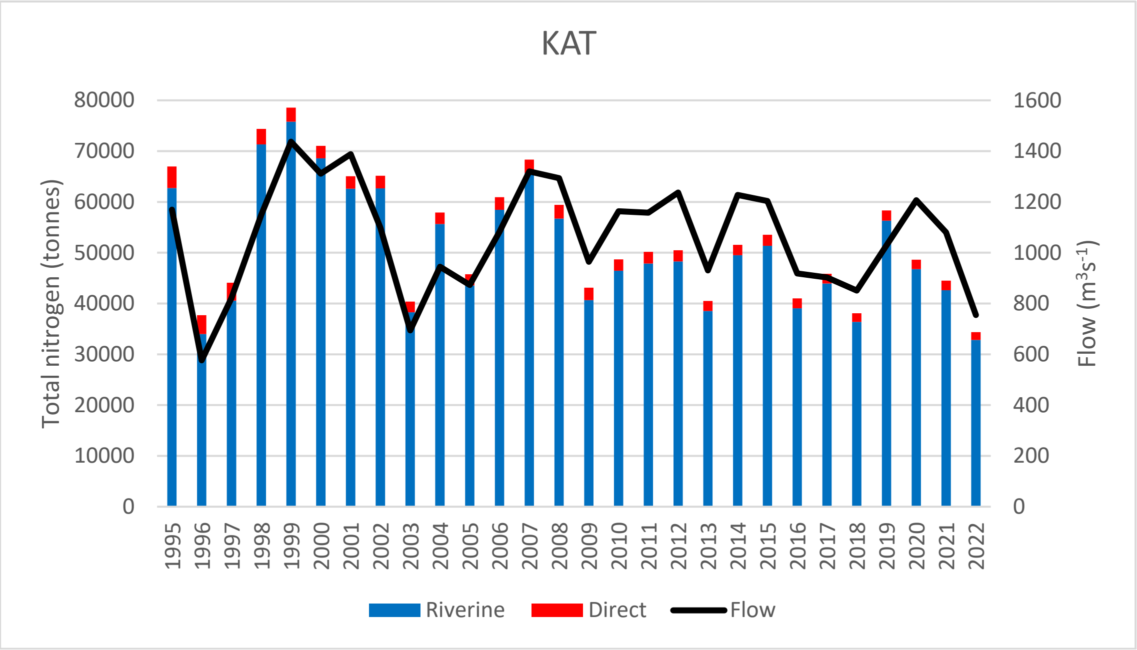
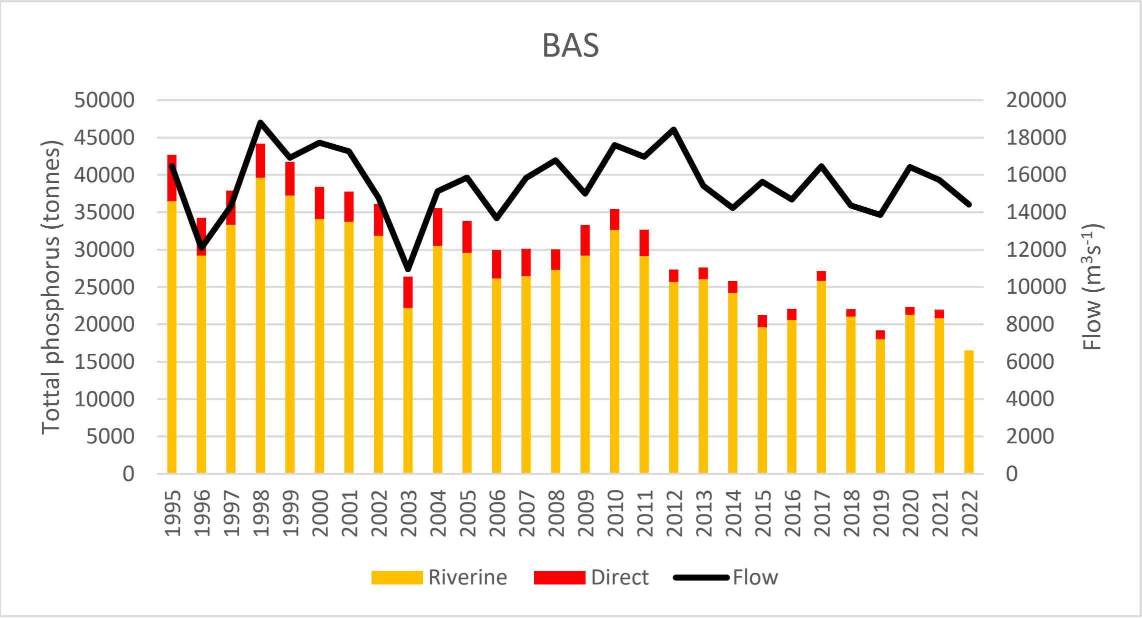
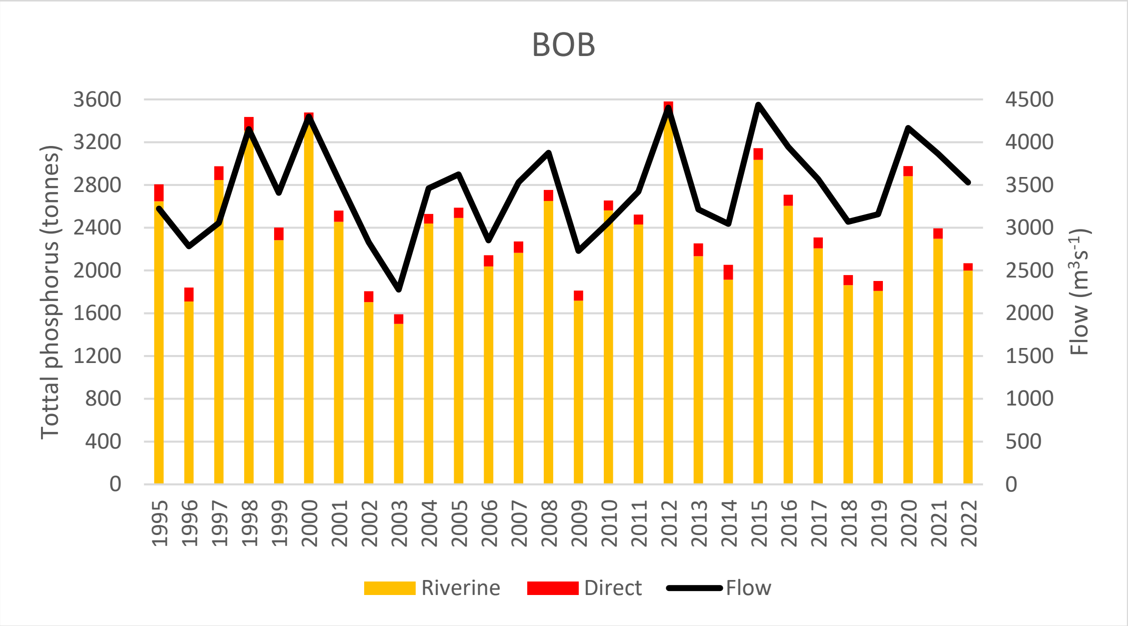
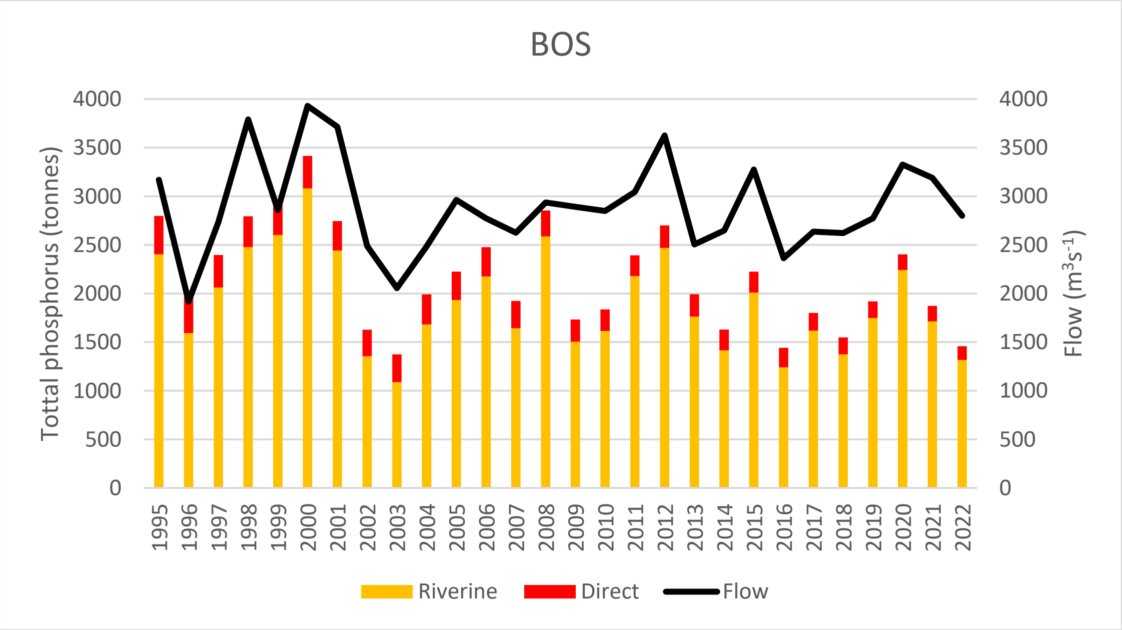
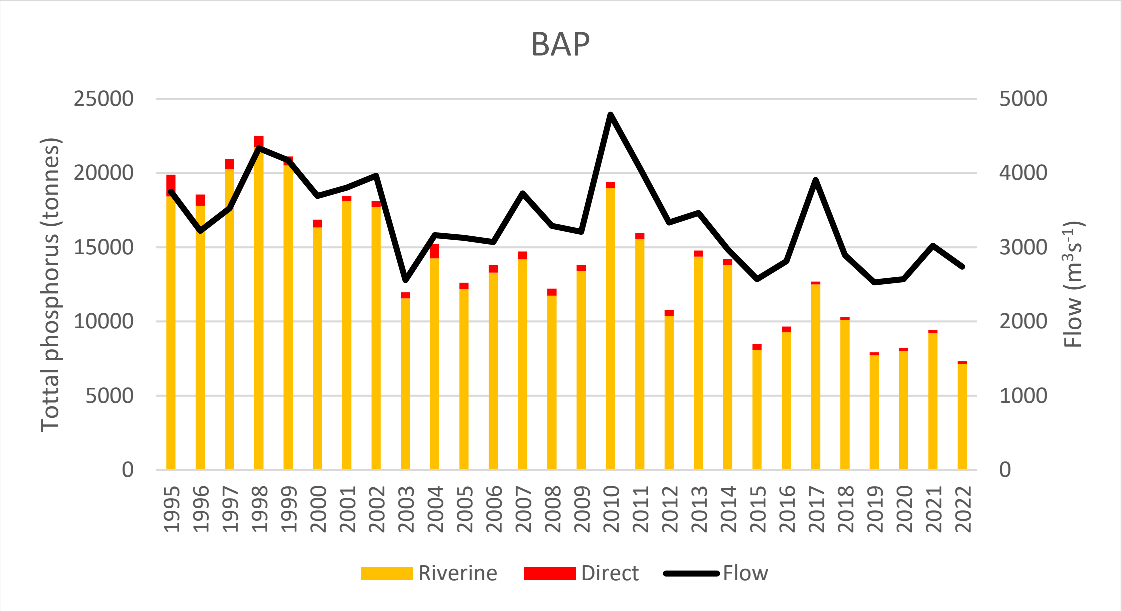


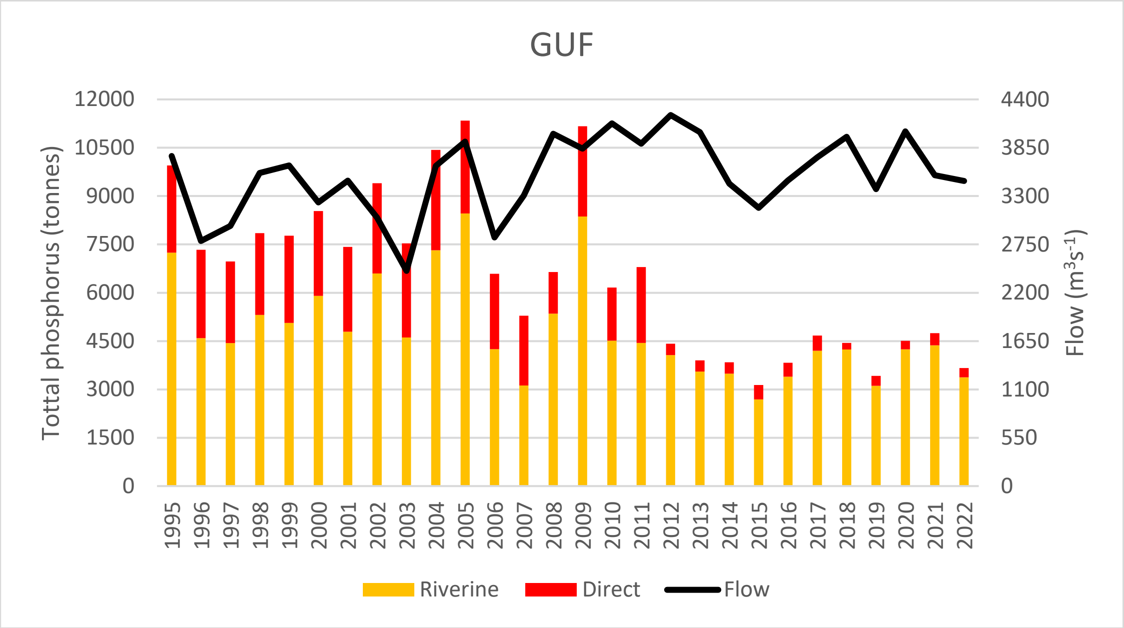
Figure 2A: Annual riverine and direct inputs of total nitrogen in tonnes and annual waterborne flow (m^{-3} s^{-1}) to the seven Baltic Sea sub-basin and to the Baltic Sea in 1995-2022. Data behind the figures are shown in Tables 2-5. For an explanation of the basin abbreviations, see the caption to Figure 1.

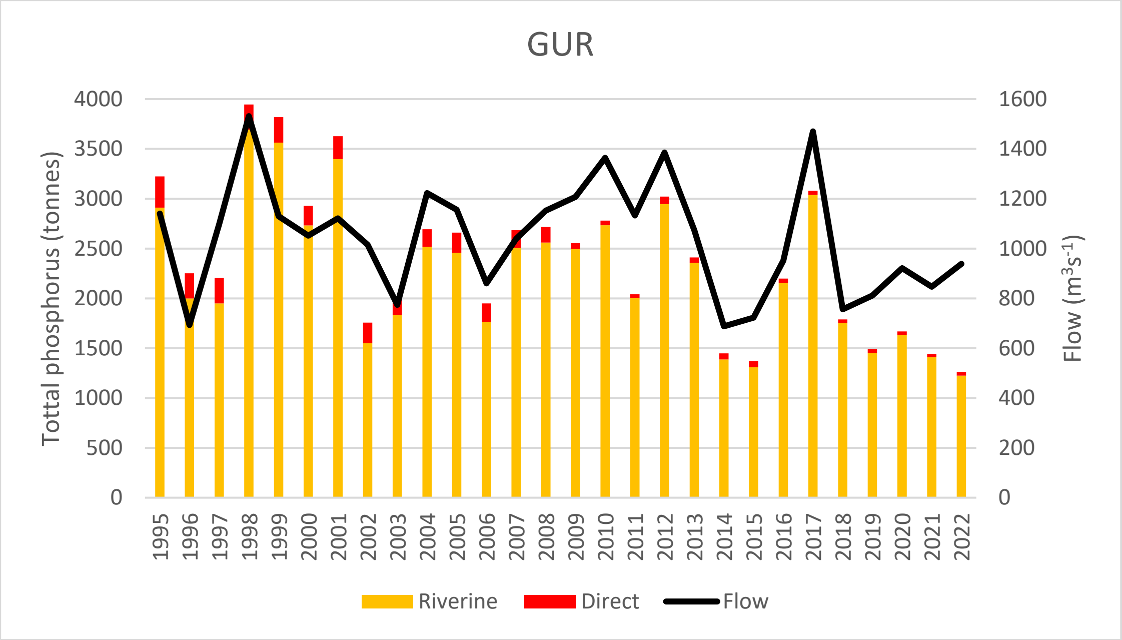


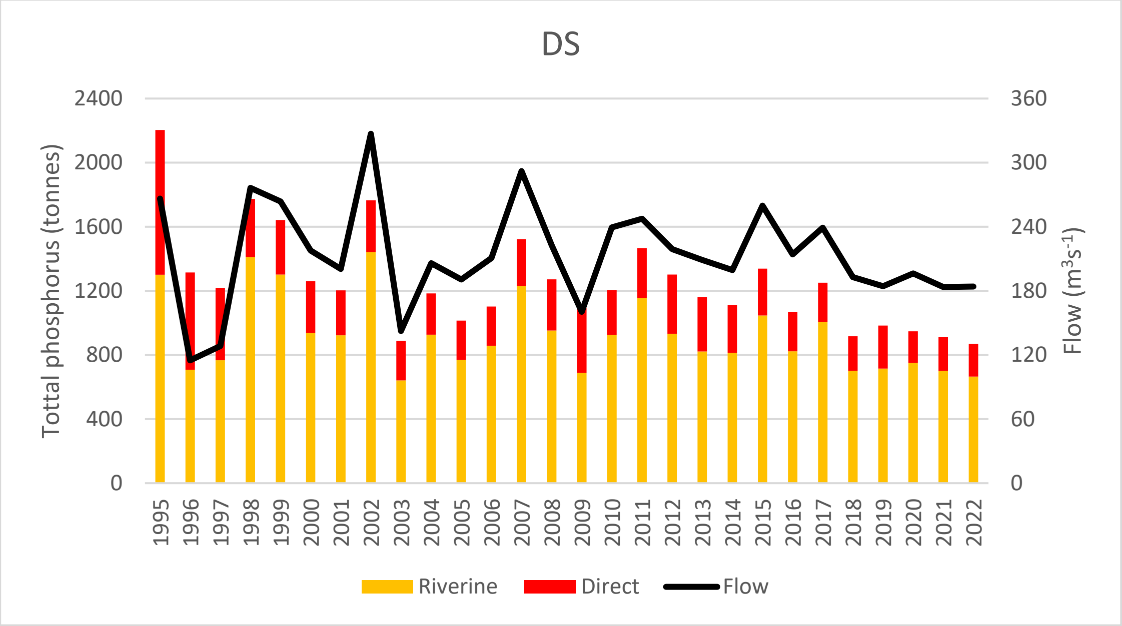

BOB
Tottal phosphorus (tonnes)
3600
3200
2800
2400
2000
1600
1200
800
400
0
Flow (m^3s^{-1})
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022
Riverine
Direct
Flow


BOS
Tottal phosphorus (tonnes)
4000
3500
3000
2500
2000
1500
1000
500
0
Flow (m^3s^{-1})
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 2022
Riverine
Direct
Flow


BAP
Tottal phosphorus (tonnes)
25000
20000
15000
10000
5000
0
Flow (m^3s^{-1})
5000
4000
3000
2000
1000
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 2022
Riverine
Direct
Flow


GUF
Total phosphorus (tonnes)
Flow (m³s⁻¹)
12000
10500
9000
7500
6000
4500
3000
1500
0
4400
3850
3300
2750
2200
1650
1100
550
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 2022
Riverine
Direct
Flow


GUR
Tottal phosphorus (tonnes)
Flow (m³s⁻¹)
4000
3500
3000
2500
2000
1500
1000
500
0
1600
1400
1200
1000
800
600
400
200
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 2022
Riverine
Direct
Flow


DS
Tottal phosphorus (tonnes)
Flow (m³s⁻¹)
2400
2000
1600
1200
800
400
0
360
300
240
180
120
60
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 2022
Riverine
Direct
Flow

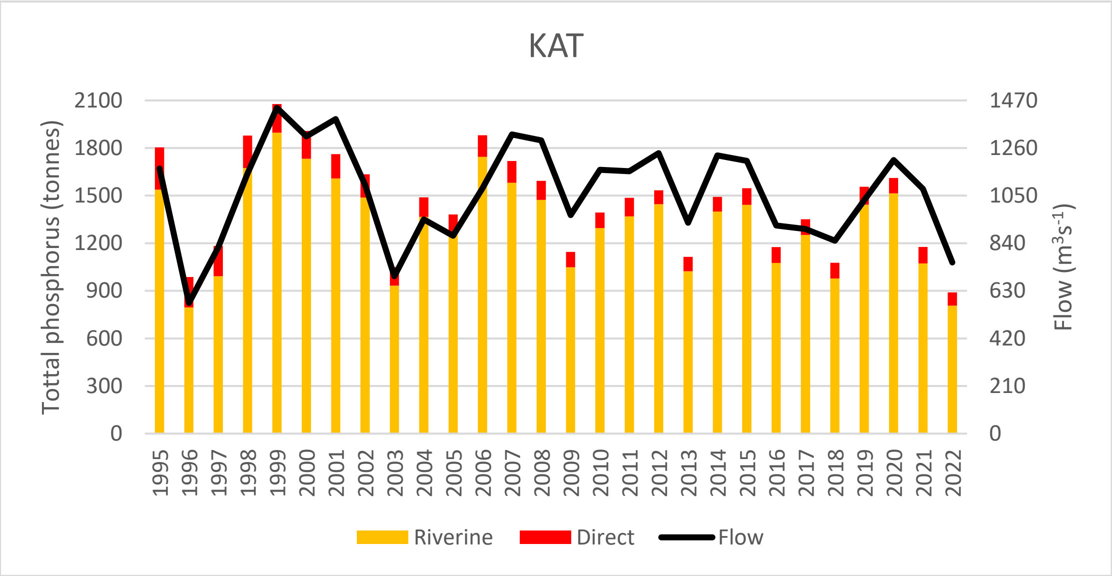


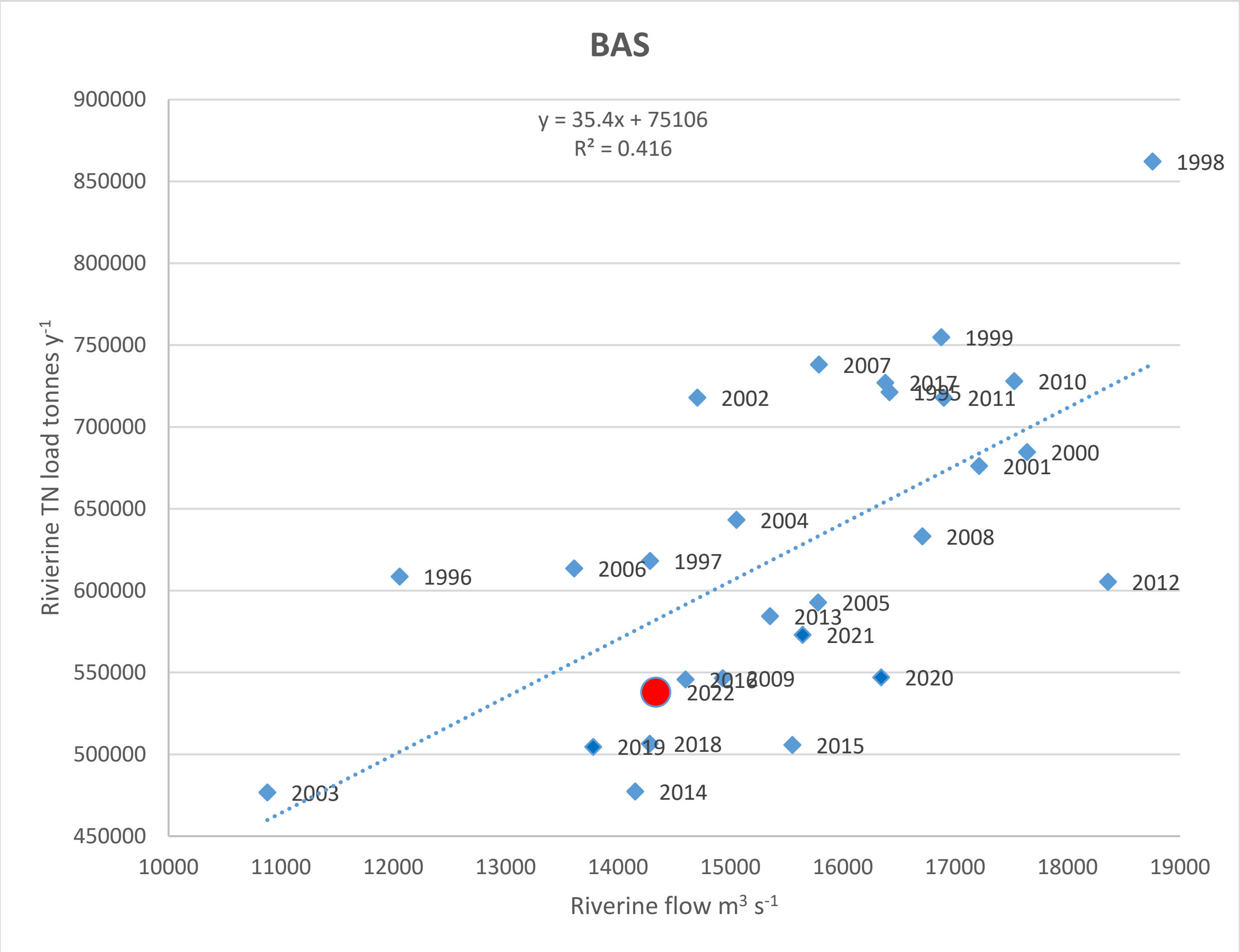
Figure 2B: Annual riverine and direct inputs of total phosphorus in tonnes and annual waterborne flow (m^{-3} s^{-1}) to the seven Baltic Sea sub-basin and to the Baltic Sea in 1995-2022. Data behind the figures are shown in Tables 2 and 6-8. For an explanation of the basin abbreviations, see the caption to Figure 1.

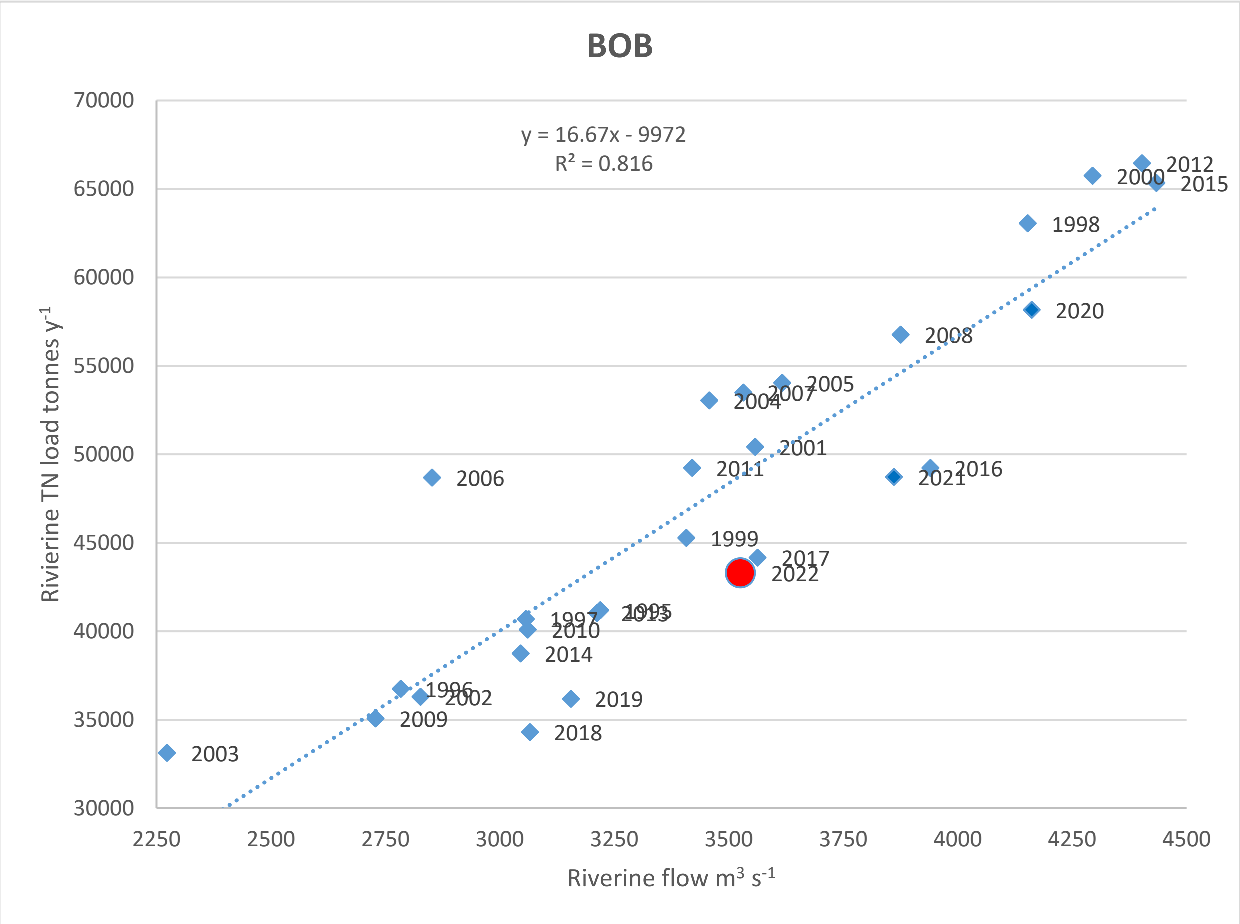
The correlation between the annual riverine TN and TP inputs, respectively, and water flow during 1195-2022 are shown as scatter and linear regression plots in Figure 3. The significance of the linear regression is tested statistically (see caption to Figure 3). The plots allow for characterization and evaluation of the TN and TP riverine inputs 1995-2022 specifically the inputs in 2022. 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.

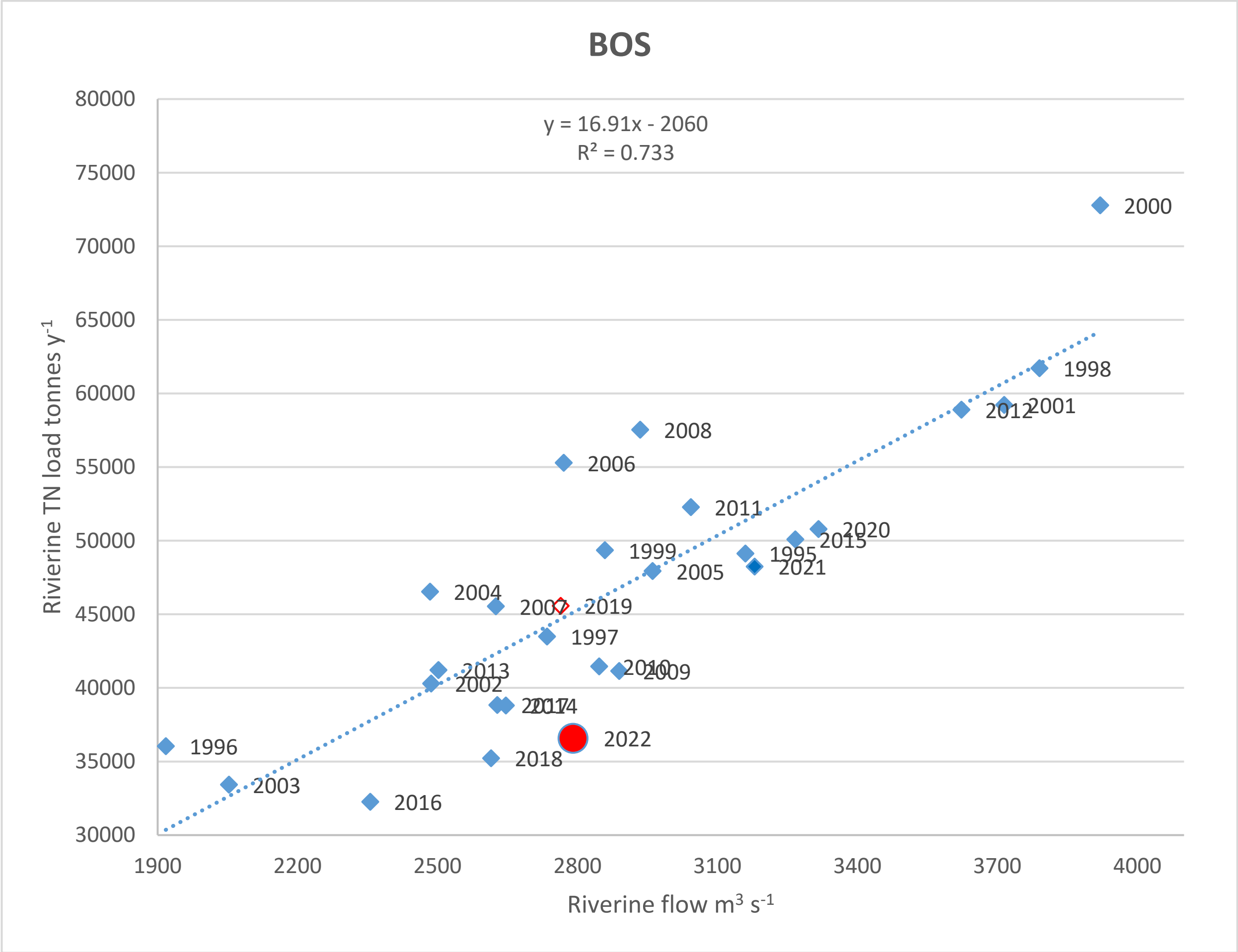
Riverine TN and TP inputs in 2022 were under or markedly under what the regressions line indicates for the magnitude of flow during 1995-2021 to Baltic Sea, except for TN to Gulf of Riga (much over the regression line), and to Gulf of Finland and Baltic Proper (a bit over the regressions line). For TP riverine inputs was much under the regression line for all basins. Total riverine nitrogen inputs in 2022 to Kattegat and to Baltic Sea was the lowest during the 1995-2022. For TN to Gulf of Riga the 11% lower flow than average (1995-2021) has resulted in 6% higher TN inputs than average (2012-21) and a 14% higher flow-weighted TN concentration than average of 2012-2021 (see table 1c). The situation looks as 2021 for nitrogen and might indicate the significant increase of nitrogen inputs to Gulf of Riga shown in Svendsen et al, 2023 and due to that the low flow in 2022 was higher than the flow in 2020 and 2021 from e.g. Lithuania, which might have leached some of the nitrogen pool stored in the soils during the very dry years 2020-2021.

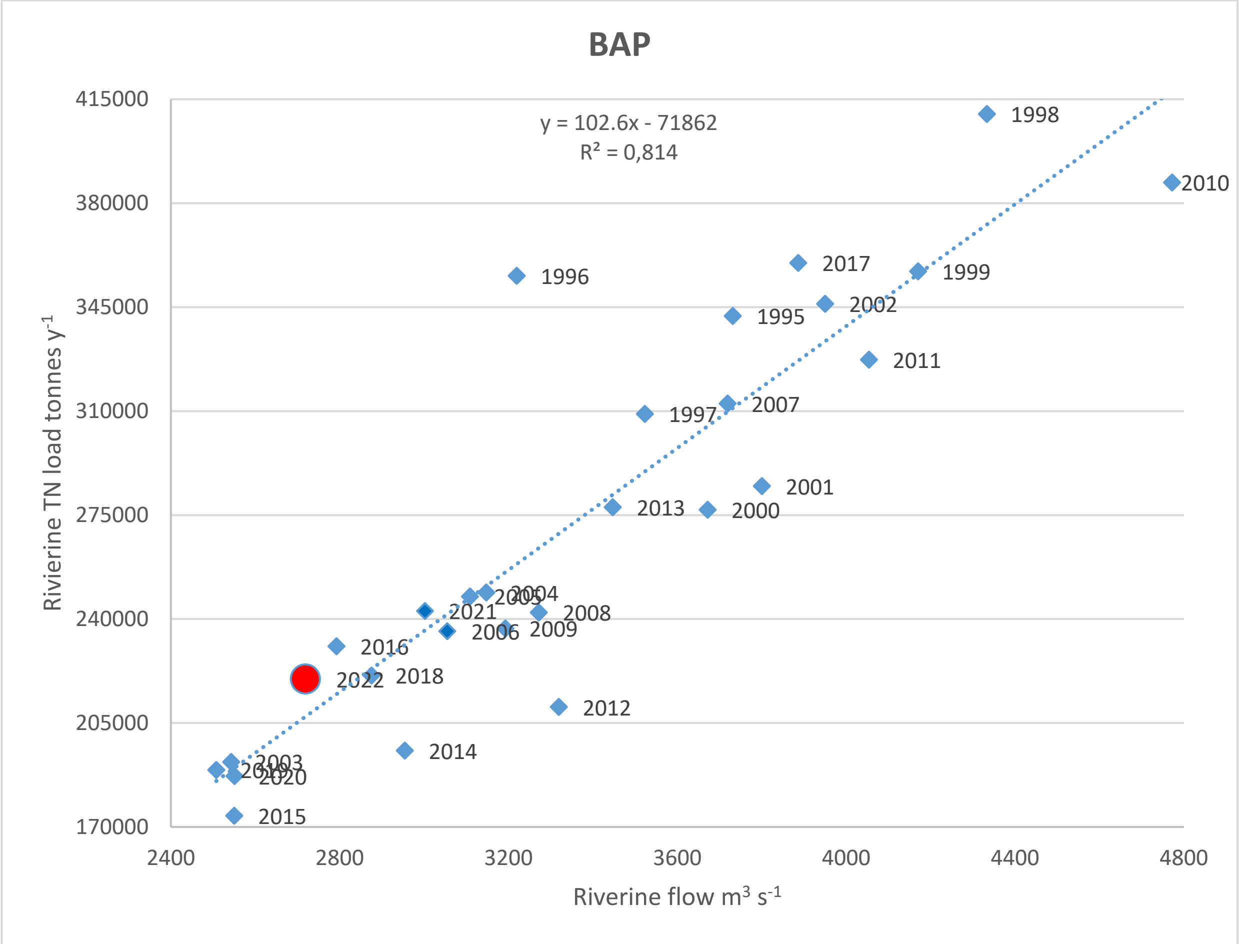
Total riverine phosphorus inputs in 2022 to Baltic Proper, Gulf of Riga, Kattegat and to Baltic Sea was the lowest during the 1995-2022 Overall, the Figures 3A and B indicate a rather considerable range of nutrient inputs for any particular flow.

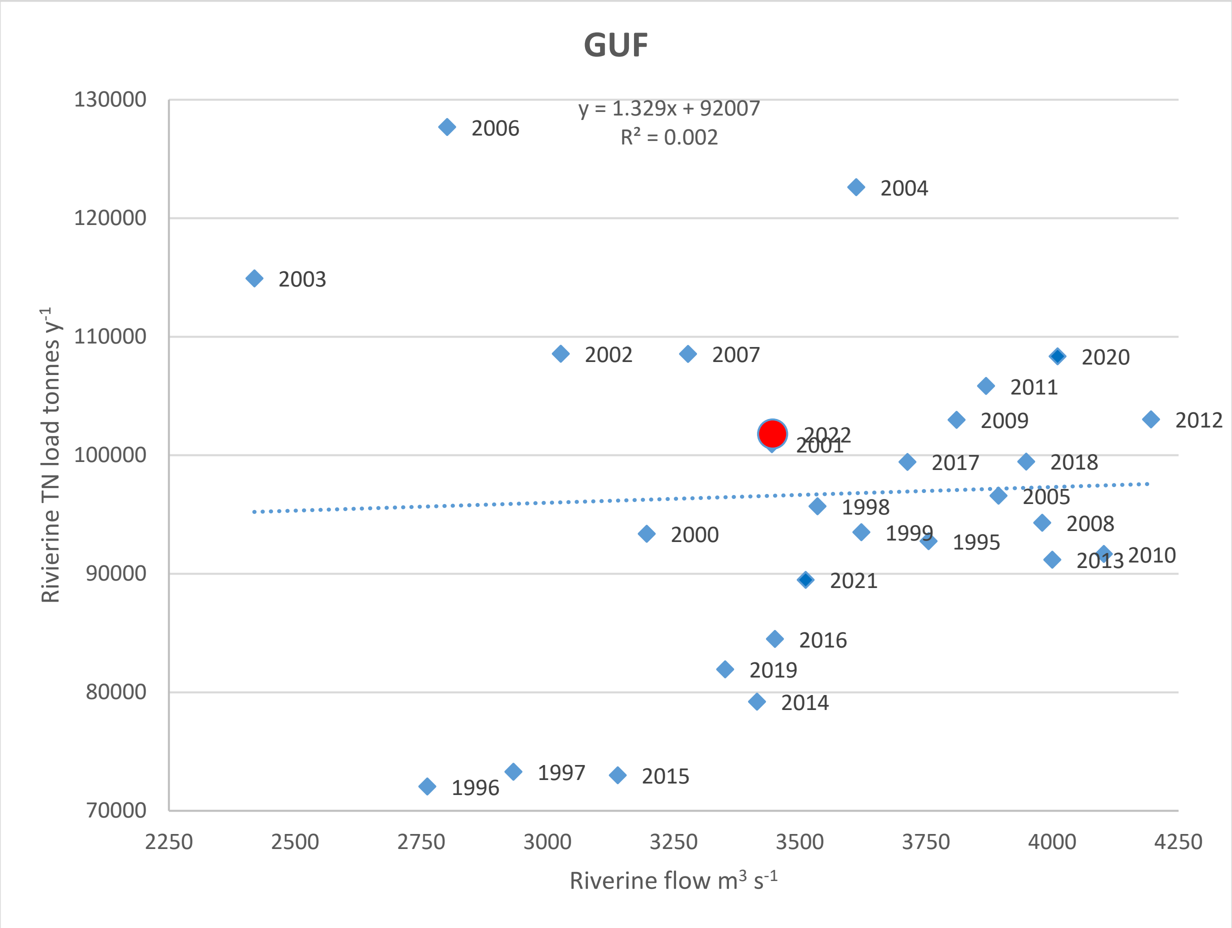
As a rule of thumb, a decrease in riverine TN and/or TP inputs during 1995 to 2022 is significant if most of the inputs of the latest 13-14 years falls below the dotted lines in Figure 3A and B. This is true for many basins for particularly phosphorus. If nutrient inputs from sources with low dependency 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 in the catchment.

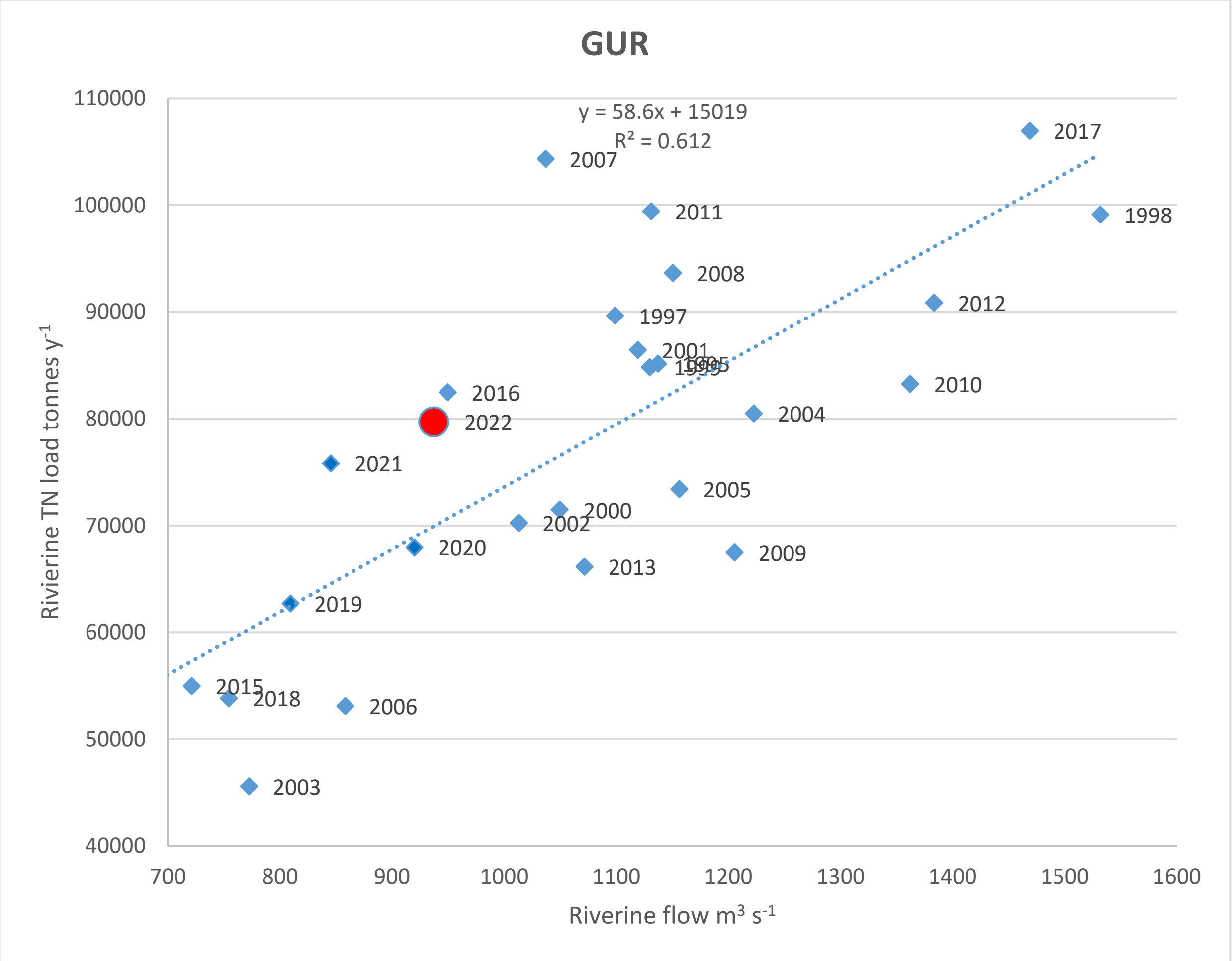

BAS
y = 35.4x + 75106
R² = 0.416
900000
850000
800000
750000
700000
650000
600000
550000
500000
450000
Rivierine TN load tonnes y-1
10000
11000
12000
13000
14000
15000
16000
17000
18000
19000
Riverine flow m3 s-1
1998
1999
2007
2017
1995
2011
2010
2002
2000
2001
2004
2008
1996
2006
1997
2012
2005
2013
2021
2016
2009
2022
2020
2019
2018
2015
2003
2014

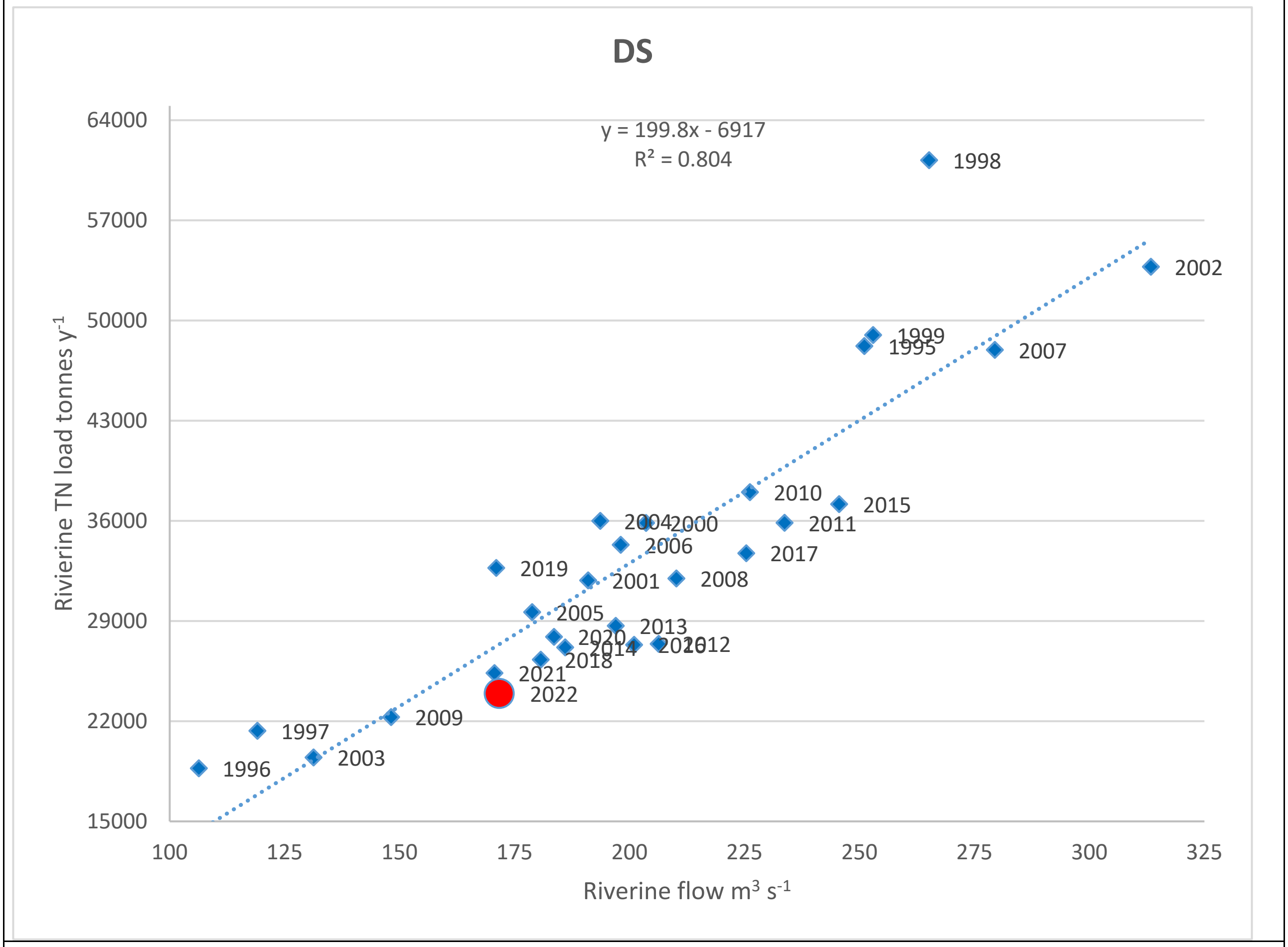

BOB
y = 16.67x - 9972
R² = 0.816
70000
65000
60000
55000
50000
45000
40000
35000
30000
Rivierine TN load tonnes y-1
2250
2500
2750
3000
3250
3500
3750
4000
4250
4500
Riverine flow m3 s-1
2012
2000
2015
1998
2020
2008
2004
2007
2005
2001
2006
2011
2021
2016
1999
2017
2022
1997
2010
2013
1995
2014
1996
2002
2009
2019
2018
2003


BOS
y = 16.91x - 2060
R² = 0.733
Riverine TN load tonnes y-1
80000
75000
70000
65000
60000
55000
50000
45000
40000
35000
30000
1900
2200
2500
2800
3100
3400
3700
4000
Riverine flow m3 s-1
2000
1998
2012
2001
2008
2006
2011
2020
2015
1999
1995
2021
2005
2004
2007
2019
1997
2013
2002
2010
2009
2017
2014
2022
1996
2018
2003
2016


BAP
y = 102.6x - 71862
R² = 0,814
Riverine TN load tonnes y-1
415000
380000
345000
310000
275000
240000
205000
170000
2400
2800
3200
3600
4000
4400
4800
Riverine flow m3 s-1
1998
2010
1996
2017
1999
1995
2002
2011
1997
2007
2001
2013
2000
2005
2004
2021
2006
2009
2008
2016
2022
2018
2012
2014
2003
2019
2020
2015


GUF
y = 1.329x + 92007
R² = 0.002
Rivierine TN load tonnes y-1
130000
120000
110000
100000
90000
80000
70000
Riverine flow m3 s-1
2250
2500
2750
3000
3250
3500
3750
4000
4250
2006
2004
2003
2002
2007
2020
2011
2009
2012
2022
2001
2017
2018
2005
1998
2008
2000
1999
1995
2013
2010
2021
2016
2019
2014
1997
2015
1996


GUR
y = 58.6x + 15019
R² = 0.612
Rivierine TN load tonnes y-1
110000
100000
90000
80000
70000
60000
50000
40000
Riverine flow m3 s-1
700
800
900
1000
1100
1200
1300
1400
1500
1600
2017
2007
2011
1998
2008
2012
1997
2001
1995
2016
2010
2022
2004
2021
2005
2002
2000
2020
2009
2013
2019
2015
2018
2006
2003


DS
y = 199.8x - 6917
R² = 0.804
Rivierine TN load tonnes y-1
Riverine flow m3 s-1
64000
57000
50000
43000
36000
29000
22000
15000
100
125
150
175
200
225
250
275
300
325
1998
2002
1999
1995
2007
2010
2015
2004
2000
2011
2006
2017
2019
2001
2008
2005
2013
2020
2014
2016
2012
2018
2021
2022
2009
1997
2003
1996

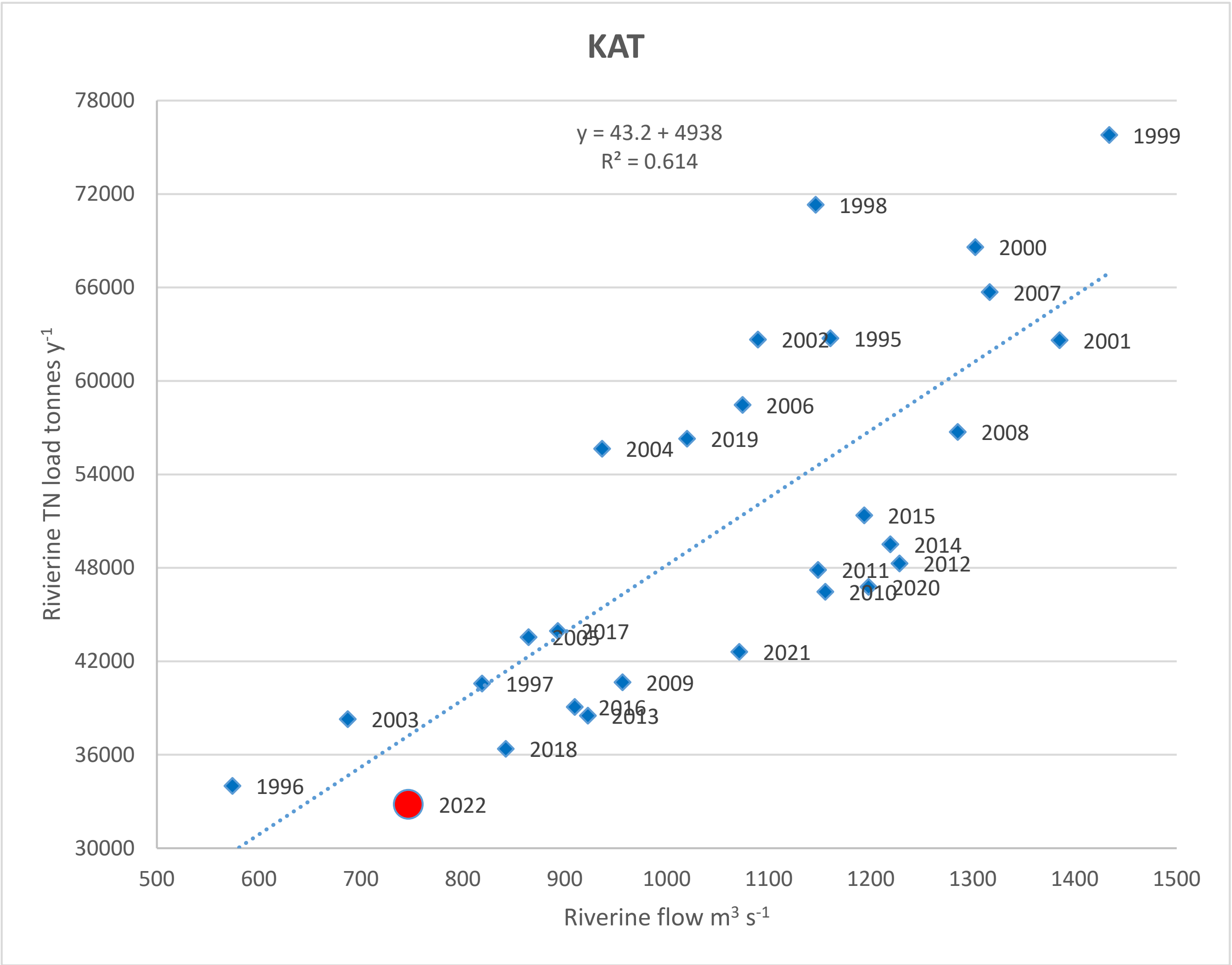
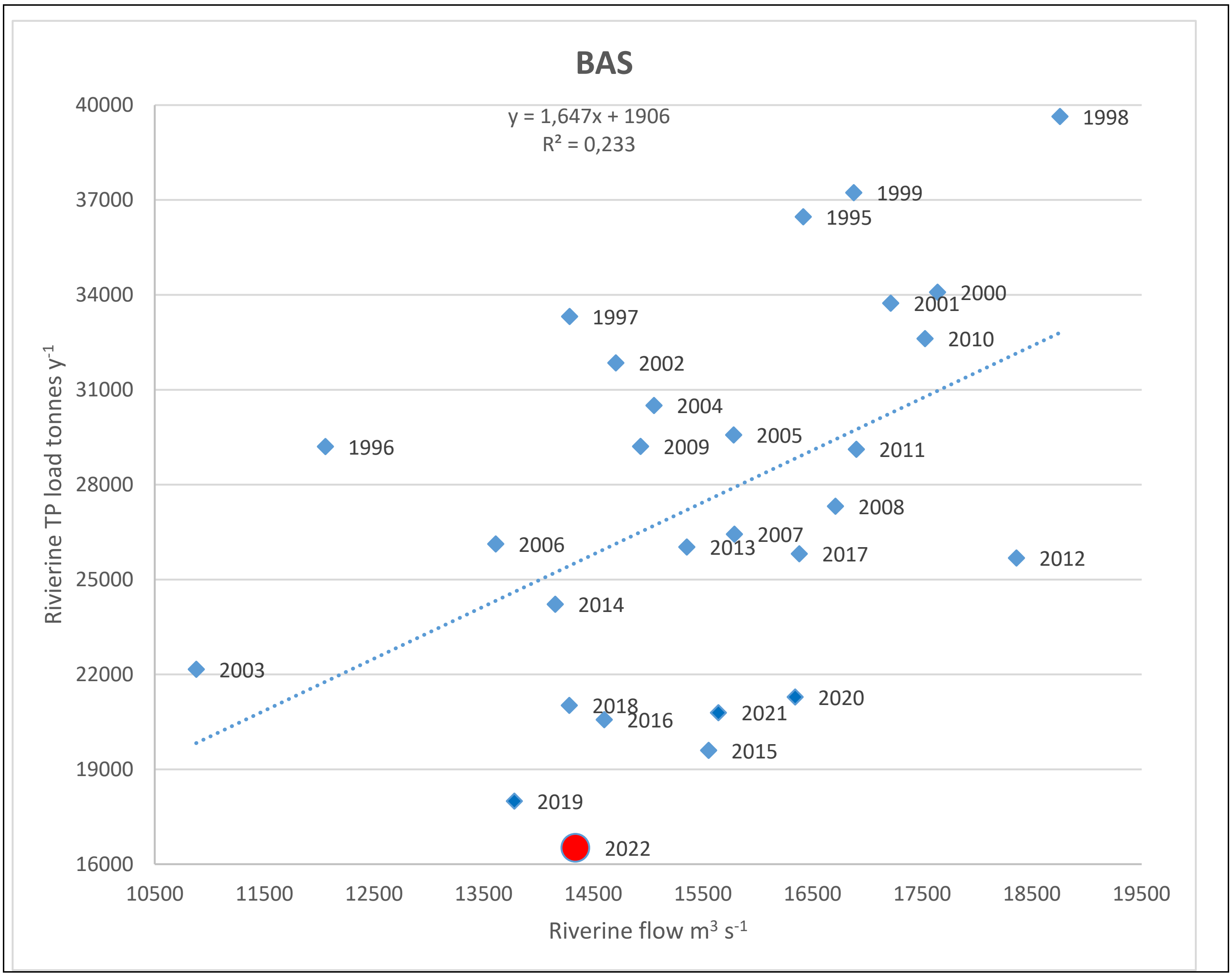
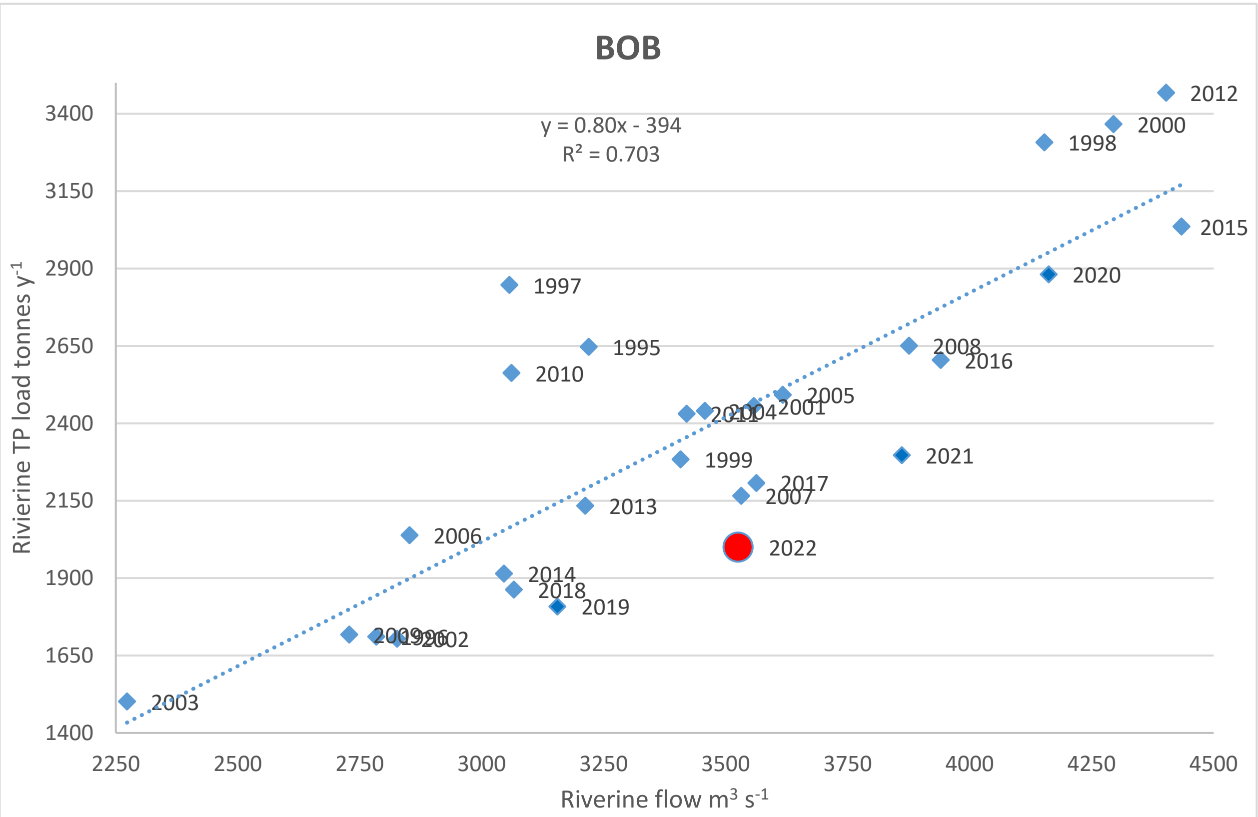
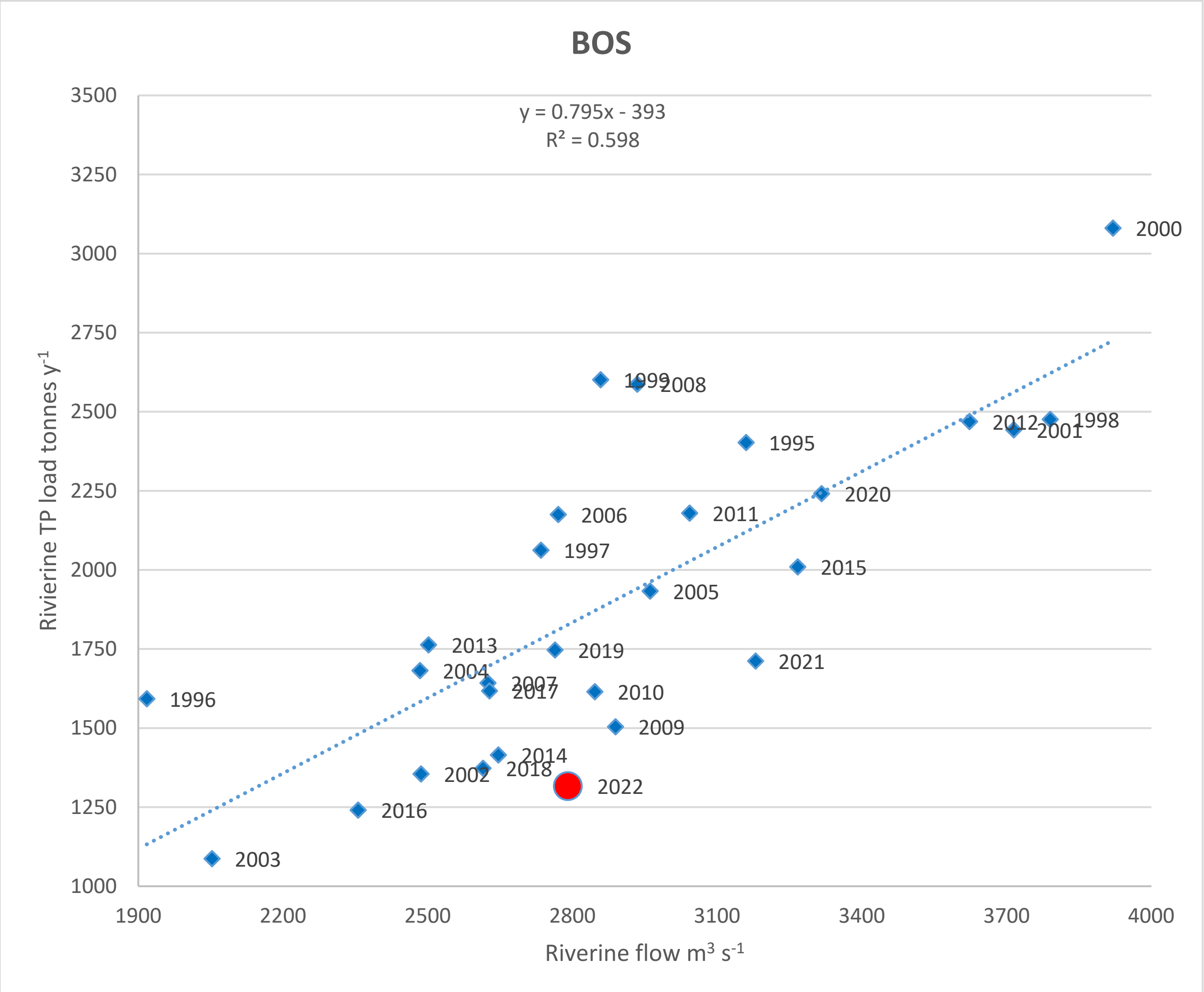
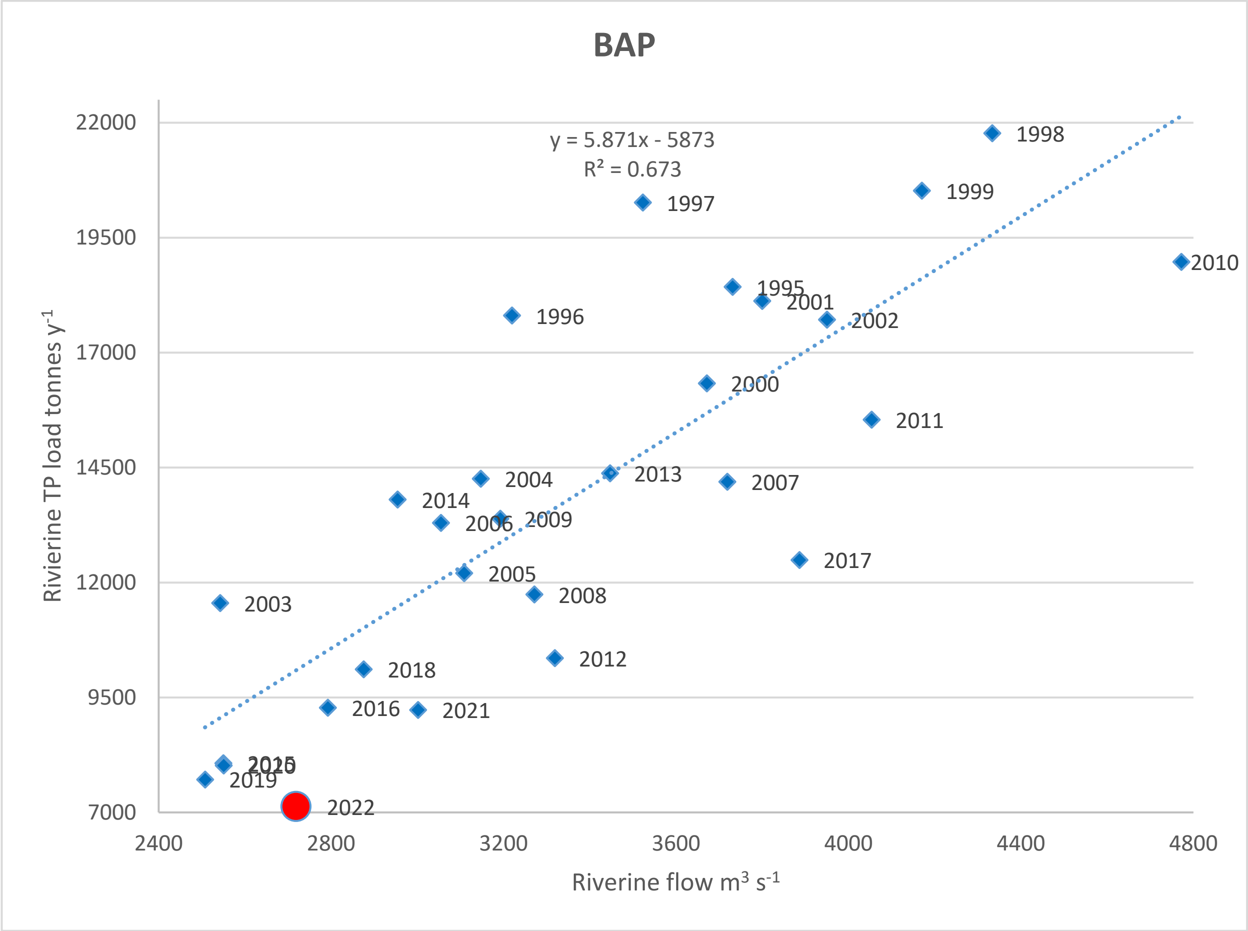

KAT
y = 43.2 + 4938
R² = 0.614
Rivierine TN load tonnes y-1
Riverine flow m3 s-1
78000
72000
66000
60000
54000
48000
42000
36000
30000
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1999
1998
2000
2007
2002
1995
2001
2006
2008
2004
2019
2015
2014
2012
2011
2010
2020
2005
2017
2021
1997
2009
2016
2013
2003
2018
1996
2022

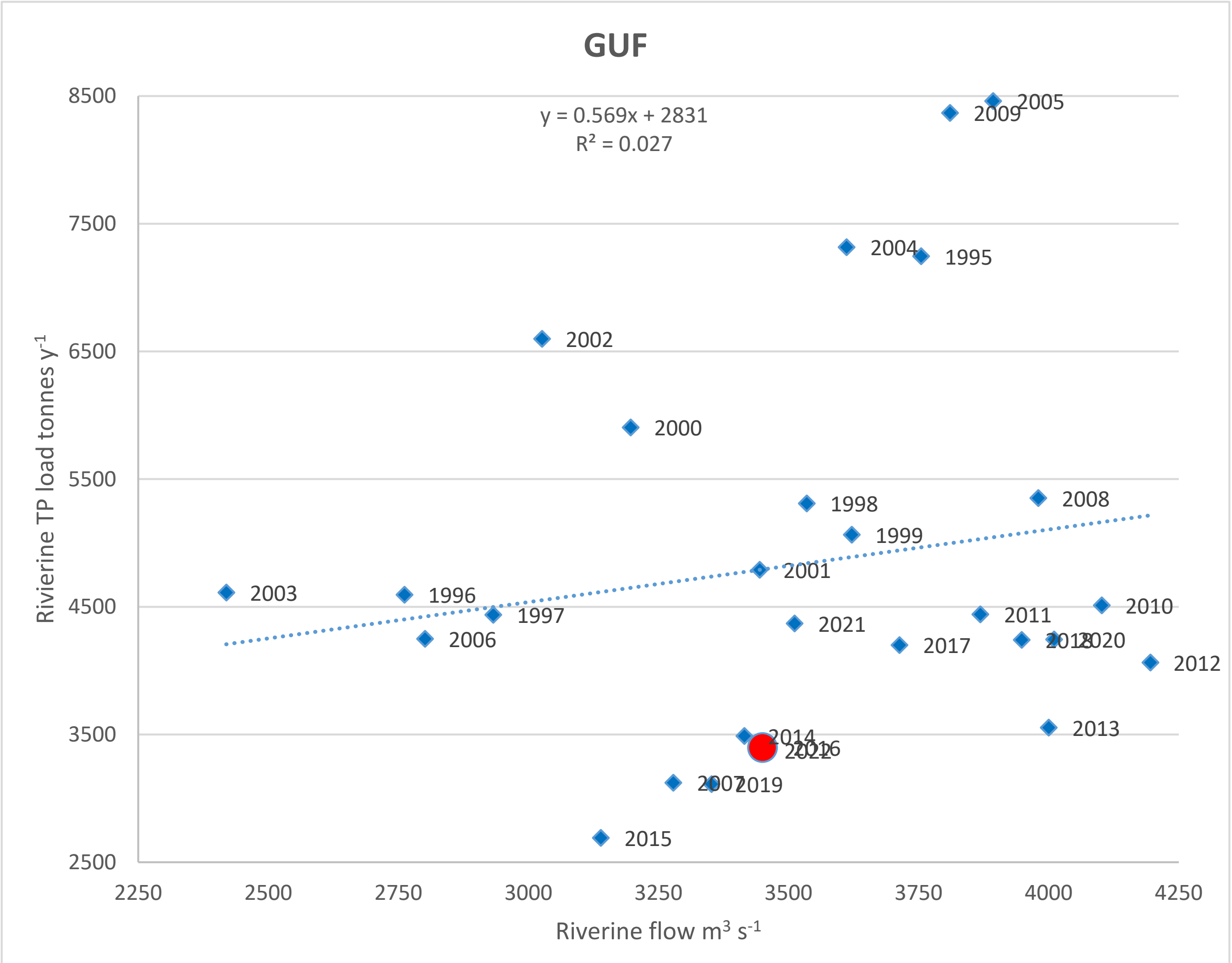
Figure 3A. Linear regression plots of annual riverine flows (m^3 s^{-1}) against annual riverine total nitrogen inputs (TN) to the seven Baltic Sea sub-basins and to the Baltic Sea during 1995-2022. Most recent year (2022) is marked with a big red dot and "2022" to the right of the dot. The linear regression 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.

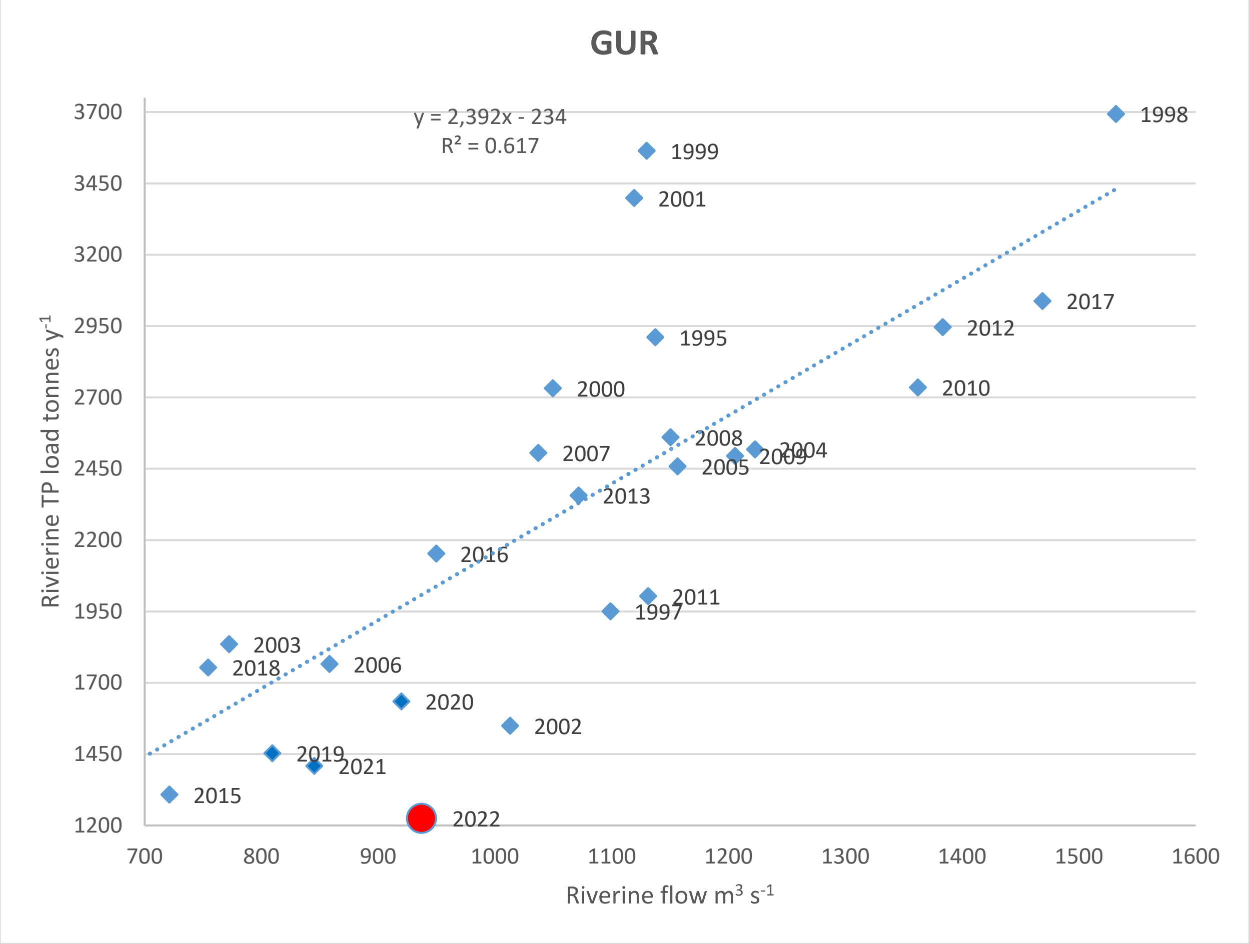


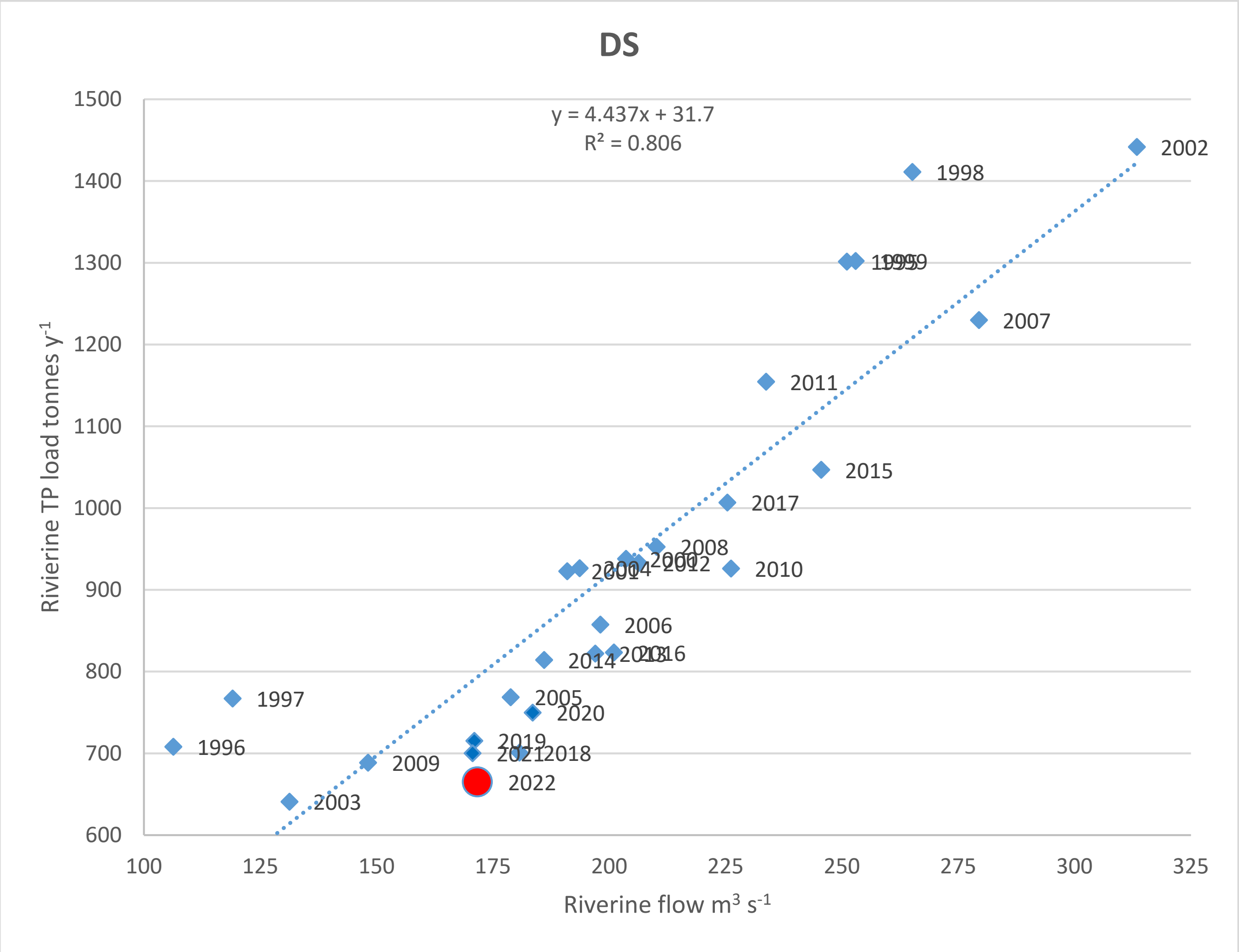

BOB
y = 0.80x - 394
R² = 0.703
Rivierine TP load tonnes y-1
Riverine flow m3 s-1
3400
3150
2900
2650
2400
2150
1900
1650
1400
2250
2500
2750
3000
3250
3500
3750
4000
4250
4500
2012
2000
1998
2015
2020
1997
1995
2010
2008
2016
2011
2004
2001
2005
1999
2021
2017
2007
2013
2006
2022
2014
2018
2019
2009
1996
2002
2003


BOS
y = 0.795x - 393
R² = 0.598
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
1999
2008
2012
2001
1998
1995
2020
2006
2011
1997
2015
2005
2013
2019
2004
2007
2017
2021
1996
2010
2009
2014
2002
2018
2022
2016
2003


BAP
y = 5.871x - 5873
R² = 0.673
Rivierine TP load tonnes y-1
Riverine flow m3 s-1
22000
19500
17000
14500
12000
9500
7000
2400
2800
3200
3600
4000
4400
4800
1998
1999
1997
2010
1995
2001
2002
1996
2000
2011
2004
2014
2013
2007
2006
2009
2017
2005
2008
2003
2012
2018
2016
2021
2015
2020
2019
2022


GUF
y = 0.569x + 2831
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
2006
2021
2011
2010
2017
2018
2020
2012
2013
2014
2016
2022
2007
2019
2015


GUR
y = 2,392x - 234
R² = 0.617
Rivierine TP load tonnes y-1
Riverine flow m3 s-1
3700
3450
3200
2950
2700
2450
2200
1950
1700
1450
1200
700
800
900
1000
1100
1200
1300
1400
1500
1600
1998
1999
2001
2017
2012
1995
2000
2010
2008
2004
2009
2007
2005
2013
2016
2011
1997
2003
2018
2006
2020
2002
2019
2021
2015
2022


DS
y = 4.437x + 31.7
R² = 0.806
Rivierine TP load tonnes y-1
Riverine flow m3 s-1
1500
1400
1300
1200
1100
1000
900
800
700
600
100
125
150
175
200
225
250
275
300
325
2002
1998
1995
1999
2007
2011
2015
2017
2008
2001
2004
2000
2012
2010
2006
2014
2013
2016
1997
2005
2020
1996
2019
2021
2018
2009
2022
2003

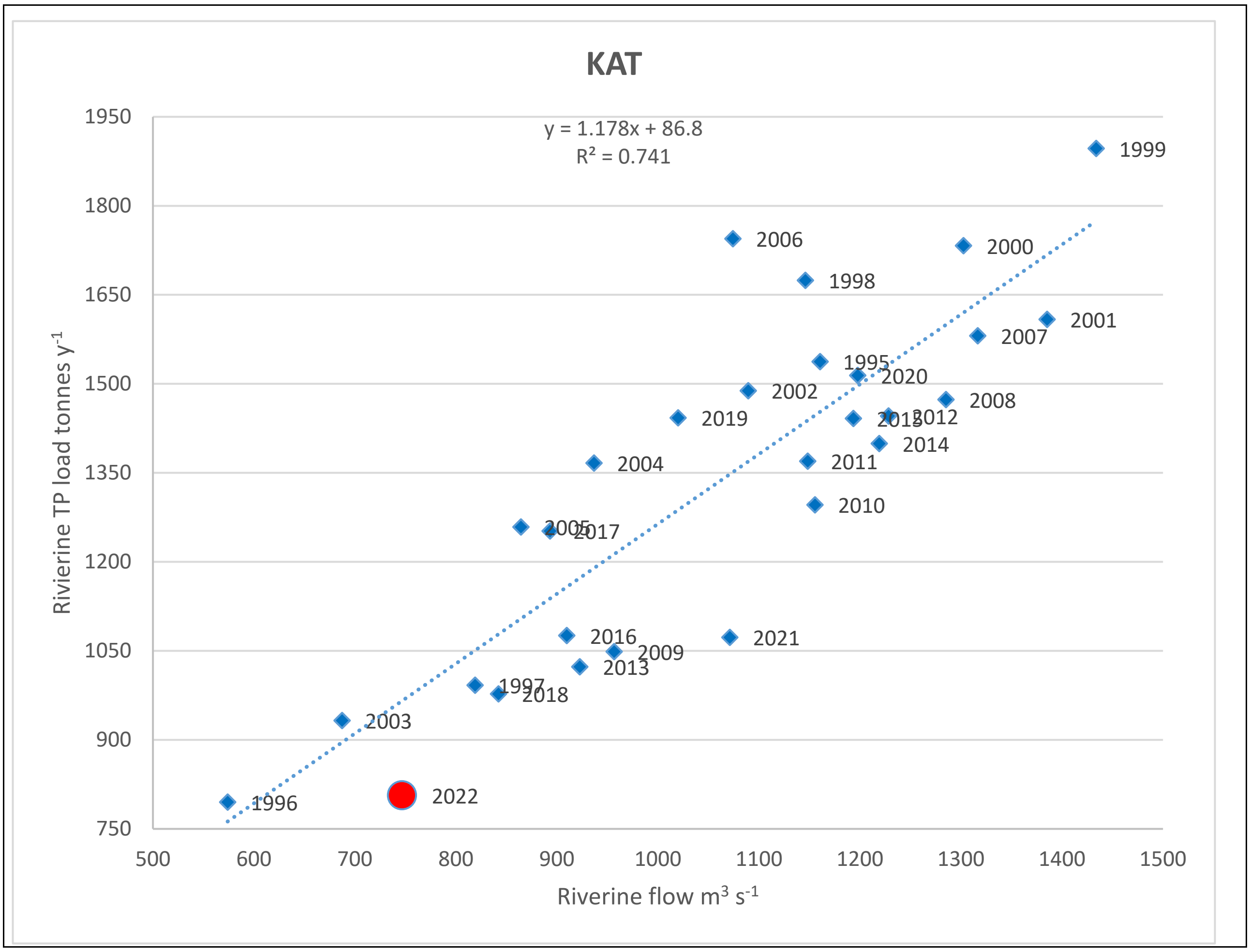


Figure 3B. As figure 3A but for total phosphorus 1995-2022. All relations besides TP to GUF are significant. For an explanation of abbreviations, see the caption to Figure 1.

Göta River constitutes more than 50% of the flow to Kattegat. The correlation between riverine flow and TN and TP load for Kattegat seems affected by the Göta River where the water level (and as a consequent the flow in the river) in the very big Lake Vänern during 2008-2022 are regulated to prevent flooding. If we divided timeseries 1995-2022 of the flow and TN load in 1995-2008 and 2009-2022 (the later covering the period with regulating water level/flow to prevent flooding) there is a very high corelation between flow and TN load (figure 3c) in each of the two periods (r^2 =0,9666 for 1995-2005 and 0,9499 for 2009-2022) but lower correlation fort 1995-2022 (r^2 = 0,7262), This impact for Göta River explains the pattern I figures 3a and 3b for Kattegat.

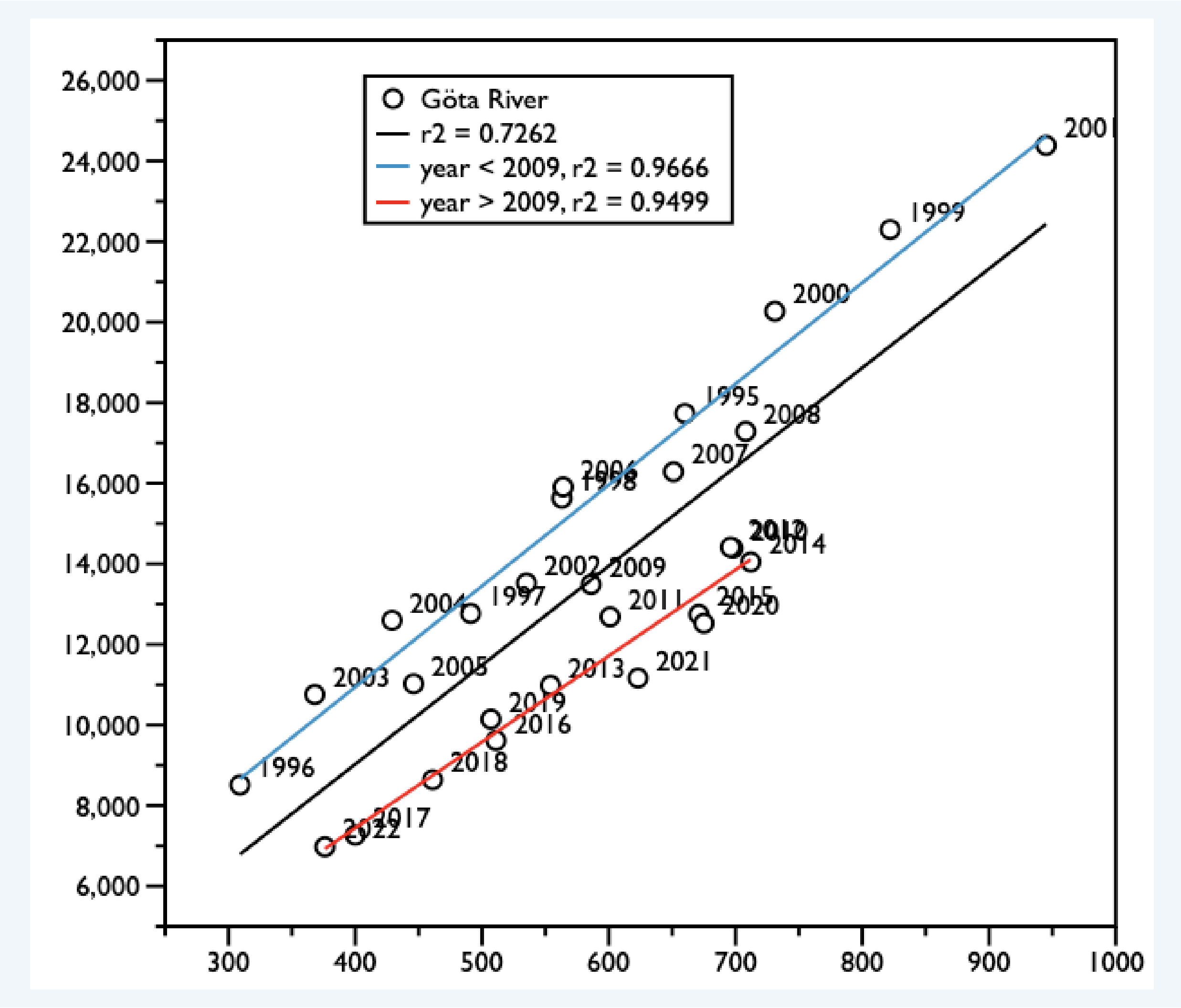
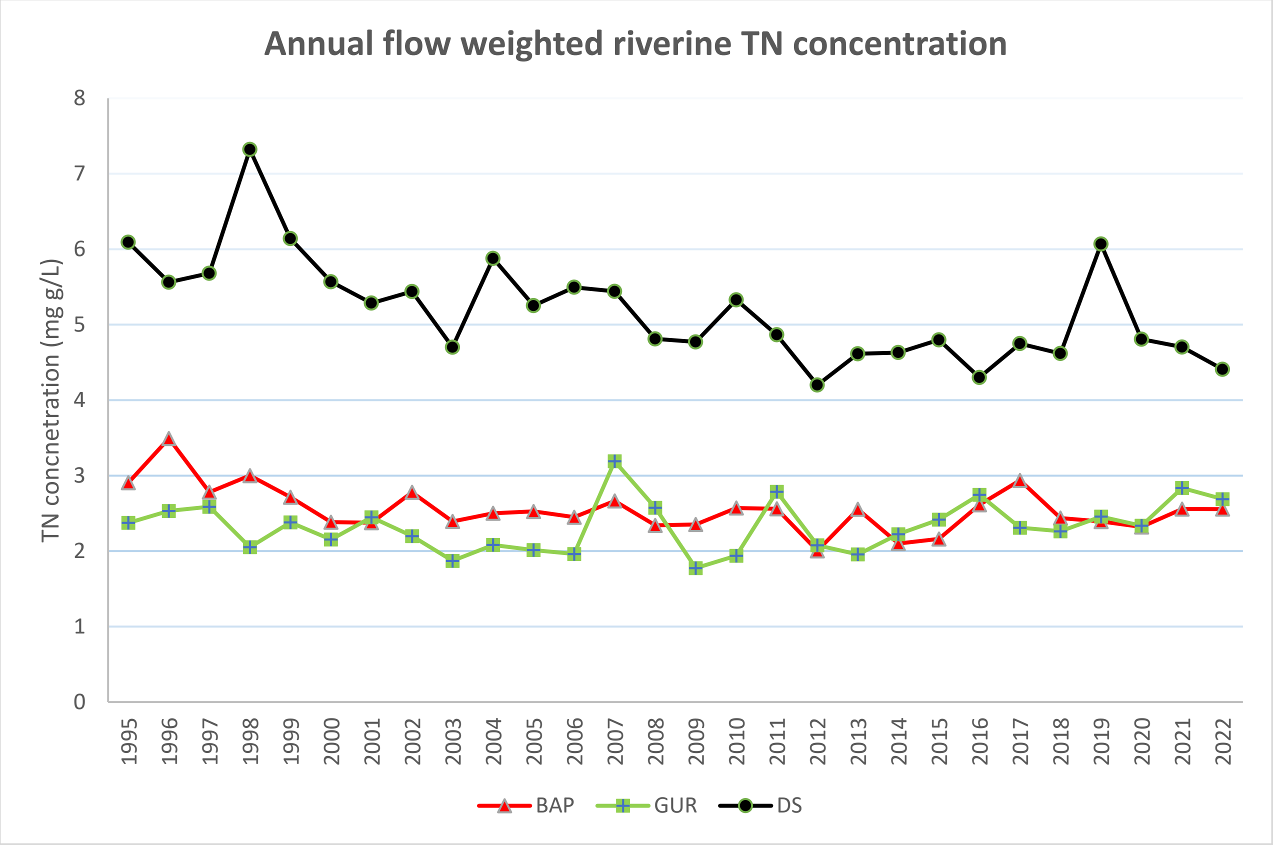
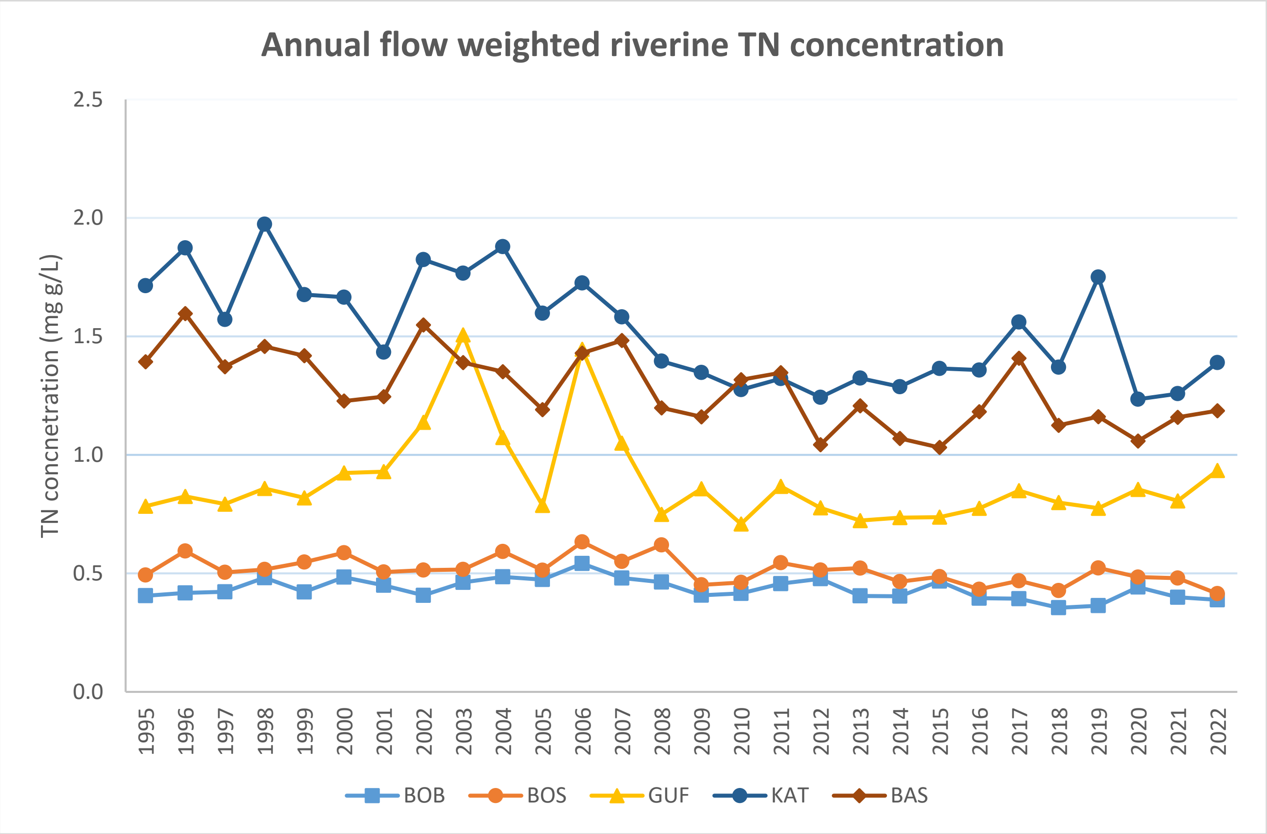


Figure 3c. Linear regression plots of annual riverine flows ($m^3 s^{-1}$) on the horizontal axis against annual riverine total nitrogen inputs (TN) on the vertical axis for Göta River during 1995-2008 (blue line) and 2009-2022 (red line), and for the complete period 1995-2022 (black line), respectively. R^2 indicates how much of the variation is explained by the regression, e.g. R^2 =0.9666 say that nearly 97 % of the variation is explained (high correlation) by the regression.

Flow weighted annual riverine concentrations og TN and TP 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 1995-2022 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 Bay, 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 is sub-divided as the flow-weighted TN and TP riverine 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 riverine 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, geology and soils characteristics, and climate combined 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 1995-2021, see Table 1a and b. On average, the area specific flow to the Baltic Sea is 9 l s^{-1} km^{-2} (8.3 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 1995-2021. 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 to Kattegat. A corresponding pattern was seen for Swedish catchment to Kattegat. Annual flow-weighted TN concentration to Gulf of Riga in 2021 and 2022 was among the highest during 1995-2022 after two year (2019 and 2020) with very dry conditions. Flow-weighted TN concentration in 2022 to Gulf of Finland was the highest since 2007 even though flow was very close to average, and no obvious explanation have been provided. TN flow weighted concentration to Danish Straits in 2022 was the second lowest and for TP the lowest during 1995-2022. TP flow weighted concentration in 2022 to Bothnian Bay, Bothnian See, Baltic Proper, Gulf of Riga, and Baltic Sea were also the lowest during 1995-2022.




Annual flow weighted riverine TN concentration
TN concnetration (mg g/L)
2.5
2.0
1.5
1.0
0.5
0.0
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
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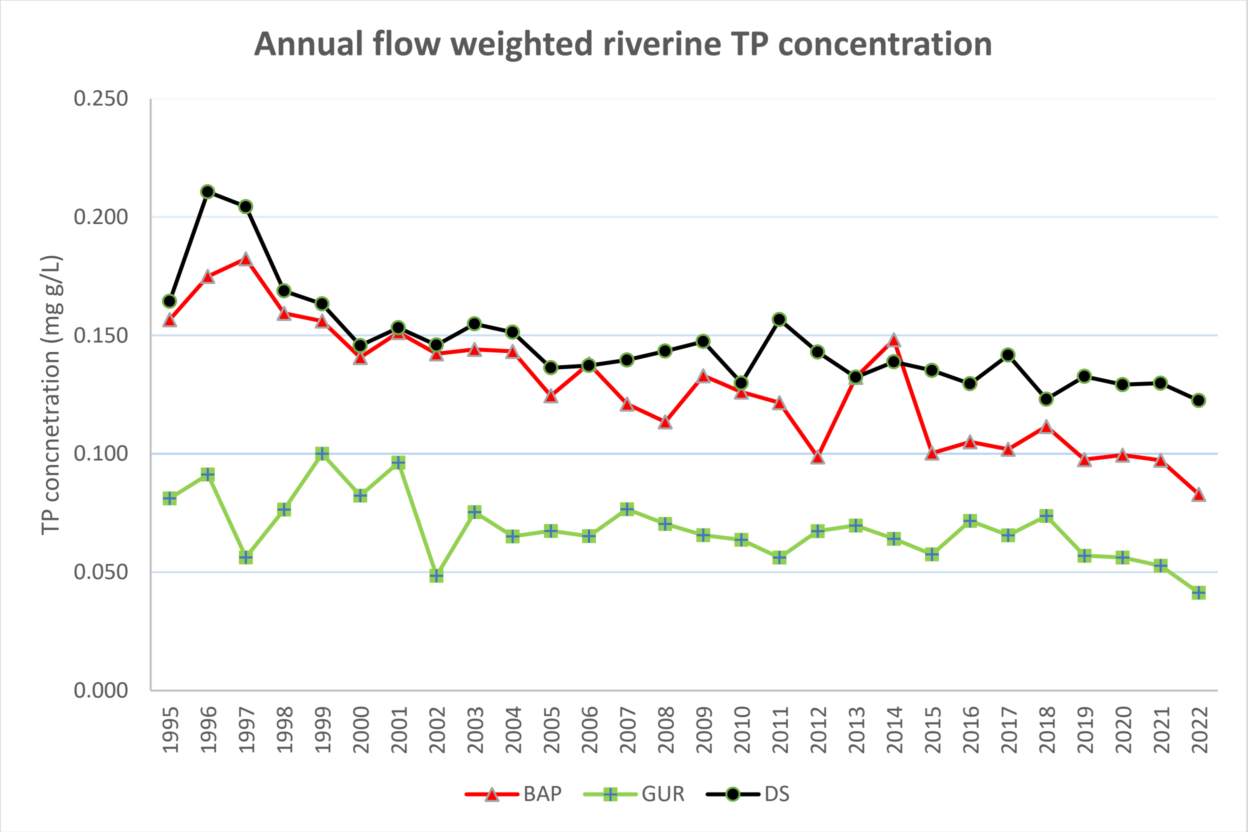
2016
2017
2018
2019
2020
2021
2022
BOB
BOS
GUF
KAT
BAS


Annual flow weighted riverine TP concentration
TP concnetration (mg g/L)
0.250
0.200
0.150
0.100
0.050
0.000
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
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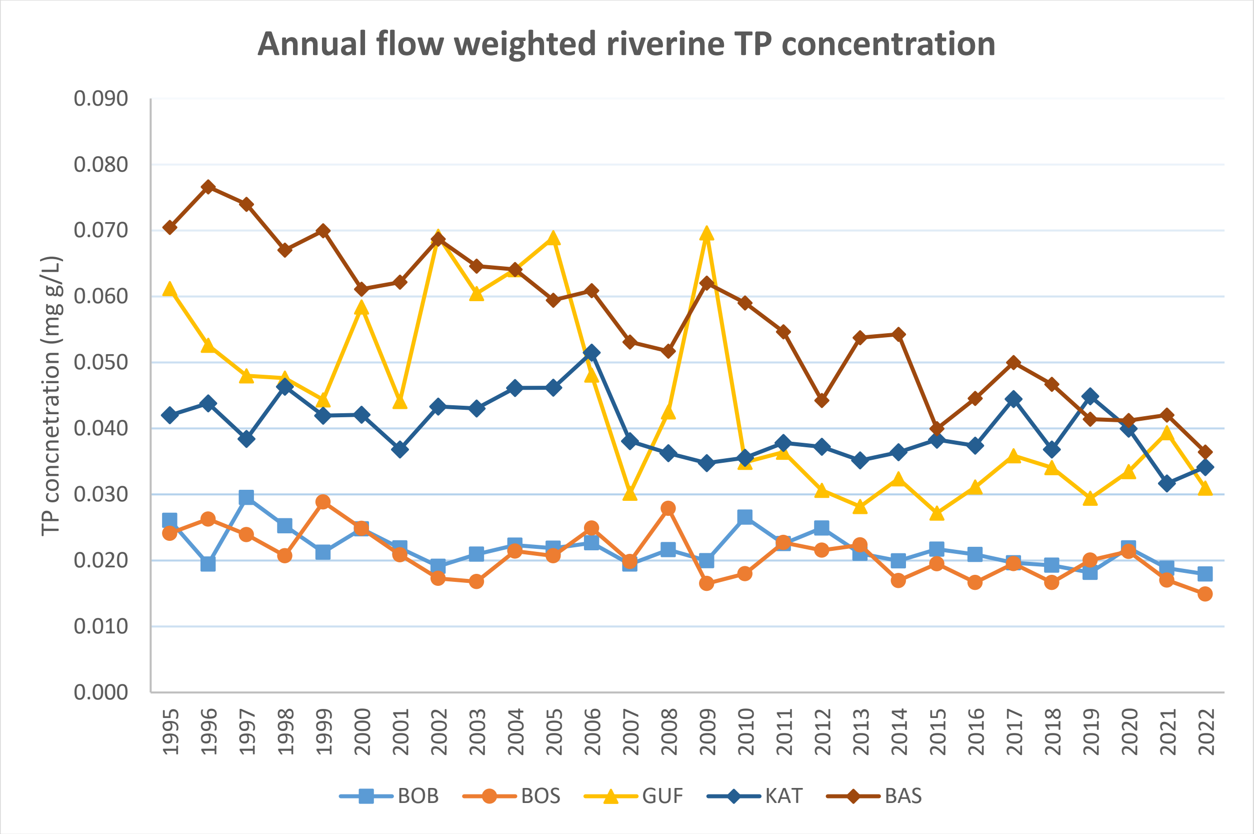

Figure 4. Annual average flow-weighted riverine total nitrogen (the two uppermost figures) and total phosphorus (the two lowermost plots) concentrations for the seven Baltic Sea basins and the Baltic Sea (calculated as total annual riverine inputs divided with the corresponding annual flow) during 1995-2022 (in mg/L). Baltic Proper, Gulf of Riga and Danish Straits are in separate figures (1 and 3, respectively from the top down) due to higher flow-weighted concentrations than to the remaining basins (plot 2 and 4, respectively 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.

Nitrogen and phosphorus fractions of the riverine nutrient inputs 1995-2022

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).

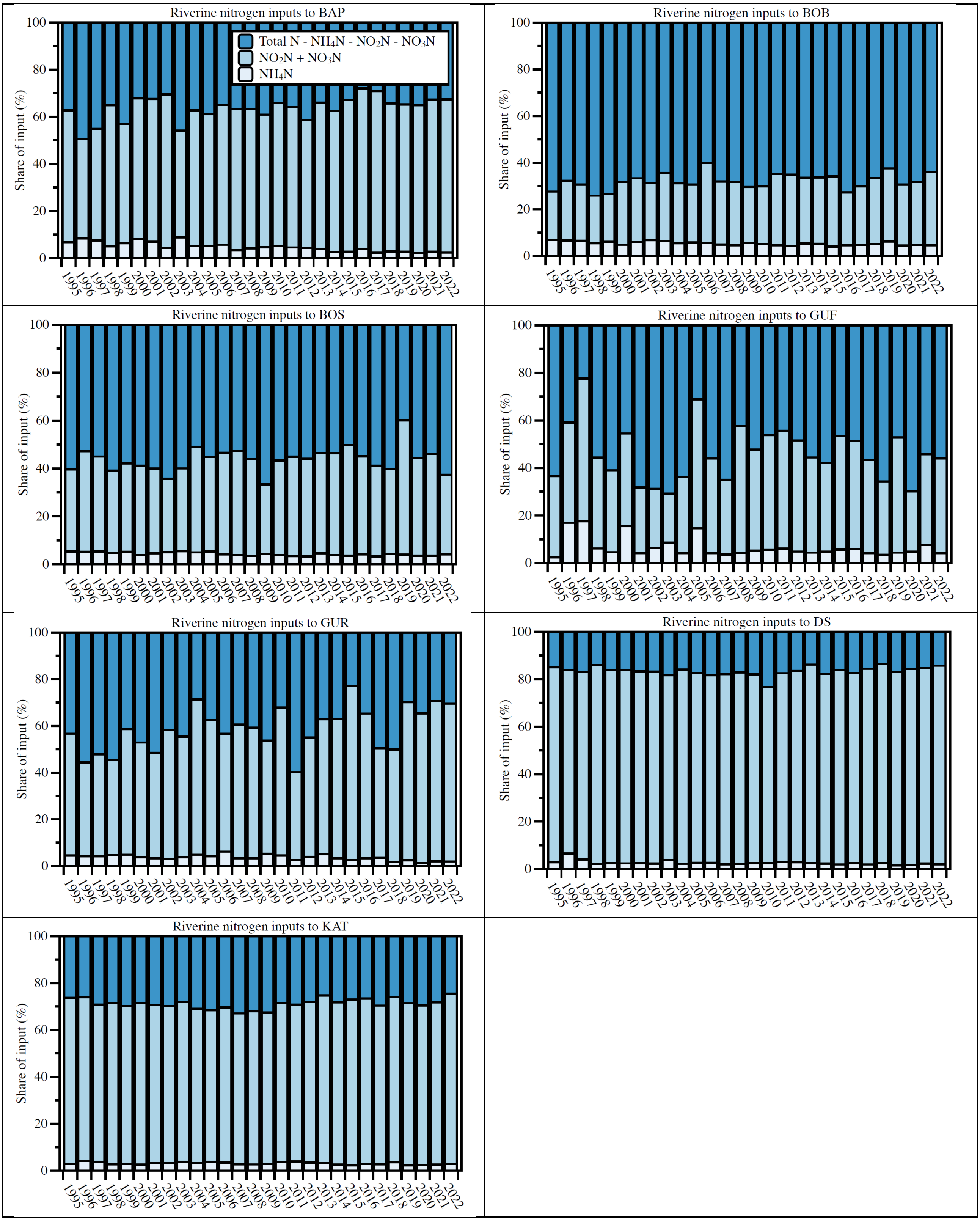

Figure 5. Shares of nitrogen fractions of the total annual nitrogen inputs to the seven Baltic Sea basins during 1995-2022.

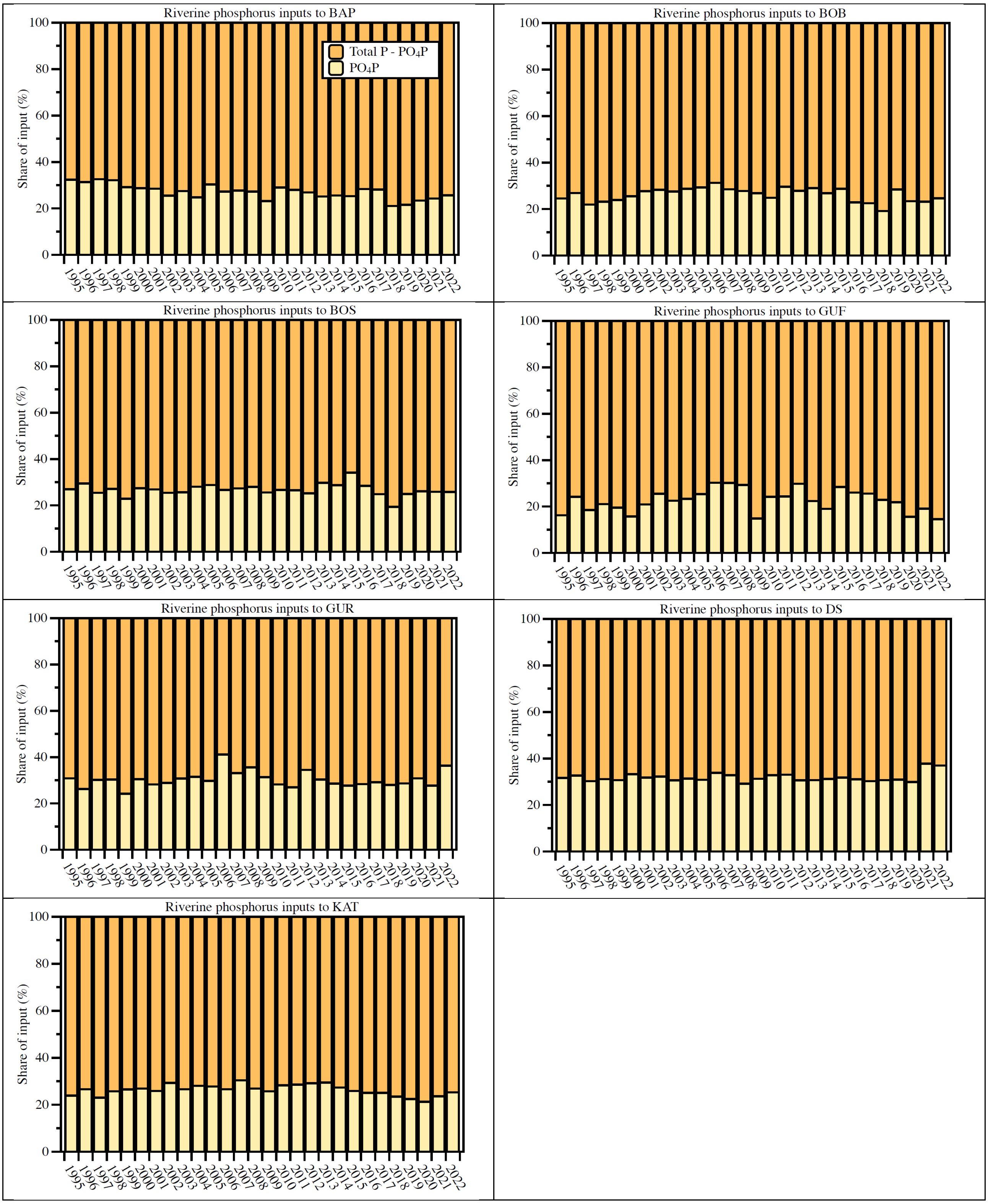

Figure 6. Shares of phosphorus fractions of the total annual phosphorus inputs to the seven Baltic Sea basins during 1995-2022.

Policy relevance and policy references[4]

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[4] Regarding atmospheric inputs the relevant policies are: The Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone under UNECE Convention on Long-range Transboundary Air pollution

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

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

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.

(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).

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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 during 1995-2022 (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	3,224	3,170	3,750	3,755	1,141	266	1,170	16,475
1996	2,784	1,917	3,221	2,789	693	115	576	12,095
1997	3,056	2,734	3,524	2,959	1,099	128	821	14,323
1998	4,153	3,790	4,335	3,562	1,532	276	1,149	18,797
1999	3,407	2,858	4,172	3,648	1,130	264	1,437	16,916
2000	4,298	3,929	3,691	3,227	1,052	218	1,311	17,726
2001	3,557	3,714	3,804	3,475	1,121	200	1,388	17,260
2002	2,830	2,488	3,964	3,055	1,015	327	1,098	14,778
2003	2,277	2,055	2,557	2,449	774	142	694	10,949
2004	3,461	2,484	3,162	3,643	1,223	206	945	15,123
2005	3,623	2,963	3,127	3,920	1,156	191	873	15,853
2006	2,853	2,773	3,071	2,828	860	211	1,083	13,678
2007	3,532	2,625	3,726	3,306	1,039	292	1,320	15,840
2008	3,876	2,937	3,289	4,008	1,152	223	1,294	16,779
2009	2,729	2,891	3,209	3,839	1,207	160	964	15,000
2010	3,061	2,848	4,788	4,128	1,364	239	1,163	17,593
2011	3,420	3,045	4,071	3,896	1,133	247	1,158	16,969
2012	4,403	3,625	3,333	4,222	1,385	219	1,237	18,425
2013	3,213	2,504	3,463	4,027	1,073	209	930	15,419
2014	3,046	2,648	2,972	3,442	688	200	1,228	14,222
2015	4,437	3,275	2,570	3,165	723	260	1,204	15,635
2016	3,944	2,364	2,811	3,477	951	214	918	14,680
2017	3,566	2,636	3,908	3,742	1,471	239	903	16,464
2018	3,069	2,622	2,894	3,974	756	193	851	14,359
2019	3,158	2,772	2,527	3,378	811	184	1,029	13,860
2020	4,165	3,326	2,569	4,036	922	196	1,207	16,421
2021	3,864	3,189	3,021	3,538	847	184	1,080	15,723
2022	3,529	2,799	2,738	3,472	939	184	755	14,416

Table 3. Annual total nitrogen (TN) direct inputs to the seven Baltic Sea sub-basins and the Baltic Sea during 1995-2022 (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	3,491	5,151	16,671	17,386	1,164	12,786	4,245	60,894
1996	3,359	5,117	11,774	14,708	1,224	7,449	3,700	47,331
1997	3,432	4,846	10,314	13,080	1,250	5,907	3,527	42,356
1998	3,673	4,935	9,128	12,305	1,247	6,216	3,063	40,567
1999	3,541	4,798	8,167	12,618	1,251	5,082	2,773	38,229
2000	3,480	4,980	8,850	12,838	1,400	7,007	2,447	41,002
2001	3,186	4,634	6,953	12,960	1,521	4,168	2,438	35,861
2002	3,167	4,534	6,830	13,007	1,430	3,431	2,506	34,905
2003	3,235	4,545	6,693	12,905	1,815	3,037	2,086	34,315
2004	3,160	4,592	6,555	11,810	1,442	3,157	2,280	32,997
2005	2,934	4,456	6,409	10,169	1,573	2,959	2,219	30,719
2006	3,005	4,762	6,899	9,306	1,768	3,134	2,475	31,349
2007	3,019	4,351	7,718	9,610	2,379	3,357	2,635	33,068
2008	3,038	4,309	6,911	9,155	2,460	3,022	2,700	31,594
2009	2,890	4,169	6,434	10,055	1,277	3,272	2,466	30,564
2010	3,000	3,967	6,919	9,711	1,121	2,907	2,233	29,859
2011	3,150	3,837	6,972	10,076	1,143	3,244	2,306	30,727
2012	3,315	4,256	6,627	9,708	1,107	3,145	2,198	30,355
2013	3,678	4,203	6,472	9,506	696	3,251	2,009	29,816
2014	3,740	3,955	5,973	9,178	516	3,160	2,044	28,565
2015	3,461	4,190	6,271	8,806	543	3,384	2,164	28,819
2016	3,655	4,088	5,276	9,135	518	3,171	1,950	27,792
2017	3,363	4,028	5,505	10,210	432	3,399	1,918	28,855
2018	3,066	3,787	4,759	7,970	402	3,035	1,682	24,702
2019	3,016	3,698	4,686	10,099	442	3,387	2,027	27,356
2020	2,721	3,515	4,719	9,672	348	3,114	1,846	25,936
2021	3,195	3,379	4,958	9,855	394	3,317	1,875	26,973
2022	3,081	3,373	4,841	9,261	370	3,009	1,561	25,496

Table 4. Annual total nitrogen (TN) riverine inputs to the seven Baltic Sea sub-basins and the Baltic Sea during 1195-2022 (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	41,185	49,122	342,047	92,747	85,143	48,217	62,735	721,196
1996	36,744	36,042	355,572	72,043	55,485	18,699	33,998	608,582
1997	40,695	43,484	309,048	73,289	89,654	21,327	40,575	618,071
1998	63,059	61,715	410,043	95,686	99,101	61,204	71,308	862,116
1999	45,276	49,349	357,061	93,503	84,813	48,986	75,791	754,779
2000	65,745	72,777	276,785	93,369	71,477	35,847	68,593	684,592
2001	50,427	59,217	284,755	100,936	86,421	31,832	62,613	676,201
2002	36,291	40,286	346,127	108,561	70,246	53,752	62,657	717,920
2003	33,127	33,422	191,896	114,916	45,561	19,462	38,281	476,666
2004	53,050	46,526	248,911	122,618	80,488	35,989	55,645	643,229
2005	54,038	47,933	247,598	96,587	73,410	29,619	43,551	592,736
2006	48,685	55,282	235,950	127,692	53,096	34,325	58,459	613,489
2007	53,491	45,534	312,552	108,545	104,323	47,946	65,701	738,092
2008	56,768	57,529	242,203	94,303	93,654	31,974	56,720	633,149
2009	35,075	41,142	236,836	102,985	67,471	22,288	40,652	546,449
2010	40,094	41,454	386,967	91,665	83,258	38,001	46,463	727,902
2011	49,237	52,274	327,310	105,839	99,413	35,858	47,866	717,797
2012	66,448	58,895	210,386	103,024	90,863	27,404	48,279	605,300
2013	41,023	41,204	277,663	91,184	66,131	28,662	38,511	584,379
2014	38,748	38,805	195,699	79,197	48,130	27,155	49,514	477,247
2015	65,338	50,081	173,783	73,003	54,953	37,161	51,370	505,687
2016	49,233	32,258	230,827	84,492	82,469	27,334	39,065	545,678
2017	44,162	38,843	359,921	99,448	106,954	33,748	43,949	727,024
2018	34,306	35,232	221,038	99,476	53,821	26,312	36,386	506,570
2019	36,190	45,584	189,210	81,926	62,697	32,721	56,297	504,626
2020	58,173	50,781	187,118	108,360	67,939	27,902	46,774	547,048
2021	48,728	48,246	242,741	89,488	75,816	25,374	42,617	573,011
2022	43,293	36,568	219,763	101,784	79,691	23,935	32,812	537,845

Table 5. Annual total nitrogen (TN) waterborne (riverine + direct) inputs to the seven Baltic Sea sub-basins and the Baltic Sea during 1995-2022 (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	44,676	54,273	358,718	110,133	86,307	61,004	66,980	782,090
1996	40,103	41,159	367,345	86,751	56,709	26,148	37,698	655,913
1997	44,126	48,330	319,362	86,368	90,904	27,234	44,102	660,427
1998	66,732	66,650	419,171	107,991	100,348	67,420	74,371	902,683
1999	48,817	54,147	365,227	106,121	86,064	54,067	78,564	793,008
2000	69,225	77,756	285,635	106,207	72,877	42,854	71,040	725,594
2001	53,613	63,851	291,708	113,895	87,942	36,000	65,051	712,062
2002	39,459	44,820	352,957	121,568	71,676	57,183	65,162	752,824
2003	36,363	37,966	198,589	127,822	47,376	22,499	40,367	510,981
2004	56,211	51,118	255,466	134,428	81,930	39,147	57,925	676,226
2005	56,972	52,389	254,007	106,756	74,983	32,578	45,770	623,455
2006	51,689	60,045	242,850	136,998	54,864	37,459	60,934	644,838
2007	56,510	49,885	320,270	118,156	106,701	51,303	68,336	771,160
2008	59,805	61,838	249,114	103,458	96,113	34,995	59,420	664,743
2009	37,965	45,311	243,270	113,041	68,748	25,560	43,118	577,013
2010	43,094	45,422	393,887	101,376	84,379	40,909	48,695	757,761
2011	52,387	56,111	334,281	115,914	100,556	39,102	50,171	748,524
2012	69,763	63,151	217,012	112,732	91,970	30,549	50,477	635,655
2013	44,701	45,408	284,136	100,690	66,827	31,914	40,519	614,194
2014	42,487	42,760	201,672	88,375	48,645	30,314	51,558	505,812
2015	68,799	54,270	180,054	81,809	55,495	40,545	53,534	534,506
2016	52,888	36,346	236,103	93,627	82,988	30,504	41,014	573,470
2017	47,525	42,871	365,425	109,659	107,386	37,147	45,867	755,880
2018	37,372	39,019	225,796	107,446	54,223	29,347	38,068	531,272
2019	39,206	49,283	193,896	92,025	63,139	36,108	58,324	531,981
2020	60,894	54,296	191,838	118,033	68,288	31,016	48,620	572,984
2021	51,923	51,625	247,699	99,344	76,210	28,691	44,492	599,984
2022	46,374	39,941	224,605	111,045	80,061	26,944	34,372	563,341

Table 6. Annual total phosphorus (TP) direct inputs to the seven Baltic Sea sub-basins and the Baltic Sea during 1995-2022 (in tonnes). For an explanation of abbreviations, see the caption to Figure 1.

TP	tonnes							
Direct	**BOB**	**BOS**	**BAP**	**GUF**	**GUR**	**DS**	**KAT**	**BAS**
1995	158	395	1,463	2,707	314	902	267	6,205
1996	130	373	755	2,738	253	606	192	5,047
1997	128	333	691	2,534	255	452	191	4,584
1998	128	318	735	2,542	253	363	204	4,544
1999	119	318	596	2,705	254	340	181	4,513
2000	112	334	529	2,631	197	322	176	4,301
2001	105	302	341	2,630	230	281	153	4,041
2002	102	272	387	2,800	208	323	146	4,240
2003	90	287	416	2,920	163	248	117	4,241
2004	89	308	961	3,117	175	258	123	5,031
2005	95	292	413	2,881	203	246	123	4,253
2006	104	301	498	2,340	184	245	136	3,809
2007	105	281	529	2,163	179	292	137	3,687
2008	103	266	472	1,289	157	320	120	2,726
2009	94	230	398	2,801	59	404	97	4,082
2010	92	222	416	1,650	46	278	98	2,802
2011	93	214	416	2,354	38	312	116	3,543
2012	113	231	418	353	76	369	88	1,649
2013	120	229	404	347	55	339	91	1,585
2014	139	215	409	356	61	297	93	1,570
2015	108	215	400	447	64	292	105	1,630
2016	104	200	385	430	46	246	100	1,512
2017	101	182	197	471	42	244	99	1,336
2018	95	175	178	203	36	216	99	1,001
2019	93	172	199	307	38	268	113	1,191
2020	94	161	180	264	33	198	97	1,028
2021	97	161	195	376	33	211	103	1,176
2022	68	141	195	290	37	205	84	1,021

Table 7. Annual total phosphorus (TP) riverine inputs to the seven Baltic Sea sub-basins and the Baltic Sea during 1995-2022 (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	2,647	2,403	18,427	7,246	2,911	1,301	1,537	36,471
1996	1,711	1,593	17,804	4,595	2,000	708	795	29,205
1997	2,847	2,062	20,261	4,438	1,950	767	992	33,317
1998	3,307	2,476	21,770	5,310	3,693	1,411	1,674	39,641
1999	2,283	2,601	20,520	5,064	3,564	1,302	1,897	37,231
2000	3,366	3,080	16,331	5,905	2,732	938	1,733	34,085
2001	2,456	2,443	18,121	4,790	3,398	923	1,609	33,739
2002	1,704	1,355	17,715	6,598	1,549	1,442	1,488	31,851
2003	1,501	1,087	11,551	4,612	1,835	641	932	22,160
2004	2,440	1,682	14,256	7,316	2,518	926	1,366	30,504
2005	2,492	1,933	12,202	8,461	2,458	769	1,259	29,573
2006	2,038	2,175	13,295	4,250	1,765	857	1,744	26,125
2007	2,166	1,643	14,190	3,122	2,505	1,230	1,581	26,436
2008	2,650	2,587	11,740	5,352	2,560	953	1,473	27,315
2009	1,718	1,504	13,386	8,368	2,495	689	1,049	29,207
2010	2,562	1,615	18,972	4,512	2,735	926	1,296	32,617
2011	2,431	2,179	15,541	4,441	2,003	1,154	1,370	29,119
2012	3,468	2,469	10,355	4,064	2,946	933	1,446	25,680
2013	2,134	1,763	14,374	3,554	2,356	822	1,023	26,026
2014	1,914	1,415	13,802	3,488	1,387	814	1,399	24,219
2015	3,035	2,009	8,067	2,691	1,308	1,047	1,442	19,599
2016	2,605	1,241	9,273	3,397	2,152	823	1,076	20,568
2017	2,208	1,618	12,492	4,201	3,038	1,007	1,252	25,815
2018	1,863	1,373	10,114	4,241	1,754	701	978	21,025
2019	1,809	1,747	7,716	3,112	1,453	715	1,443	17,994
2020	2,882	2,241	8,020	4,245	1,635	750	1,514	21,287
2021	2,297	1,712	9,230	4,370	1,409	700	1,073	20,792
2022	2,000	1,316	7,126	3,374	1,225	665	806	16,512

Table 8. Annual total phosphorus (TN) waterborne (riverine + direct) inputs to the seven Baltic Sea sub-basins and the Baltic Sea during 1995-2022 (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	2,805	2,797	19,889	9,952	3,225	2,204	1,804	42,677
1996	1,841	1,965	18,559	7,332	2,253	1,314	987	34,252
1997	2,975	2,395	20,953	6,971	2,205	1,219	1,183	37,901
1998	3,436	2,794	22,505	7,852	3,946	1,774	1,878	44,185
1999	2,402	2,919	21,116	7,769	3,818	1,643	2,077	41,744
2000	3,478	3,414	16,860	8,535	2,929	1,260	1,908	38,386
2001	2,561	2,745	18,462	7,421	3,628	1,203	1,761	37,780
2002	1,806	1,627	18,102	9,399	1,757	1,765	1,634	36,091
2003	1,591	1,374	11,967	7,532	1,998	889	1,050	26,401
2004	2,529	1,990	15,216	10,433	2,693	1,184	1,489	35,535
2005	2,587	2,225	12,615	11,342	2,661	1,014	1,381	33,825
2006	2,143	2,476	13,793	6,590	1,950	1,102	1,880	29,934
2007	2,271	1,923	14,719	5,285	2,684	1,522	1,718	30,123
2008	2,753	2,853	12,212	6,641	2,717	1,272	1,593	30,042
2009	1,812	1,734	13,784	11,169	2,554	1,092	1,145	33,290
2010	2,654	1,837	19,388	6,162	2,781	1,204	1,394	35,419
2011	2,523	2,393	15,957	6,796	2,041	1,466	1,486	32,662
2012	3,581	2,700	10,773	4,417	3,022	1,302	1,534	27,329
2013	2,254	1,993	14,778	3,901	2,411	1,161	1,114	27,611
2014	2,054	1,630	14,210	3,844	1,448	1,112	1,493	25,789
2015	3,144	2,224	8,466	3,138	1,372	1,339	1,546	21,229
2016	2,709	1,441	9,659	3,827	2,199	1,070	1,176	22,080
2017	2,309	1,800	12,689	4,671	3,080	1,251	1,351	27,150
2018	1,958	1,549	10,292	4,445	1,789	917	1,077	22,026
2019	1,902	1,919	7,915	3,419	1,491	984	1,555	19,185
2020	2,976	2,402	8,201	4,509	1,668	948	1,612	22,315
2021	2,395	1,873	9,425	4,746	1,442	911	1,176	21,968
2022	2,068	1,458	7,321	3,665	1,261	870	890	17,533

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 2016b). EMEP subsequently compiles and reports this information to HELCOM including a BSEF on nutrient emissions and deposition (e.g. Gauss, 2023a and 2023b).

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. Svendsen et al, 2024) 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 and 2023).

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[5] 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 – 2022.

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

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[5] 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.

rates, i.e. they should as a minimum reflect the main annual river flow pattern. Further details are provided in the PLC-guidelines (HELCOM, 2022).

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, 2022). 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, 2022). 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, 2022 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 (2022). 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, 2022) 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 1995-2022 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. Some countries have procedures where older data to minor extend are updated annually due to used methodology for unmonitored areas

Weakness: Data from some parts of the Baltic Sea catchment and some of the direct inputs in the beginning of the time series (1995-2022) 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:

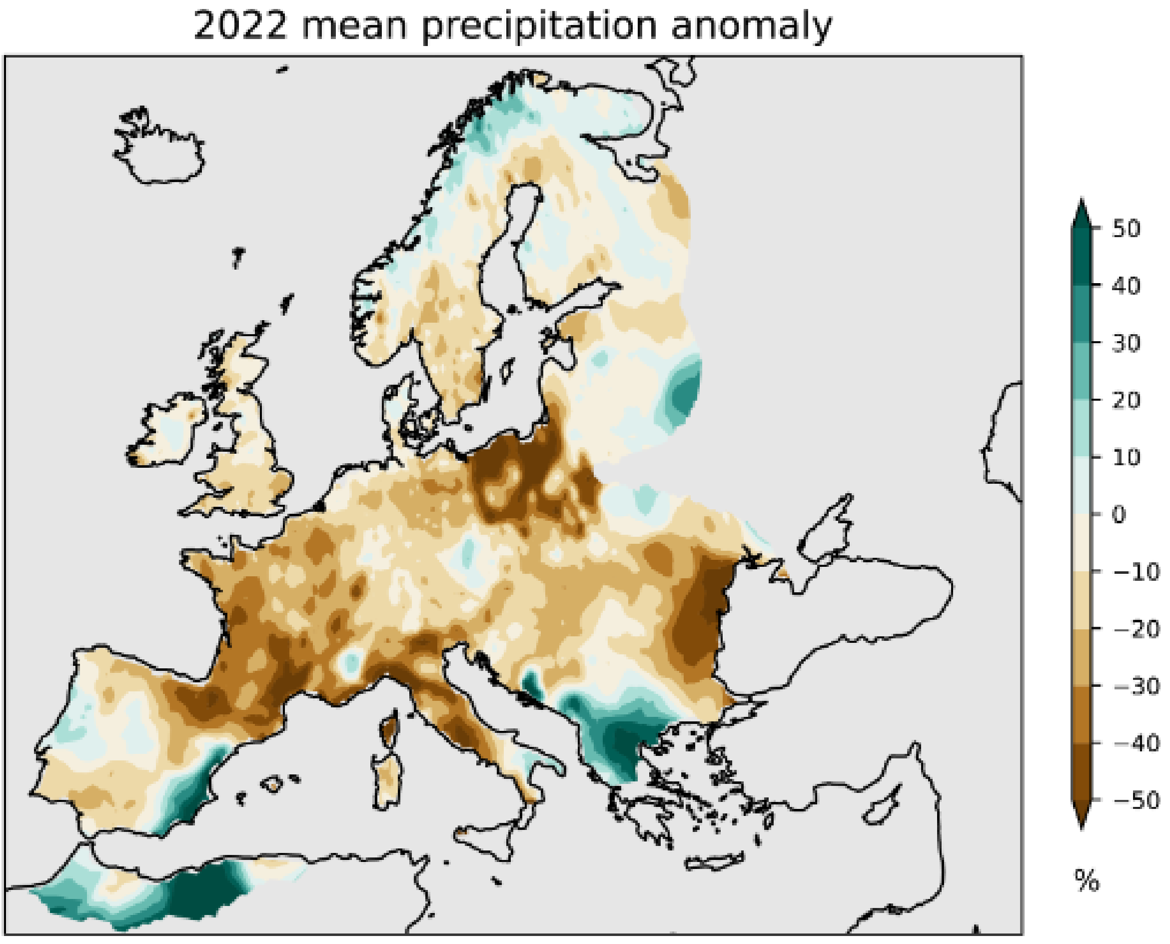
Total nitrogen and phosphorus inputs from all unmonitored areas must be modelled/estimated with methods that provide consistent and comparable results. The sampling frequency and strategy in rivers should be adjusted to flow and concentrations regime and patterns in individual rivers, and at least 12 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 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.

Annex

Rainfall maps 2023 from Copernicus

The annex includes maps showing precipitation in Europe in 2022 as deviation from the reference period 1991-2020 on an annual bais (figure A.1 and A.2) and seasonally (figures A.3 and A.4) . The maps are dowloadet from Corpernicus Climate Change Services. The data source are E-OBS which are gridded observational dataset.

We acknowledge the E-OBS dataset from the EU-FP6 project UERRA (https://www.uerra.eu) and the Copernicus Climate Change Service, and the data providers in the ECA&D project (https://www.ecad.eu)" "Cornes, R., G. van der Schrier, E.J.M. van den Besselaar, and P.D. Jones. 2018: An Ensemble Version of the E-OBS Temperature and Precipitation Datasets, J. Geophys. Res. Atmos., **123**. doi:10.1029/2017JD028200"


2022 mean precipitation anomaly

Data source: E-OBS Credit: C3S/KNMI Reference Period: 1991-2020

Figure A.1 Annual precipitation anomalies expressed as a percentage of the annual average for the reference period 1991-2020. Data source. E-OBS: Credit: C3S/ECMWF/KNMI

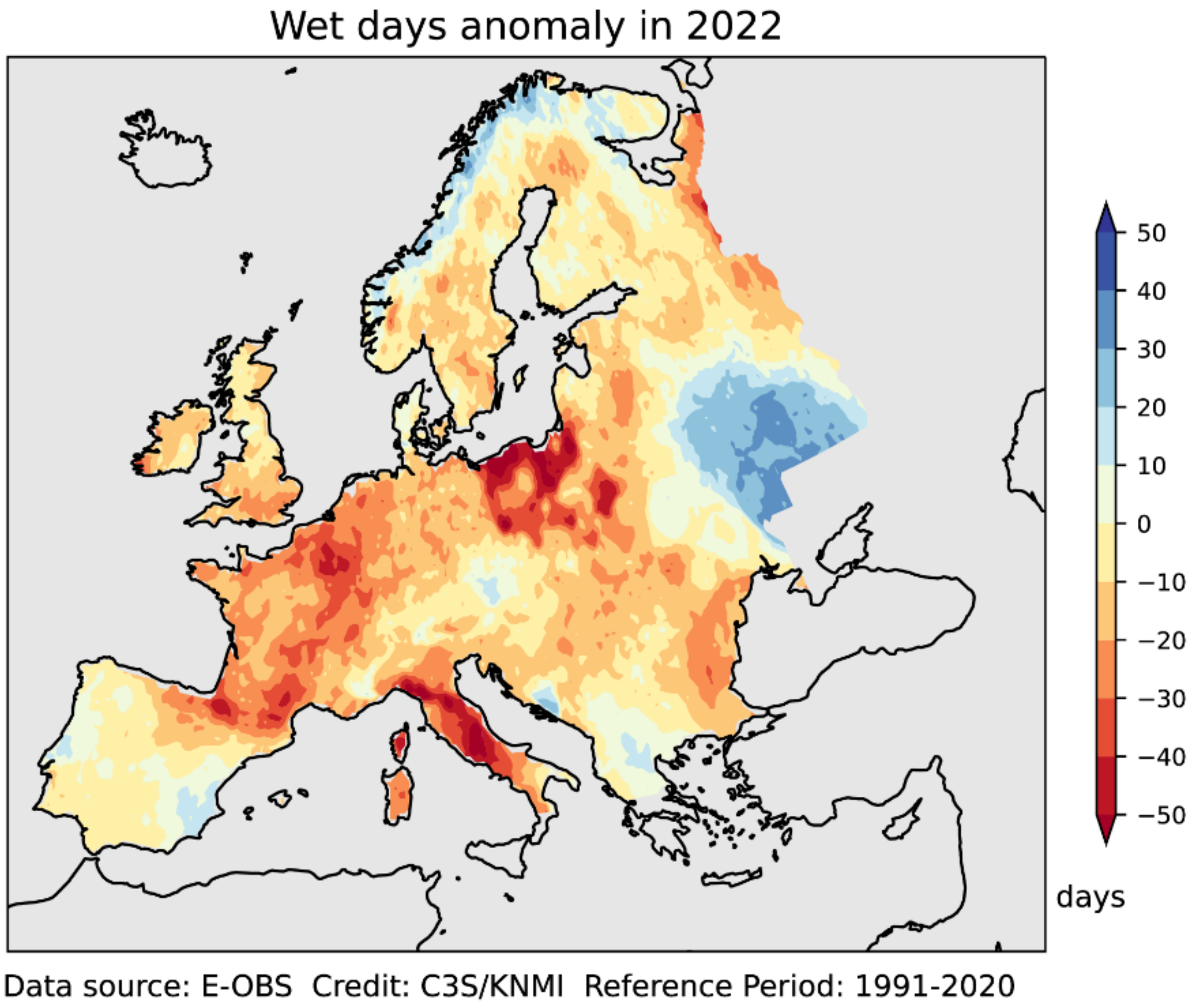
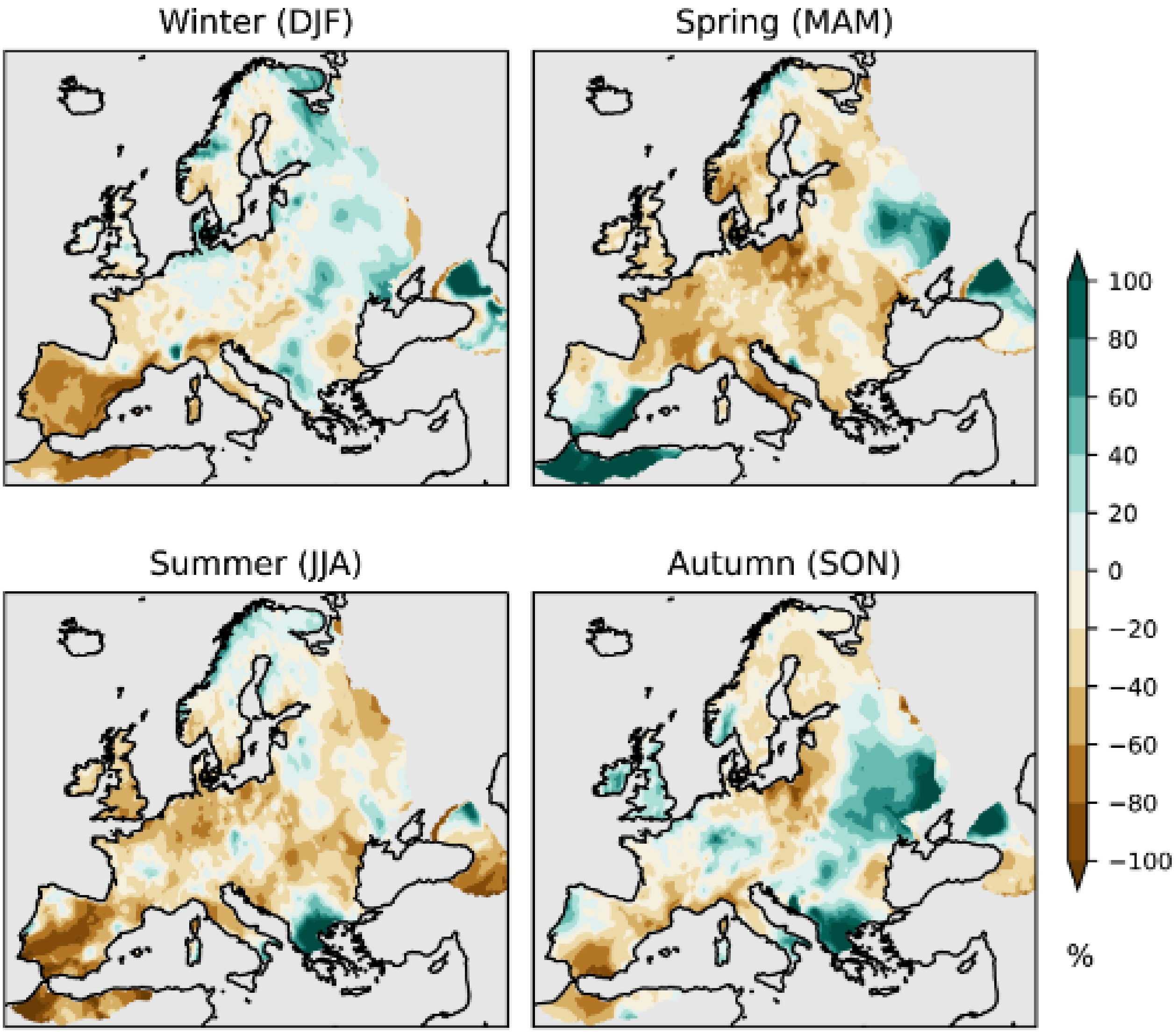


Figure A.2 Wet day anomalies relative to the average for 1991-2020 reference period. Shade of red are negative anomalies blue are positive. Wet day = accumulated precipitation one day 1 mm or more. Data source: E-OBS. Credit: C3S/ECMWF/KNMI



Data source: E-OBS Credit: C3S/KNMI Reference Period: 1991-2020

Figure A.3 Seasonal precipitation anomalies expressed as a percentage of the seasonal average for the reference period 1991-2020. Winter covers December 2021-Februar 2022, Spring March 2022-May 2022, Summer July2022-August 2022 and Autumn September 2022-November 2022. Data source. E-OBS: Credit: C3S/ECMWF/KNMI.

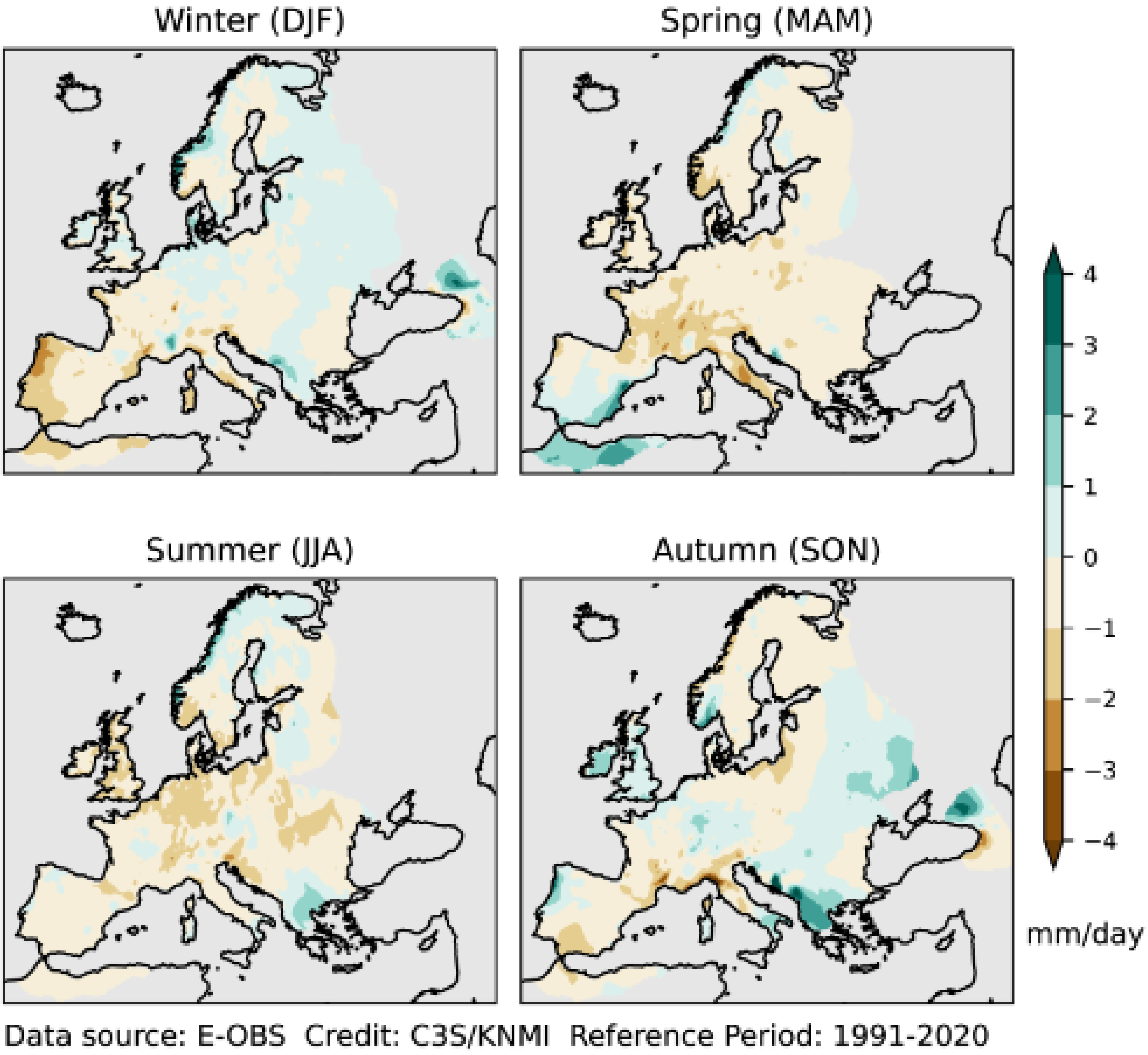


Figure A.4 Seasonal precipitation anomalies expressed as a mm/day of the seasonal average for the reference period 1991-2020. Winter covers December 2021-Februar 2022, Spring March 2022-May 2022, Summer July2022-August 2022 and Autumn September 2022-November 2022. Data source. E-OBS: Credit: C3S/ECMWF/KNMI.